ADDIS ABABA UNIVERSITY

COLLEGE OF NATURAL SCIENCE

SCHOOL OF EARTH SCIENCES

ENGINEERING SOIL CHARACTERIZATION IN SULULTA TOWN, CENTRAL ETHIOPA

A Thesis Submitted to School of Graduate Studies of Addis Ababa University in Partial Fulfillment of Degree of Masters in Engineering Geology

BY:

Hawi Hailu

Advisor:

Dr.Trufat H/Mariam

Addis Ababa University

June, 2017

ACKNOWLEDGEMENT

I am grateful indeed to the almighty God the merciful and compassionate. First and foremost I would like to extend my thanks and appreciation to my advisor Dr.Trufat H/Mariam for his limitless efforts in guiding me throughout my research work.

I would like to express appreciation to Dr.Tarun K. Raghuvanshi for his support by providing me computational sheet program developed by him for calculation of bearing capacity of shallow foundation.

School of Earth sciences Addis Ababa University deserves thanks for support me during my research work.

Addis Ababa University Female Scholarship, my sponsor, also deserves thank for providing me the chance to my MSc study and its financial support until the completion of the study.

I would like to forward my appreciation to Ethiopian Institute of Geological Survey and National Metrological Agency for providing me necessary data for this research.

My special credit and appreciation goes to Feyera Mosisa and his wife Samirawit Oli, Sinbone Gudeta, Temesgen Wale and Dereje Gonder for their continues encouragement during conducting this research thesis.

Finally, I am grateful to my parents, my beloved brothers Melese Hailu and Amenu Hailu, my sisters and my friends for their motivation, support and understanding during the study. This work is dedicated to all of you and without you not be where to this level. Since it is difficult to mention all who assisted me, I take this opportunity to say, thank you.

Engineering Soil Characterization in Sululta Town, Central Ethiopia
Hawi Hailu MSc in Engineering Geology June, 2017

ABSTRACT

Soil characteristic is a measure of soil's suitability to provide a proposed civil structure. Soil characterization is essential to provide the information for design and construction of engineered structures. In a country like Ethiopia which is developing at high growth rate and which needs many construction works in the future, geotechnical investigation on the engineering characteristics of soil is very essential. Sululta Town one of the towns of Oromia special zone surrounding Finfinnee in which big volume of construction is being undergoing. Thus, this research is concerned with engineering soil characterization in Sululta Town. The study was conducted in order to characterize soil of the study area for engineering practices. Specifically, the study focuses on index properties and strength and consolidation tests in order to examine the soils' characteristics. In order to characterize the soils, laboratory tests index properties such as Natural moisture content, Grain size analysis, Atterberg limits test, Specific gravity and Free swell conducted on disturbed samples and engineering properties such as shear strength and consolidation tests were conducted on undisturbed samples. The soil of the study area was classified by using Unified Soil Classification System (USCS) and American Association of state High way and Transportation Officials (AASHTO) classification schemes. The soil type was identified as it is uniform throughout the town. Grain size Analysis result showed that, the area characterized by fine grained (cohesive) soils. Laboratory test result revealed that Natural moisture content of the soil ranges from 23.27 to 65.48. The Liquid Limit ranges from 41.8 to 91.5%. Likewise, the plasticity index in percent of the soils ranges from 11.63 to 44.59%. Besides, the free swell test results showed range from 30% (low expansion potential) to 80 % (high expansion potential). As a result of the index property tests the soil of the study area has been classified as A-7-5 as per AASHTO classification system whereas soils classified as ML and MH by USCS. Based on the shear strength and consolidation laboratory tests, bearing capacity and settlement analysis for the soils was also conducted. The main geotechnical problems that affect design and development of civil structures in the town were identified as existence of shallow Ground Water table, cohesive soils of high plasticity characteristics and low bearing capacity of the soils. Bearing capacity analysis result showed that, the soil of the study area characterized as low bearing capacity soils that needs improvement before construction of large structures. Finally, the conclusion drawn from the present study showed that the soils of the study area are not suitable for engineering practices unless it improved by appropriate measures.

Key words: *Allowable Bearing Capacity, Liquid Limit, Soil characterization, Soil Classification, Sululta town*

ACRONYMS

AASHTO	American Association of state High way and Transportation Officials
Ac	Activity
ASTM	American Standard of Testing Materials
CI	Consistency Index
GI	Group Index
GIS	Geographic Information System
Gs	Specific Gravity
GSE	Geological Survey of Ethiopia
LL	Liquid Limit
LI	Liquidity Index
MH	In organic Silt with high plasticity
NMC	Natural Moisture Content
OUPI	Oromia Urban Planning Institute
PI	Plasticity Index
PL	Plastic Limit
SDBH	secondary data bore hole
T_v	Consolidation time factor
t_{50}	Time during which 50% of consolidation takes place
t_{90}	Time during which 90% of consolidation takes place
TP	Test pit
USCS	Unified Soil Classification System
UTM	Universal Transverse Mercator grid
W	Water content
C_v	Coefficient of consolidation

Table of Contents

List of tables

List of Figures

CHAPTER ONE

1. INTRODUCTION

1. 1 Back ground of the problem

Soil characteristics are a measure of a soil's suitability to provide a proposed purpose. Strength of the foundation of civil engineering structures depends on the characteristics of the soil on which built. Poor soil conditions in terms of engineering increase the cost of construction by necessitating special foundation structures and/or mean that some type of engineering soil treatment is required (Bell, 2005). To obtain essential information for foundation of such structures soil investigation is the basic requirement. The success or failure of foundation of structures depends on the consistency of soil characterization parameters that result from soil investigation used for design of the foundation. For example, in the United States, the cost of repair of damage to property built on expansive clay exceeds two billion dollars annually (Bell, 2005). It is most obvious that foundations built on problematic soils cause damage to structures. It is also necessary to obtain sufficient information on characteristics of soils and economic studies of the proposed project. Public building officials may require soil data together with the recommendations of the geotechnical consultant prior to issuing a building permit, particularly if there is a chance that the project will endanger the public health or safety or degrade the environment. Insufficient geotechnical investigations, faulty interpretation of results, or failure to portray results in a clearly understandable manner may contribute to inappropriate designs; delays in construction schedules, costly construction modifications, and use of substandard borrow material, environmental damage to the site, post construction remedial work, and even failure of a structure and subsequent litigation (Bowles, 1996). The volume change, deformation, strength and hydraulic conductivity of fine grained soils are very important for engineering problems (Mitchel, 1976). Risks inherent within the soils are attributed to significant cost and time overruns on construction projects. Problematic soils affect the engineering behavior of soil and rock both as materials of construction and as foundation materials. In a country like Ethiopia which is developing at high growth rate and which needs many construction works in the future, geotechnical investigation on the engineering characteristics of soil is very essential. Because these data are very important for civil engineers in preliminary design and in designing foundation, pavement, retaining structures and other structures for future construction projects in the country. In the same manner, Peck (1996) suggested that, the shallow existence of ground water at a site for construction of structures is also responsible for failure of structures.

1.2 Statement of the Problem

The study of soil characterization incorporates not only defining the extent and range of distribution of problematic soil but also overall soil formation processes to define their impact on civil engineering works. In a country like Ethiopia which is developing at fast growing rate and which needs many construction works in the future, geotechnical investigation on the characterization of soil is very essential. Because these data are very important for civil engineers in preliminary design and in designing foundation, pavement, retaining structures, etc. for future construction projects in the country. In Ethiopia many researches have studied on engineering properties of soils in order to identify their performance for engineering practice. However, the engineering property of the soil in the town is not studied (Sululta city Municipality, 2016). Sululta Town is one of the fastest growing towns of the country in which the rate of industrialization, urbanization and population growth is high. In Sululta town, there is a big volume of construction works, many buildings are being under construction. Consequently, this research is directed to the study on the Engineering soil characterization in Sululta Town. The study focus on the index properties, shear strength and consolidation characteristic identifying the soil types, characteristics of the soil and preparing soil map of the town in order to ensure safe and cost-effective design of civil structure in the town. Finally, this study aims to conclude and suggest feasible useful recommendations with suggesting for future works using different scientific methods and for different research problem in the area.

1.3 Objectives of the study

1.3.1 General Objective

The main Objective of this research is to determine engineering characteristics of the Sululta Town in order to provide soil information for safe and cost effective design of civil structures.

1.3.2 Specific Objectives

To meet out the general objective of this research the following specific objectives were designed as follows:

- To provide general understanding on genesis and soil characteristics of Sululta Town.
- To identify the types of soils
- To determine the index and engineering properties of the soils

- To define the soils' engineering application
- To prepare Geotechnical soil map of the town at 1:50,000 scale

1.4 Significance of the study

The study generally gives due attention on the characteristics and types of soils found in Sululta town. It will be used by later researchers interested to study in Sululta town as preliminary information. Furthermore, the importance of the study was to identify the areas of problematic soils in the study area. Since, the soils of Sululta Town are not studied yet for Engineering practices and no any engineering soil data in the city Municipality. This research may be used by the city Municipality as an engineering soil data source

1.5 Scope of the study

The scope of this research is limited to characterization of Sululta town soils in terms of its index and engineering properties (shear strength and consolidation characteristics). To accomplish these parameters six test pits with maximum depth of 3m were excavated and fifteen proper representative (11 disturbed and 4 undisturbed) samples were collected.

1.6 Limitation of the research

There is no organized secondary data regarding soils of the study area is available with town's municipality. This is because most of the geotechnical works are conducted for simple purposes and not supported with standardized data collection and well organized data recording.

1.7 Organization of the thesis

The research is organized into seven chapters. Each chapter covers specific topic in the research work. In chapter one background of the problem, statement of the problem, objective and significance of the study discussed. Chapter two deals with a brief literature review. Chapter three deal with description of the study area. Chapter four deals with methodology used in the study. Chapter five deals with laboratory tests, results and discussion of results. Chapter six covers soil Genesis, soil classification and Geotechnical soil mapping and the last chapter seven give conclusion and recommendation.

CHAPTER TWO

2. LITERATURE REVIEW

2.1 Soil Genesis

Soil is a product of interaction between climate, parent material, relief and organisms over a period of time. While climate (Maynardet al., 2004) and organisms (Quideauet al., 2001) actively influence soil formation, topography indirectly affects the rate of pedogenesis and distribution of soils (Wang et al., 2001). The effect of topography on soil genesis had long been documented (Pregitzer et al., 2000). It had been recognized that soils vary in vertical and lateral directions and that such variations follow systematic changes (Wilding and Dress, 1983). Graham et al. (1990) proposed a conceptual model relating slope processes to pedogenesis in which transported parent material interrupts the orderly progression of soil development in residual parent material. Characterization of geological materials is crucial in soil genesis studies, as parent material (i.e., petrographic, geochemical and mineralogical composition) has long been recognized as a fundamental factor in soil formation (Dokuchaiev, 1879; Jenny, 1941; Paton, 1978 as cited in Alemayehu *et al.,* 2014)

According to Grim (1968) Five major factors interact to create different types of soils are:

2.1.1 Soil Forming Factors

According to Grim (1968) five major factors interact to create different types of soils are:

Parent Materials

Every soil inherits character from the parent material from which it formed (Wilson, 1975). It is recognized that soil is the end product of weathering of rocks. The material could have been bedrock that weathered in place or smaller materials carried by flooding rivers, moving glaciers, or blowing winds. Parent material is changed through biological, chemical and environmental processes, such as weathering and erosion.

The main parent materials of soils classified in to three groups as sedimentary rocks, igneous rocks and metamorphic rocks.

Climate

Temperature and moisture influence the speed of chemical reactions, which in turn help control how fast rocks weather and dead organisms decompose. Soils develop faster in warm, moist climates and slowest in cold or arid ones.

Organisms

Plants root, animals burrow, and bacteria eat these and other organisms speed up the breakdown of large soil particles into smaller ones. For instance, roots produce carbon dioxide that mixes with water and forms an acid that wears away rock.

Relief (landscape)

The shape of the land and the direction it faces make a difference in how much sunlight the soils gets and how much water it keeps. Deeper soils form at the bottom of a hill because gravity and water move soil particles down the slope.

Time

All of these factors work together over time. Older soils differ from younger soils because they have had longer to develop. As soil ages, it starts to look different from its parent material. That is because soil is dynamic. Its components minerals, water, air, organic matter, and organisms constantly change. Components are added and lost. Some move from place to place within the soil. And some components are totally changed, or transformed overtime. These soil forming factors will be followed to generate the genesis of the soils of the study area.

Vegetation

Vegetation is also dominant factor in soil formation as it is the primary source of organic matter and because of its major role in the nutrient cycling and hydrology of a site. Vegetation may reflect surface soil types, although its significance is difficult to interpret because of the effects of climate and other factors. To interpreters with local experience, both cultivated and natural vegetation cover may be reliable indicators of soil type.

2.2 Engineering Soil Characterization

Soil characteristics are a measure of a soil's suitability to provide a proposed purpose (Shakoor, 1991).There are a number of relatively simple laboratory tests and field visual identification which are useful in identifying various soil types. According to Bowles (1970), Lambe (1951) and Kezdi (1980) the grain size and plasticity characteristics of soils determined at laboratory are the main properties to characterize and classify soils.

Since soil characterization is important for engineering practices, different researches are conducted in different parts of Ethiopia. Some of the researchers are summarized following.

Lulseged Ayalew (1990). Engineering Geological Characterization of the Clay soils of Bole Area

Gebremedhin Birhane (2010), Engineering Geological Soil and Rock Characterization in the Mekelle Town, Northern Ethiopia: Implications to Engineering Practice

Dagnachew Debebe (2011), Investigation on Some of the Engineering Characteristics of soils In Adama Town, Ethiopia. From these studies the existence of problematic soils in different parts of the country is identified.

2.2.1 General soil characteristics

Texture

The texture describes how a soil feels and is determined by the amounts of sand, silt, and clay particles present in the soil sample (Belay Hunde, 2014). The soil texture influences how much water, heat, and nutrients will be stored in the soil profile**.**

Structure

Structure refers to the natural shape of aggregates of soil particles, called peds, in the soil. The soil structure provides information about the size and shape of pore spaces in the soil through which water, heat, and air flow, and in which plant roots grow. Soil ped structure is described as granular, blocky, prismatic, columnar, or platy.

Color

The color of soil is determined by the chemical composition of soil particles, the amount of organic matter in the soil, and the moisture content of the soil. Usually, the greater the moisture contents of a soil, the darker its color. Differences in color in relation to other characteristics, such as drainage, clay content, grain packing, and root distribution, are clues to local oxidation and reduction and to movement and rearrangement of constituents (Munsell, 2000).

Shape

The shape of the grains also affects the bearing capacity. Angular particles form denser mass due to their capability of interlocking. They are more stable than the rounded particles which can roll or slide past one another (Shakoor, 1991). According to Shakoor (1991) for characterization purposes, engineering properties of soils are commonly grouped in to index properties and engineering properties.

2.2.2. Index properties

Index properties are the properties of soil that help in identification and classification of soil. The index properties of soil are:

Natural Moisture Content (NMC)

Natural Moisture Content has effect on soils behavior when used for construction purposes and foundation of structures. Moisture content affects settlement condition (consolidation), shear strength and suitability of soil for compaction. Natural Moisture content is used to predict degree of consolidation of soils Moisture content and consistency limits which aids in describing a soil's suitability. A coarse-grained, sandy or gravelly soil generally has good drainage characteristics and may be used in its natural state (Krishna, 2002.) A fine-grained, clayey soil with a high PI may have need of significant treatment, particularly if used in a moist location. Moisture content of soils can be determined in laboratory using ASTM D2216 procedure. Murthy(1985,1986) noted that it is possible to estimate whether a soil is pre-consolidated from overburden pressure by noting the position of water content *w* with respect to LL and PL.

1. If water content *w* is close to LL than to PL the soil is likely to be normally consolidated.
2. If water content *w* is close *to* plastic limit than LL the soil is likely to be pre-consolidated.

Grain-size Analysis

Grain size Analysis provides the grain size distribution, affects engineering properties of soils and it is used in classifying soils (Arora, 2004) Soil particle size has a definite relation to its bearing capacity. Empirical tests showed that well-graded, coarse-grained soils generally can be compacted to a greater density than fine-grained soils because the smaller particles have a tendency to fill the spaces between the larger one. Grain size of soils can be determined in laboratory by following ASTM D 422 Standard test method

Consistency Limits

The plastic limit as defined by Atterberg (1911) is a measure of soil brittleness, and does not correspond to fixed soil strength. water content in percent at which a pat of soil in standard cup and cut by a groove of standard dimensions will flow together at a base of a groove at a distance 13mm (1/2 inch) when subjected to 25 shocks from the cup being dropped 10 mm in standard Liquid Limit apparatus operated at a rate of 2 shocks per second.

Liquid limit is water content at which soil begin to crumble when rolled in to thread of approximately 3 mm thickness. Average of water contents obtained from different trials of plastic limit of the same sample (Atterberg, 1911).

Plastic Index is the numerical difference between Plastic limit and liquid limit. Samuel (1989) suggested that, the high plastic index soil indicates that the existence of high amount of clay contained in the soil. Used to determine whether the soil is cohesive or not. According to Atterberg (1911) not all plastic soils are cohesive but those with PI greater than 5.Consistency limits of soils determined at laboratory according to ASTM D 4318.

Table 2.1 Swelling potential of soils

Swelling Potential	Plasticity Index
Low	0-15
Medium	10-35
High	20-55
Very high	35 and above
(After Chen,1988)	

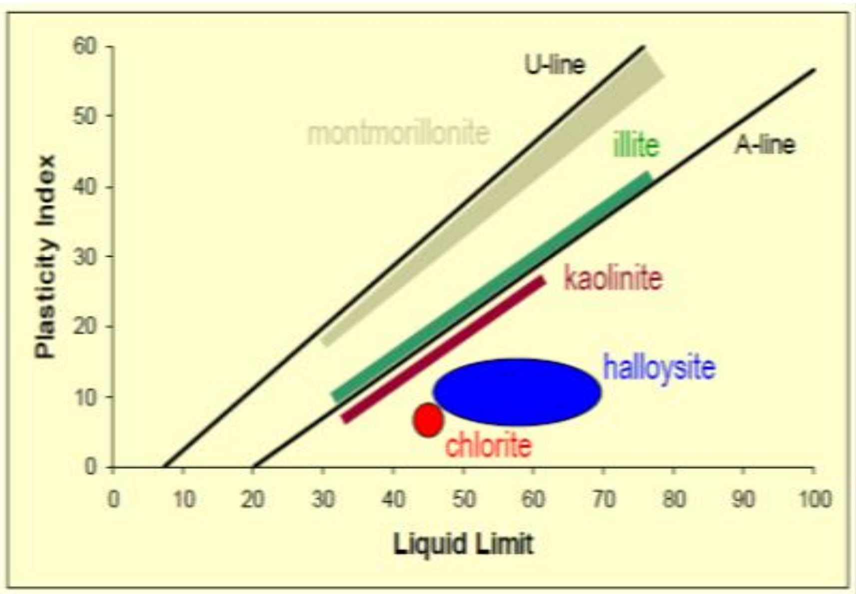


Fig.2.1 Mineral identification using Casagrande PI-LL chart

Specific Gravity

Specific gravity of solid matter in a soil particle may be defined as the ratio of unit weight of solid matter to the unit weight of water. The specific gravity of solid particles without void space is called the true or absolute or real specific gravity and is usually denoted by a letter Gs. This soil property is tested for soil particle pass the No.4 sieve (ASTM D85400)

Free swell

According to Holtz (1956) cited in Bell (1983), soils having free swell value as high as 100% can cause considerable damage to lightly loaded structures, and soils having free swell value below50% seldom exhibit appreciable volume change even under very light loadings.

Activity

Skempton (1953) classifies clays according to their activities. Following his classification, three degree of colloidal activity (Activity, Ac = PI/ percentage by weight finer than 2μm) have been established as indicated in table 2.2.

Table 2.2 Activity of soils

Activity	Soil type
< 0.75	In active clays
0.75-1.25	Normal clays
>1.25	Active clays

(After Skempton ,1953)

2.2.3 Engineering Properties of Soil

Strength Characteristics of soils

The shear strength of a soil mass is the internal resistance per unit area that the soil mass can offer to resist failure and sliding along any plane inside it. In order to analyze soil stability problems, such as bearing capacity, slope stability, and lateral pressure on earth-retaining structures nature of shearing resistance must be understood (Mohr, 1900). The soil must be capable of carrying the loads from any engineered structure placed upon it without a shear failure and with the resulting settlements being tolerable for that structure.

Consolidation characteristics of soils

According to Johnson *et al*. (1996) soil deformation may resulted from Volume change of the soil with time, Settlement at the surface of the soil with time, pore pressure dissipation with time and temperature. This deformation in soils cause settlement in engineering structures built on it. Settlement in soil can be Elastic or Consolidation depending on the time settlement occurs

2.2.4 Engineering Application of Soils

Bearing capacity of soils

A foundation is required for distribution of loads of the super-structure on a large area. Therefore, it should be designed such that the soil below the footing does not fail in shear. Also the settlement should be within the safe limits. According to Meyerhof (1963 bearing capacity is ability of foundation soil to hold the forces from super structure without undergoing shear failure and excessive settlement. Geological and ground water condition should be understood before designing a foundation for a structure (Bell, 2007).

According to Arora (1997) ultimate bearing capacity (q_{ult}) is the gross pressure at the base of the foundation at whichthe soil fails in shear and allowable bearing capacity (q_{na}) is the net bearing pressure which can be used for the design of foundation. For the design of foundation there should be no shearing failure and moreover the settlement should also be within permissible limits. The allowable bearing pressure is the smaller of the net safe bearing capacity (q_{na}) and net safe settlement pressure (q_{np}).

$$q_{na} = q_{ns} \text{ if } q_{np} > q_{ns} \quad 2.1$$

$$q_{na} = q_{np} \text{ if } q_{ns} > q_{np} \quad 2.2$$

.

Terzaghi's bearing capacity equation is written as:

$$q_u = CN_C + qN_q + 0.5.\gamma.B.N_y \quad 2.3$$

WhereN_C , N_q , N_y are known as Terzghi's bearing capacity factors which are dimensionless depend on angle of shearing resistance$N_C = cot\emptyset' \left[\frac{a^2}{2cos^2(45^0+{}^{\emptyset}/_{2})} - 1\right]$

$$N_q = cot\emptyset'\left[\frac{a^2}{2cos^2(45^0 + {}^{\emptyset}/_{2})}\right]$$

$$N_y = \frac{1}{2}\left[\frac{k_p}{cos^2\emptyset'} - 1\right]tan\emptyset'$$

Where k_p is coefficient of passive earth pressure and $a = e^{\left(\frac{3\pi}{4}-\emptyset'\right)}\, tan\emptyset'$

Hansen

$$q_u = c' N_c s_c d_c i_c b_c g_c + \gamma D N_q s_q d_q i_q b_q g_q + 0.5 B\gamma N_\gamma s_\gamma d_\gamma i_\gamma b_\gamma g_\gamma \quad 2.4$$

Meyerhof

$$q_u = c' N_c s_c i_c d_c + \gamma D N_q s_q i_q d_q + 0.5 B\gamma N_\gamma s_\gamma i_\gamma d_\gamma \quad 2.5$$

Where

$Nq = e\pi \tan\emptyset\, tan^2(45+\emptyset 2)$

$Nc = Nq - 1 \cot\emptyset$

$N\gamma = 1.5\ Nq - 1 \tan\emptyset$

Where, C=cohesion q=load B=width of foundation ϒ=unit weight **ϕ**=angle of internal friction Sc, Sq, Sϒ=shape factors dc, dq, dϒ=depth factors Nc, Nq, Nϒ=bearing capacity factors Ic, iq, iϒ=inclination factors Gc, gq, gϒ=ground factors Bc, bq, bϒ=base factors

Settlement in Soils

Elastic or Immediate settlement (*Si*) takes place during or immediately after the construction of engineered structures. It is also known as the distortion settlement as it is due to distortions with in the foundation soil. Although the settlement is not truly elastic, it is computed using elastic theory especially for cohesive soils.

Consolidation settlement (*Sc*) is component of the settlement occurs due to gradual expulsion of water from the voids of the soil. This component is determined using Terzaghi’s theory of consolidation. Ranjan *et al*.(1993) noted that Settlement in granular soils is elastic settlement due to the immediate deformability of the soils whereas consolidation settlement occurs in fine grained soils due to Volume change of the soil with time.Net Safe Settlement Pressure (q_{np}) is the net pressure which the soil can carry without exceeding the allowable settlement. The maximum allowable settlement generally varies between 25 mm and 40 mm for individual footing (Arora, 1997).

$$S_c = \frac{C_c H}{1+e_0} log_{10} \frac{P_{0+\Delta P}}{P_0} \qquad 2.6$$

Allowable settlement

The allowable maximum settlement depends upon the type of soil, the type of foundation and the structural framing system. The maximum settlement ranging from 20 mm to 300 mm is generally permitted for various structures. Indian Standard (IS: 1904) 1966, permits a maximum settlement of 40 mm for isolated foundations on sand and 65 mm for those on clay. According to Arora (2000) the allowable settlement is higher for clays because progressive settlements on clayey soils permit better strain adjustments in the structural members. Frederick (1979) stated that, the principal settlement for most projects occur in1 to5 years.

Soil Characterization for Urban Development

Soil characterization is an important issue for urban development. The characterization of soil is useful in urban development in that, in developing urban there has been construction of different infrastructures and industries. So, urban and industrial planning requires detailed soil characterization in order to get firm foundation for buildings and other engineering structures and determine how the soil is suitable for toxic pollutants filtering.

2.2.5 Soil Classification

Soil classification is grouping soils with similar engineering properties into a category by using results of laboratory-based index properties. The classification may be based on grain size (textural), genesis, behavior, etc. From geotechnical and Engineering geological point of view, the classification of soil may be done with the objective of finding the suitability of soil for construction of structures or foundation (Gebremedhin, 2010).

A soil classification should provide some guide to engineering performance of the soil type and should provide a means by which soil can be identified quickly (ISRM, 1981, as cited in Gebremedhin, 2010). In classification of soils for engineering purpose there are different classification systems such as Unified Soil Classification System (USCS), American Association of state Highway and Transportation Officials (AASHTO), Classification System proposed by IAEG (1981), British Soil Classification System (BSCS) for engineering purpose etc. Soils are classified using two broadly systems namely:

- Textural system based on GSD(Grain size distribution)
- System based on both textural and Atterberg Limits of the soil

Particle size (Textural) classification

I. Gravel, particle size greater than 2 mm
II. Sand, particle size between 0.06 mm to 2.0 mm
III. Silt size, particle size between o.o2 mm to 0.06mm
IV. Clay size, particle size smaller than 0.002mm

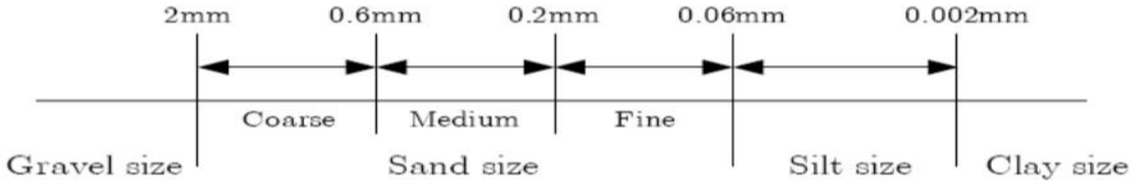


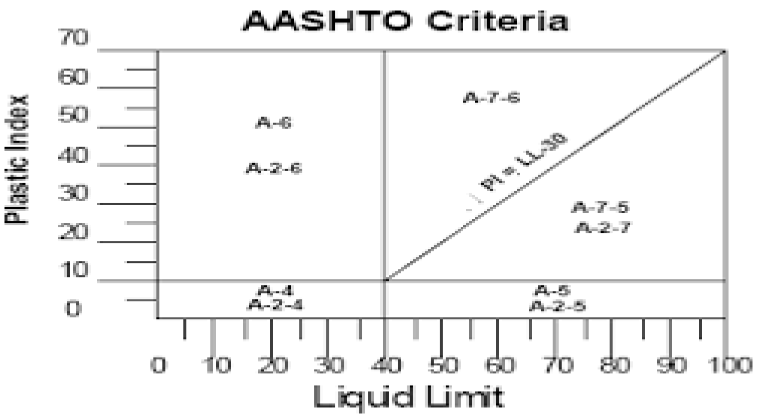
Fig.2.3 Particle size classification

AASHTO Classification System

This classification system was originally developed by Terzaghi in 1929 as public roads classification system and Used quite extensively by civil engineers in selecting soils for usage in roads and highways. In AASHTO Classification system, Soil is classified as coarse grained when less than 35% pass No.200 sieve and as fine grained whilst greater than 35% pass No.200. By rating soils according to their suitability for the support of road pavement group classification and group index to the soil assigned as A1 to A8 (best soil to worst soil) and 0 to 20(good soil to poor soil) respectively.A1 to A3 are coarse grained soils although A4 to A8 are fine grained.

$$GI = (F200 - 35)\big(0.2 + 0.005(LL - 40)\big) + 0.01(F200 - 15)(PI - 10) \qquad 2.2$$

Where, GI is group index,$F_{200}$is Percentage passing through No.200 sieve, LL is liquid limit, PI is plasticity index.



UCSC (Unified Soil Classification System)

This system is first developed by Casagrande (1948) for the purpose of airfield construction during World War II. Afterwards, it was modified to enable the system to be applicable to dam's foundations and other construction.

The four major divisions of soil using USCS are: coarse grained, fine grained, organics and peat.

Using USCS, the soil is classified based on the soils grain size and Atterberg limit test results. In this classification system coarse grained soils are for which more than 50% soil fraction retained on No.200 sieve. These coarse grained materials classified as gravel and sand based the amount of coarse fraction pass No.4 sieve. If more than 50% coarse fraction retained on No.4 sieve the soil classified as gravel, if not it classified as sand. The fine grained soil materials are those consist of less than 50% coarse materials retained on No.200 sieve. The fine grained soils grouped depending on their plasticity characteristics (LL, PI).Organic soils and peat soils are composed of various stages of decomposed organic matters.

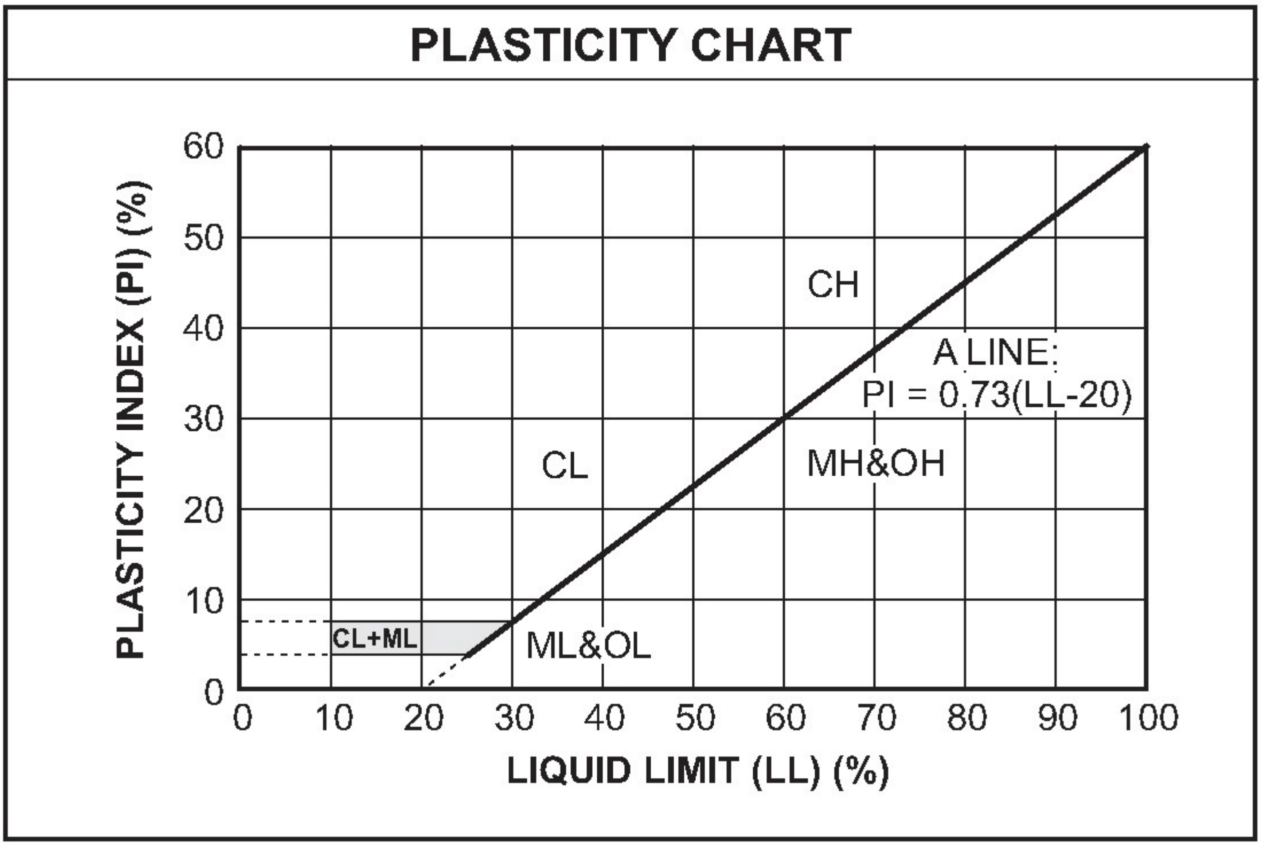


Fig.2.2 Soil classification using system USCS classification

Classification Based on Indirect Predictions of Swell Potential

An indirect prediction of swell potential includes correlations based on index properties, swell, physical indicator and a combination of them. Some of such classification systems are:-

- Alemayehu and Mesfin (1999)

One may use to check as the accuracy of laboratory test results for Expansive soils found in Ethiopia.

Table 2.3 Indicative properties of Ethiopian Expansive soils.

Clay content smaller than 2µm	50-80%
Liquid limit	80-120%
Plasticity limit	55-90%
Shrinkage limit	10-16%
Free swell	90-123%

(After Alemayehu and Mesfin, 1999)

2.3 Geotechnical Soil Mapping

Engineering soil mapping is a guide to the principles, concepts, methods, and practices involved in soil mapping, as well as the applications of soil in engineering. Fookes (1969) states that the aim of engineering soil mapping should be to produce a map on which the mapped units are defined by engineering properties or behavior, and the limits of the units are determined by changes in the physical and mechanical properties of the soil materials. Primary mapping for soil engineering follows the same basic rules and uses the same techniques established for conventional geological mapping (Barnes, 1997). The initial decisions to be made when undertaking engineering soil mapping are to identify the types of data that are to be collected to meet the survey requirements, at what scale will mapping be carried out, and what methods are to be used for data collection. In most engineering situations there will be three phases to the work: desk studies, including aerial photograph interpretation, where all existing data are compiled; primary mapping in the field; interpretation and preparation of the final maps. The objective of the engineering soil mapping is to provide information about soils engineering and engineering structures (IAEG, 2006). IAEG (2006) suggested that engineering soil mapping requires identification, classification and characterization of engineering soil units and analyzing these units to identify problematic soils and then determine the condition of foundation. Characterizing engineering soil units using engineering soil mapping is helpful in construction of structures, urban planning and development. Engineering soil mapping was carried out by various techniques:

According to Chamberlin (1882), soil mapping can be carried out using techniques such as in situ test results, laboratory test results for soils, studying the hazards in the target area regarding soil problem. Engineering soil mapping can be carried out using the soil classification schemes such as USCS and AASHTO depending on the soils index properties (Chamberlin, 1882).Another technique of soil mapping is proposed by ESB (1998), also use different techniques. EBS soil mapping is GIS based technique which is very applicable in inaccessible areas. In order to map soils using this technique, visual inspection of aerial photographs, site descriptions located with Global Positioning Satellite (GPS) receiver, samples taken for documentation and laboratory analysis, model based on available GIS data layers and pedologic characteristics. Then the collected information from field and laboratory test results present in the form of graphical presentation that is soil map. This soil map can be used by different researchers, for construction purposes, by agriculturalists etc. This soil mapping technique was employed to map the soil of the present study area.

2.4 Clay Minerals

Clay Minerals are layer silicates that are formed usually as products of chemical weathering of other silicate minerals at the earth's surface (William, 2000). Clays are formed by alteration of alumino-silicates in weathering and low temperature hydrothermal processes (Obaje, 2013). Some of the more common types are described here:

Kaolinite

This clay mineral is the weathering product of feldspars (Arora, 2000). It has a white, powdery appearance. Kaolinite is named after a locality in China called Kaolin, which invented porcelain (known as china) using the local clay mineral. The ceramics industry uses it extensively. Because Kaolinite is electrically balanced, its ability of adsorb ions is less than that of other clay minerals.

Illite

Illite resembles muscovite in mineral composition, only finer-grained. It is the weathering product of feldspars and felsic silicates. It is named after the state of Illinois, and is the dominant clay mineral in Midwestern soils. .

Montmorillonite

Montmorillonite is the most Expansive clay mineral known by its swelling behavior and highly reactive (Ashenafi, 2013). Montmorillonite has high LL, PI and Activity. This clay mineral is the weathering product of Volcanic ash and highly water absorbent (Arora, 2000).It has the ability to absorb large amounts of water, forming a water-tight barrier. It is used extensively in the oil drilling industry, civil and environmental engineering (where it is known as betonies), and the chemical industry.

2.5 Previous works

Many researches are done and ongoing in geotechnical investigation of soils in different parts of Ethiopia**.** And in previous works the soils of the studied areas are identified. From these research works summary of those reviewed for present study and presented in tale 2.4 below. The methodologies adopted in literatures will be followed in present study to characterize the soil of Sululta Town.

Table 2.4 Summary of previous works in Ethiopia

Author & year work	Title of work	Result (Type of soil in the area)
Lulseged Ayalew(1990)	Engineering Geological Characterization of the Clay soils of Bole Area	Expansive clay
Abebaw Zelalem (2005)	Basic Engineering Properties of Lateritic Soils Found in Nejo –Mendi Road Construction Area, Welega	Lateritic soils with high plasticity and finer grain size
Dagmawe Negussie(2007)	In-depth Investigation Of Relationship Between Index Property And Swelling Characteristic Of Expansive Soil In Bahir Dar	Fat or Organic Clay with a potential of expansion.
Hanna Tibebu (2008)	Study of Index Properties and shear Strength Parameters of Laterite soils in Southern Part of Ethiopia the case of Wolayita - Sodo	MH(inorganic clay with medium strength) and contain Kaolinite mineral
Gebremedhin Birhane (2010)	Engineering Geological Soil and Rock Characterization in the Mekelle Town, Northern Ethiopia: Implications to Engineering Practice	Presence of expansive soil in the town
Dagnachew Debebe(2011)	Investigation On Some Of The Engineering Characteristics Of Soils In Adama Town, Ethiopia	silt soil and clayey soil
Ashenafi Tamirat (2013)	Study On Index Properties And Swelling Pressure Of Expansive Soils Found In Dukem	Expansive soils
Belay Hunde (2014)	Investigation On Some Of Engineering Properties Of Soils Found In Ambo Town, Ethiopia	High plastic clay soils (CH) and high plastic silt soils (MH)

CHAPTER THREE

3. DESCRIPTION OF THE STUDY AREA

3.1 Location and Accessibility

Sululta is located in central Ethiopia at distance of 23km from Addis Ababa. The town is geographically bounded by location of9ºº30'00"N to 9º12'15"N latitude and 38º 42'0"E to 38º46'45"Eof the Oromia Special Zone surrounding Finfinnee. Sululta is bordered on the south by the city of Addis Ababa, on the west by the Mulo and West Shewa Zone, on the north by North Shewa zone, and on the East by Bereh. The Addis Ababa -Fitche- Gohatsion asphalted road pass through the central part of the study area.

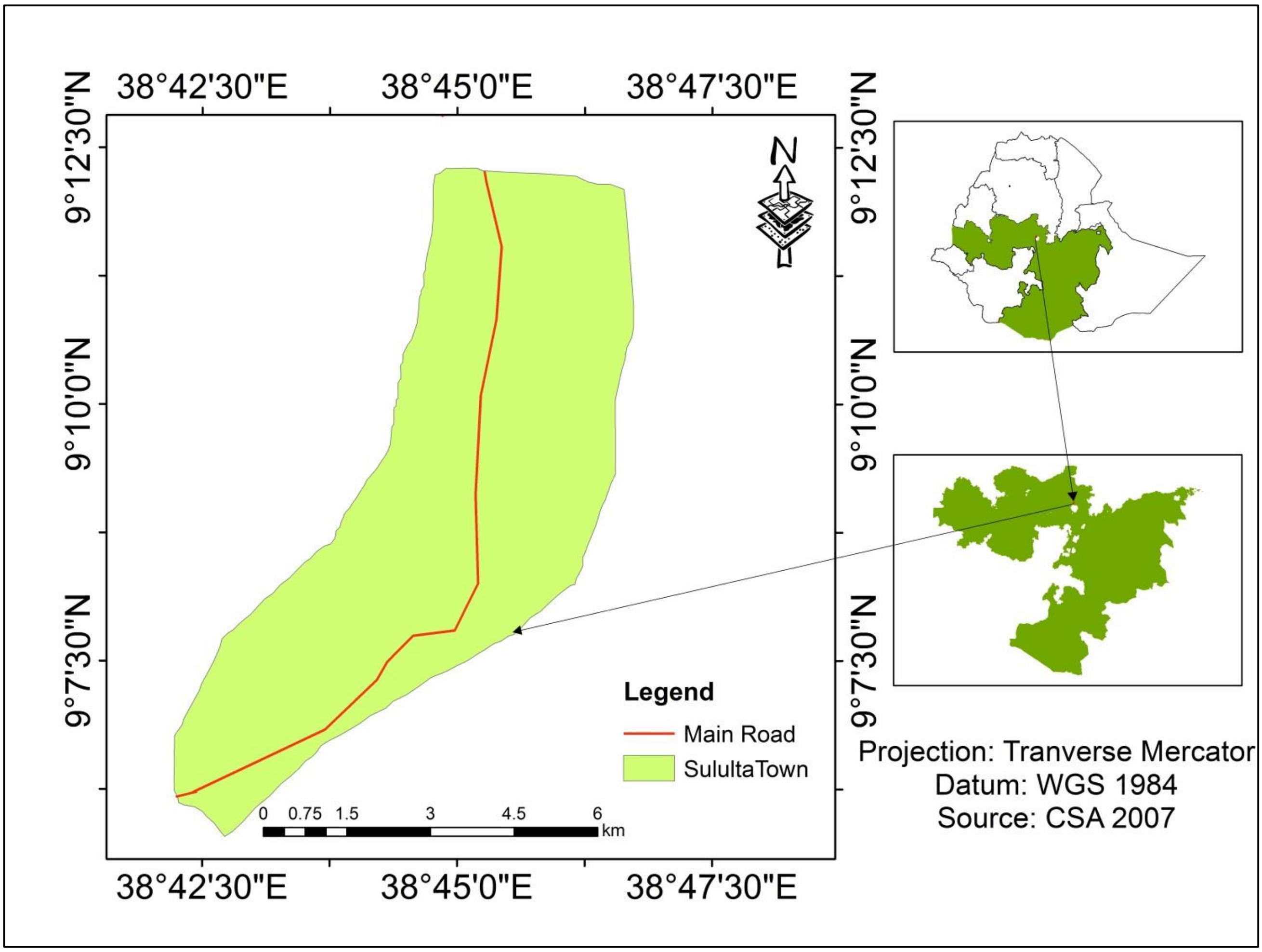


Fig. 3.1 Location map of the study area

3.2 Topography

3.2.1 Elevation

Topography has effect on drainage characteristics that can affect soil mineralogy. Its control over soil properties is particularly strong in tropical environments reflecting the importance of lateral movements of water and soil material. The Study area is surrounded by plains, mountains and valleys but Sululta town is found at flat to undulating topography. The topography of the area varies from chains of mountains around Entoto ridge in the south to plain lands in the East, North-west, and north. The average elevation in the town is 2765m above mean sea level. The altitude of the study area generally ranges in south-north direction from 2917m to 2614m above mean sea level. The topography of the study area results in the formation of alluvial soils since the weathered particles from parent materials at higher elevation to lower elevation by runoff water and streams. (See the fig 3.2 below).

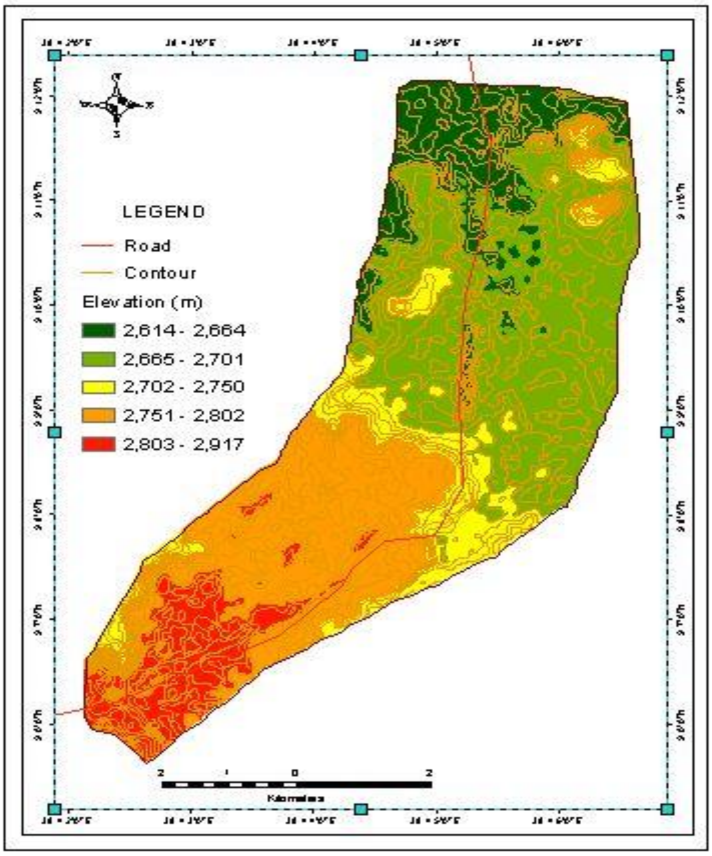


Fig.3.2 Elevation Map of the study area

3.2.2 Slope

Slope is the measure of steepness or the degree of inclination of a feature relative to the horizontal plane refers to the tangent of the angle of that surface to the horizontal. In the study area the slope is also another topographical aspect that influences the characteristics of soils.

The maximum angle above horizontal at which a material of given density and moisture content will remain in place without sliding. This measurement is used specifically for earth cuts, fills, and stockpiled aggregates at which a soil material will stand without moving. The steepest slope of the area is situated around southern ridge of Entoto and Northeastern fringes. By implication high run off and lateral erosion in these areas compared to the gentle slope place. Generally the town is marked by gentle slope that is flood prone. In the same manner with elevation the slope of study area influence the formation of alluvial soils in Sululta Town.

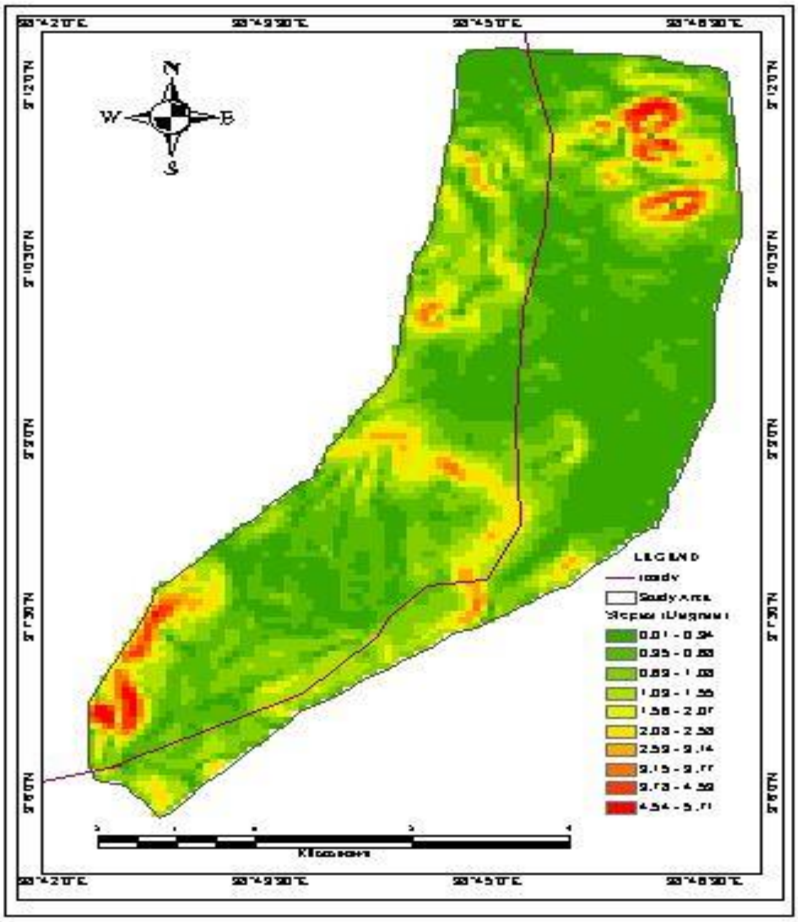


Fig.3.3 Slope Map of the area

3.3 Climate

3.3.1 Rain Fall

The data taken from National Meteorological Agency at Sululta area in the year from 2006 up to 2015 shows that the and the mean monthly rainfall of the area ranges from 2.52 mm to 312mm. The rainy season prevails from June to September. During these rainy seasons the area characterized by flooding. These rainy seasons of the study area are the seasons of soils transportation from the surrounding mountains and deposition to plain areas. The rain fall in the area plays an important role in formation of the soils as transporting agent.

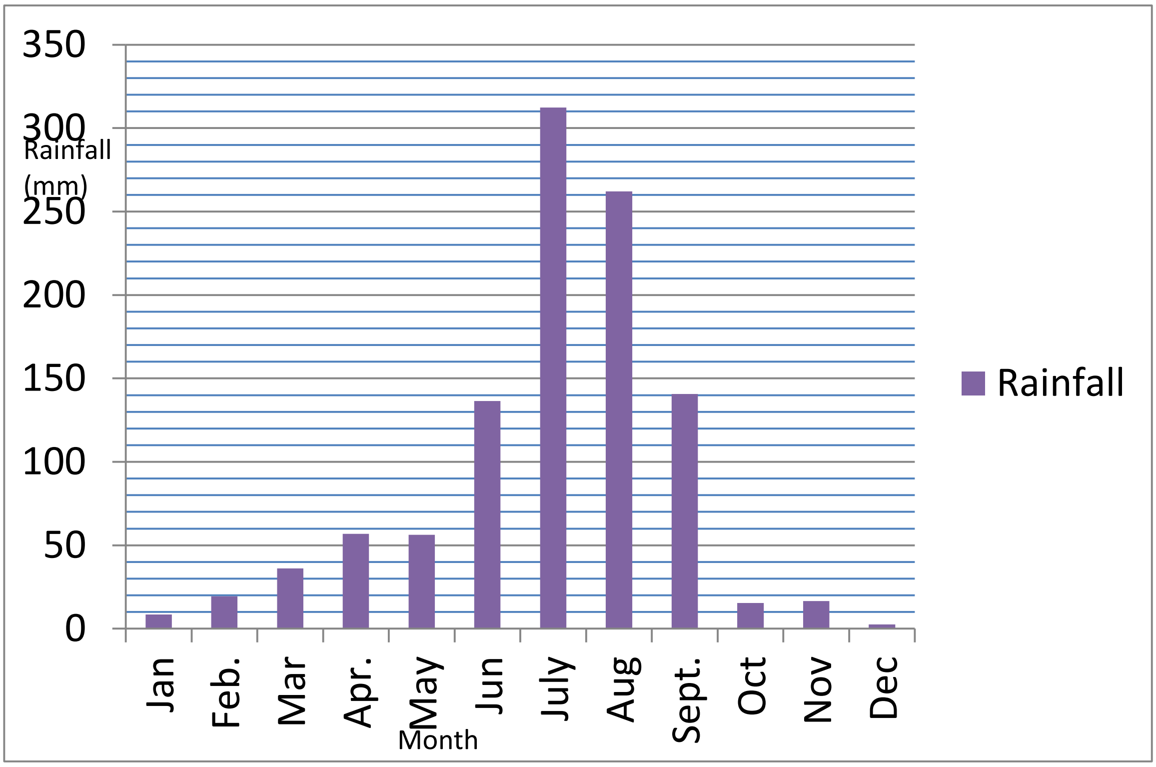


Fig.3.4 Mean monthly rainfall distribution of the study area (2006-20015)

3.3.2 Temperature

Records of National Metrological Agency shows that mean minimum ,mean maximum and mean average monthly temperature of the area for 10 years are 2.7^{0}C , 23.1^{0}C and 12.9^0 respectively. January is the season of highest temperature (Warmest season) while November is the coldest in the area. The temperature of the study area indicates that as the study area is tropical area. (Fig.3.5).

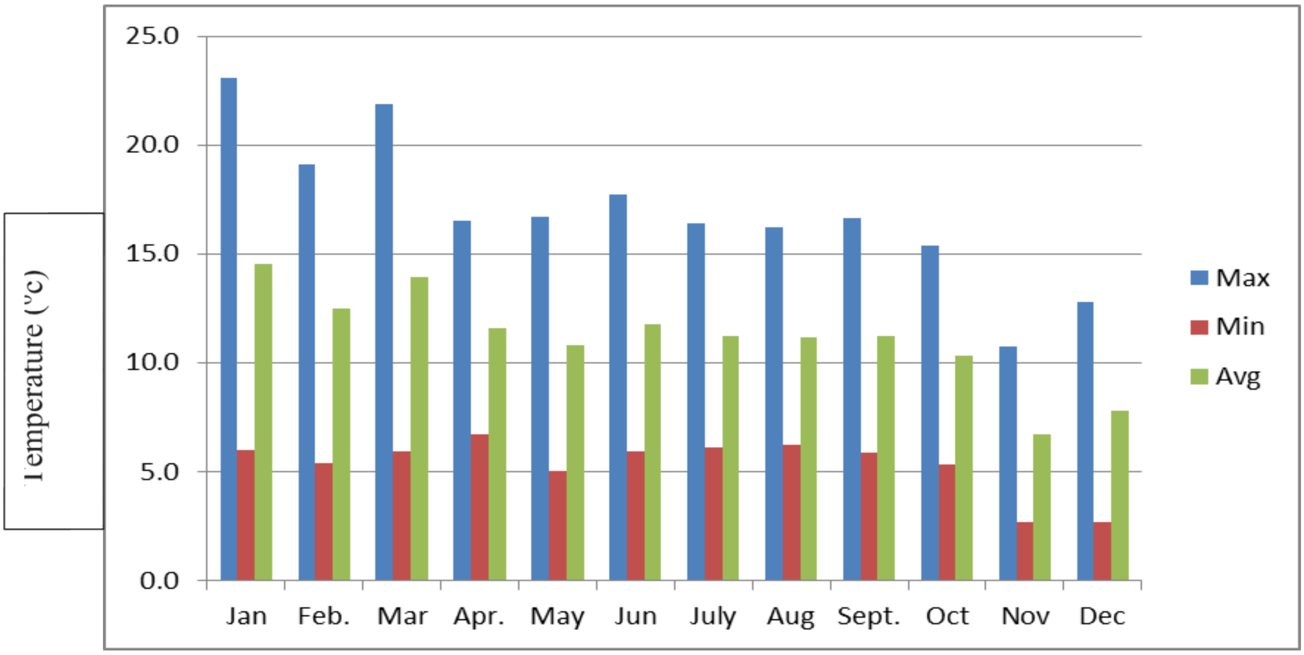


Fig.3.5 Mean monthly temperature distribution of study area (2006-2015

3.4 Drainage System

The drainage of the study area is governed by the catchments of Blue Nile River, particularly Mugher river, which is one of the tributaries of the Blue Nile. Urban drainage facility is one of the urban infrastructure development challenges in developing Countries. The drainage pattern of the study area can be illustrated as rivers and streams. Three major rivers are found in the area. These are Bilo, Dima, Orogogo rivers, while most of the areas of the town is flat and the rivers transient it are narrow in width and shallow in depth, they are over flooded. All the wet land of the study area is found in the east and Northwest of Abyssinia water factory in the town, it is not appropriate location for construction. Merga (2012) states that that flooding is a very common issue in the city of Sululta. Therefore, the flooding in the area has effect on soil characteristics. In general, rivers and streams of the study area have role in the formation of the soil of the town.

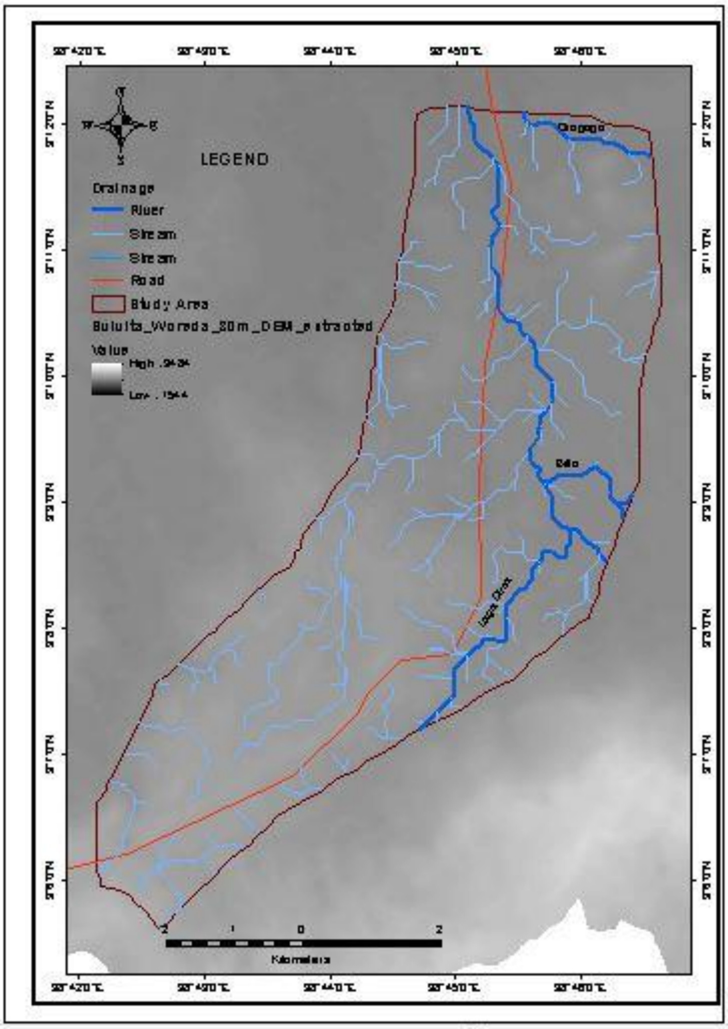


Fig. 3.6 Drainage pattern map of the study area

3.5 Ground water

The geological well data and the excavated pits for this study show that the study area is characterized by very shallow ground water. During pit excavation the ground water encountered starting from a depth of 2.2m. According to Peck (1996) correction for the water table, should be undertake if the water table lies above the loaded depth of the footing, the confining pressure of the soil is reduced. Hence, the settlement correspondingly increases as compared to the values if the water tables were below the loaded depth. Due to the lowering of ground water table, in the central part of the river catchment the springs have no flow during dry seasons. And during very dry condition, most of the springs left as tangent pond. As a result, the springs show yield variation due to the seasonal rainfall variation. Generally, the shallow ground water occurrence in the town is resulted from the flow of the subsurface water from slope areas of Entoto ridge and surrounding fringes. As a result the shallow occurrence of ground water in the study area has impact on buildings constructed and being under construction in the town, in that, it lowers the bearing capacity of the foundation soil.

3.6 Geological Setting

3.6.1 Regional Geology

The outline of the geological history of the Afro-Arabian countries – Ethiopia is believed to be in the group – was sketched by Pierre Gouin (1979) as follows:

At the end of the Precambrian era, the crystalline basement complex of the present Afro-Arabian swell had been above sea level for a long time and remained for another 370 million years until the end of Paleozoic era. Such a long period of erosion and denudation left the earth's surface almost completely pen planed. Crustal motion started in the beginning of Mesozoic era. During the late Triassic and early Jurassic periods, a regional epi-orogenic sinking of the crust commenced causing a progressive transgression of the ocean from the south east that is, from the Indian Ocean coast of present day Somalia in the general direction of Lake Tana in the North West Ethiopia.

This downward crystal movement, associated with a sedimentation process, started a cycle of marine transgression and recession of Mesozoic sea. Within this large epi-continental sea, extensive layers of sediments were deposited to form hundreds of meters of rocks consisting of sandstone, shale, gypsum, limestone and other varieties of sedimentary rocks.

The crustal movement was reversed into the upward motion during the late Jurassic period, which brought the crust's surface up to sea level by marine regression in late Cretaceous period. The regional uplift resulted in wide spread crustal fracturing during the early Tertiary period. The crystalline and sedimentary rock layers were fissured mostly along or in the vicinity of the zone of maximum uplift, thus allowing outpouring of molten lava to cover the older rock layers.

Major fault displacement along the Rift Valley was initiated during middle Tertiary period. Subsidence of large crystal blocks along steeply inclined fault zones created grabben type depressions along the rift valley and at Lake Tana. Significant volcanic activity was associated with the formation of grabbed and young volcanic rocks cover the old Tertiary volcanic in many depressions.

Present day tectonic activity occurs along the Rift Valley as evidenced by numerous earthquakes. More recent volcanism, associated with tectonic activity, had been concentrated within this structure along the edge of the adjoining plateau. The geological setting of the study area vicinity is representative of:

The Mesozoic era transgression and regression event depositions of sediments, like Adigrat sandstone, which rests uncomfortably on the crystalline basement rock, Abay beds composed of gypsum and shale units, Antalo Limestone which conformably overly the Abay beds, Amba Aradam sandstone; Tertiary and Quaternary volcanic units includes:

The Blue Nile basalts, Amba Aiba basalt, Alaji rhyolites, Tarmaber basalt and Rift volcanic.

Antalo Lime stone

This unit is exposed in the Northern, Northeastern, and Central and western parts of the area. It is mainly out crop at the Blue Nile, Jema and Muger river valleys. Most of the time lime stone forms cliffs. However at some places it shows gently sloping ridge. The contact with the underlying mud stone formation is gradational which is marked by silt stone layers followed by calcareous silt stone, silty lime stone and gradually to lime stone. However, the contact with the underlying gypsum unit is sharp (Assiged, 20007).

Abay Beds (Gohatsion formation)

This formation is mainly exposed in the northern, central and north eastern part of the study area following the Blue Nile, Jema and Muger river valley forming steep slope cliff. Assiged (2007) mentioned that the nature of the contact with overlying limestone is sharp while with the underlying sand stone is gradational.

Alaji Rhyolite

This unit is exposed in the northern central part of the study area. It is consisting of rhyolites, ignimbrites and subordinate trachyte. Obsidian bearing rhyolites are common in the study area. The obsidian composition at Segno gebeya area gives rise to the dark gray color. The age of this rock unit is Miocene, 33-15Ma (Kazmin, 1979).

Ashangi Basalt

The Asangi basalt is exposed in the northern part of the area representing the oldest fissural flood basalt next to the Blue Nile basalt volcanism in the northwestern plateau. It is strongly weathered, crushed and predominantly consisting of alkaline basalts with inter bedded pyroclastic and rare rhyolite and is commonly injected by dolerite sills and dykes. According to Kazmin (1979) the age of this unit is Eocene-Oligocene (55-24 Ma).

Alluvial Cover

The alluvial cover mainly out cropped above the Tertiary Volcanic on the plateaus and Becho plain and the alluvial unit is deposited in northern, north eastern and western parts of the study area along Jema and Muger river valleys. Its texture varies from sand to silt size.

Entoto Rhyolite and trachyte

The Entoto mixed rocks are found in the southern eastern part of the mapped area. This unit constitutes rhyolite, trachyte, ignimbrite, pyroclastic rocks and sediments. All the rocks are highly weathered and jointed with few layers of agglomerate at some places. There is a red backed soil development at the contact with the under lying basalt. This lithological unit is highly affected by joints trending E-W and N 29o. It forms high mountain chain called Entoto trending E-W (Assiged, 2007)

3.6.2 Local Geology

The local geology of the study area is generally classified into two major groups. Specifically, tertiary volcanic (plateau basalts) and Quaternary units (Rift volcanic and sediments) that classified based on their age of eruption, spatial distribution, and mode of occurrence. Tertiary plateau basalts are part of the trap series volcanic products consisting huge accumulation of volcanic rocks with minor silicic, intercalations while, that of Quaternary rift volcanic and sediments comprise variety of rock units(acidic and basic) associated with formation of the Main Rift System during Quaternary period. Conversely, both major geologic units divided to sub group

- Cheleka basalt
- Quaternary basalt
- Entoto volcanic

- Quaternary superficial sediments

Cheleka Basalt (Tcb)

This lithological unit found in the Northern part of the study area. The unit underlies younger volcanic product mapped in this study quaternary basalt (Qb).

The Cheleka basalt of the study area are characterized by columnar structure layered sequences Basalt of the area has a characteristics of flows, with different thickness, textural characteristics, and surface extension have been recognized at this particular area. It is the top most layer characterized by boulders of slightly vesicular basalt, gray in color, olivine (5 - 10%) and feldspar (possibly plagioclase) are visible minerals (OWMEB,2014).The vesicular nature of this basalt has been resulted from the escaping gaseous phases contained in the erupting basalt melt (primary Volcanic structure) and from the weathering process of olivine and plagioclase, resulting secondary minerals such as calcite, zeolite, clay, etc. minerals. The other is uniform grain size of alphabetic texture dark in color. Medium to course grained olivine and feldspars were identifiable by naked eye (OWMEB, 2014).The photograph taken at the field for Cheleka basalt is presented in the following plate.3.7

Plate.3.1 Cheleka basalt

Quaternary Basalt

This basaltic unit is situated in gently undulating lands and at surfaces usually covered by relatively thick soil in plain areas of the study area. Quaternary basalt which covers largest part of the study area overlies Cheleka basalt and underlies Entoto volcanic of younger volcanism. This unit is found in the area also surrounding Weliso and Ambo and the unit is characterized by volcanic plugs that extruded through it forming different volcanic edifice. Denser vesicles found in the upper part of the unit. The following plate in Plate.3.8 shows Quaternary basalt in the study area.

Plate.3.2 Quaternary Basalt

Entoto Volcanic

This unit is found in southern fringe of the study area around mountain chain of Entoto that surrounds Finfinnee city from Northwestern, Northern and Northeastern directions. Entoto volcanic are found constituting rhyolite, trachyte, ignimbrite, pyroclastic rocks and sediments. All the rocks are highly weathered and jointed with few layers of agglomerates at some places. The development of backed soil is observed at the contact of the underlying basalt. This Lithological unit is highly affected by joints trending E-W. Lithological units forms high mountain chain called Entoto trending E-W

Quaternary superficial sediment

This Lithological unit is formed by quaternary rift system and it covers the smallest area of the study area in the Northeastern part. The following Fig.3.9 indicates the geology of the study area.

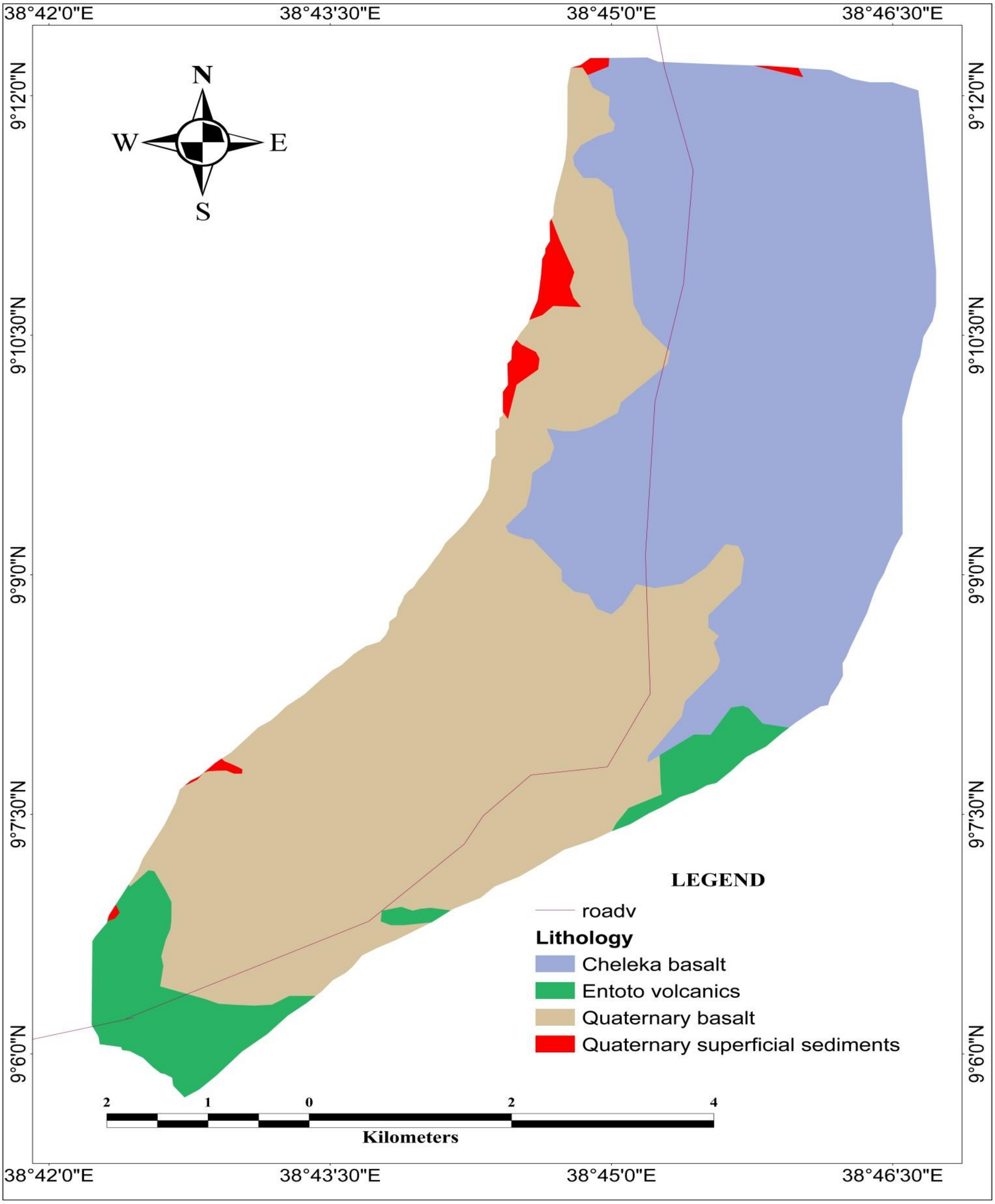


Fig.3.7 Geological map of the study area (After, GSE(2010))

3.7 Soils

Soils of the study area are classified as it is alluvial soil by Ethiopian Institute of Geological Survey department of Geohazard (EIGS,2010).The soil color is identified as reddish brown and dark grey in with clay and silty clay in texture. Usually the soils formed in tropical areas are residual soils but in this area due to its topographical situation alluvial soils are found.

Soil types of the study area are classified and defined as presented below:

Chromic luvisols

Luvisols are a characteristic soil of forested regions; identified by the presence of eluvial (Ae) horizons and illuvial (Bt) horizons where silicate clay is accumulated (Gregor, 1984). They can also be characterized by the presence of a leafy, humus surface horizon that is separated from the mineral horizon (Gregor, 1984),a horizon eluviated of clay minerals and a horizon of at least 5 cm. thick with alluvial clays (Gregor, 1984).

Vertic Cambisols

In the FAO (2001) World Reference Base for Soil Resources Cambisols is a soil with a beginning of soil formation. The horizon differentiation is weak. This is evident from weak, mostly brownish discoloration and/or structure formation in the soil profile. But they are common in areas with active erosion where they may occur in association with mature tropical. The study area is mostly covered by this soil type.

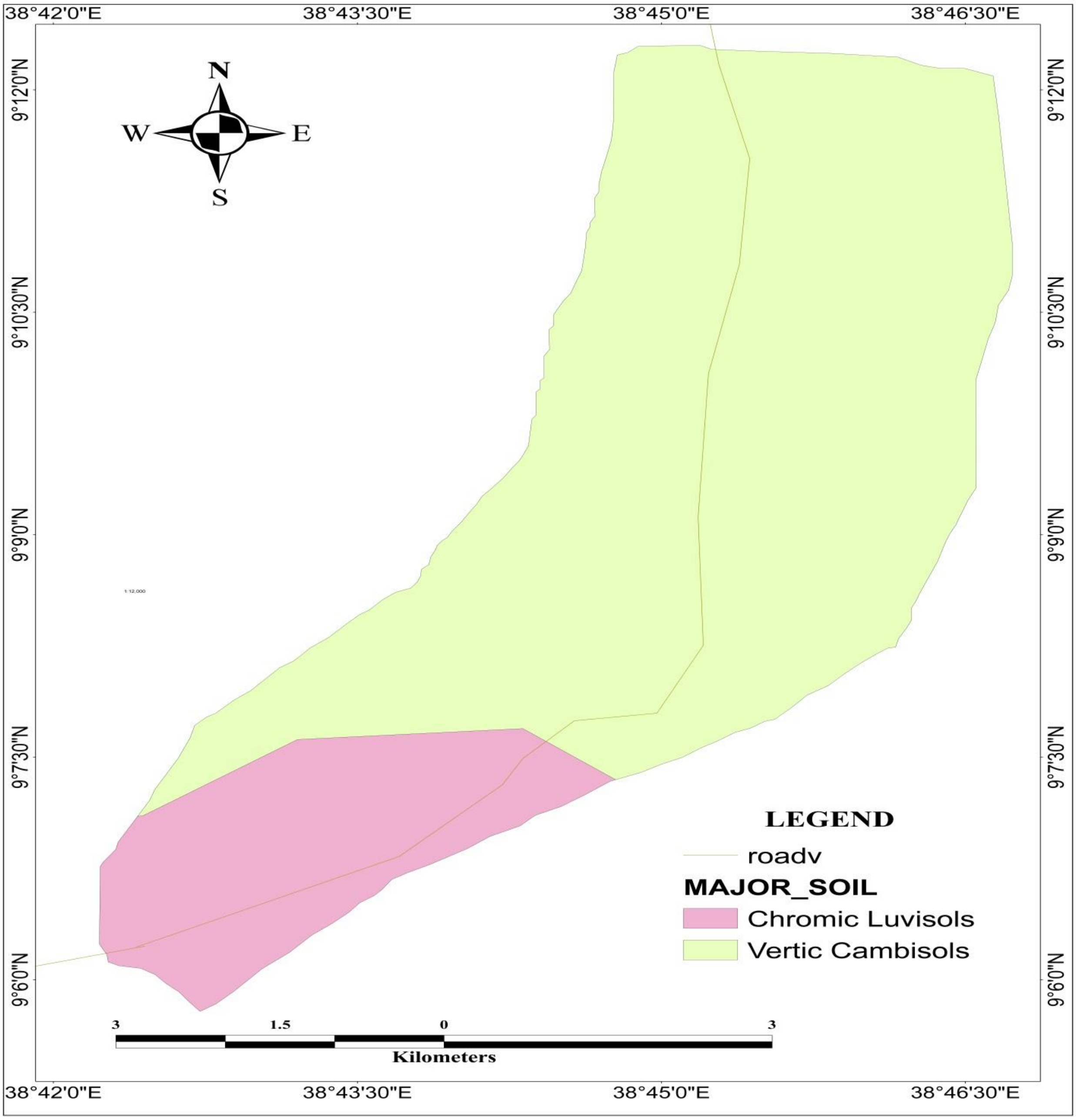


Fig.3.8

Soil map of study area (After, FAO (2001))

CHAPTER FOUR

4. RESEARCH METHODOLOGY

In order to achieve the objective of this thesis, the following methodology was followed:

4.1 Pre Field Work

- Different journals, books and most related researches accomplished on soil Engineering was revised.
- Secondary data was collected from Meteorological Agency (Meteorological data) and Ethiopian Institute of Geological survey (Geological and borehole data).
- Geologic (lithology), drainage, topographic (Elevation &slope), soil (from FAO, 2001) mapping was conducted under other study plans and by review of available USGS mapping.

4.2 Field work

- **Site Reconnaissance**: The investigation consisted of a site "walkover" at facility component locations and alignments. Surficial geologic features (bedrock outcrops, surficial soil types, topographic change and drainage) in the area were identified in order to select sites for sampling.

- Photographs were taken and lithological description for rocks was conducted.

From the six test pits only two test pits TP-1 and TP-4 are excavated to a maximum depth of 3 m whereas the others didn't reach up to 3 m due to the presence of Ground water flow.

Plate.4.1 The ground water test pit 2

Plate.4.2 The ground water at test pit 5

Plate.4.3 The ground water test pit 6

- Six sites were selected test pits are excavated to a maximum depth of 3m and 15 representative samples (11 disturbed and 4 undisturbed) were collected for laboratory tests.
- Field description and logging for each test pits conducted
- GPS Readings were collected to locate coordinates of sample test pit

Table.4.1 Location of sampling sites

Sample Test Pit	Location	Coordinates		
		Easting	Northing	Elevation(m)
TP-1	Mizan	0469109	1007093	2750
TP-2	Elemtu	0470957	1010850	2710
TP-3	Ashawa	0472778	1011038	2627
TP-4	Kajima	0472646	1012460	2606
TP-5	Laga dima	0473677	1014231	2604
TP-6	Bircuko Fabrica	0474201	1016754	2578
SDBH-1	Mizan	469935	1006868	2732
SDBH-2		470090	1006737	2744
SDBH-3		469932	1006616	2733
SDBH-4		469785	1006540	2726
SDBH-5		469439	1006586	2746
SDBH-6		469736	1006759	2733

.

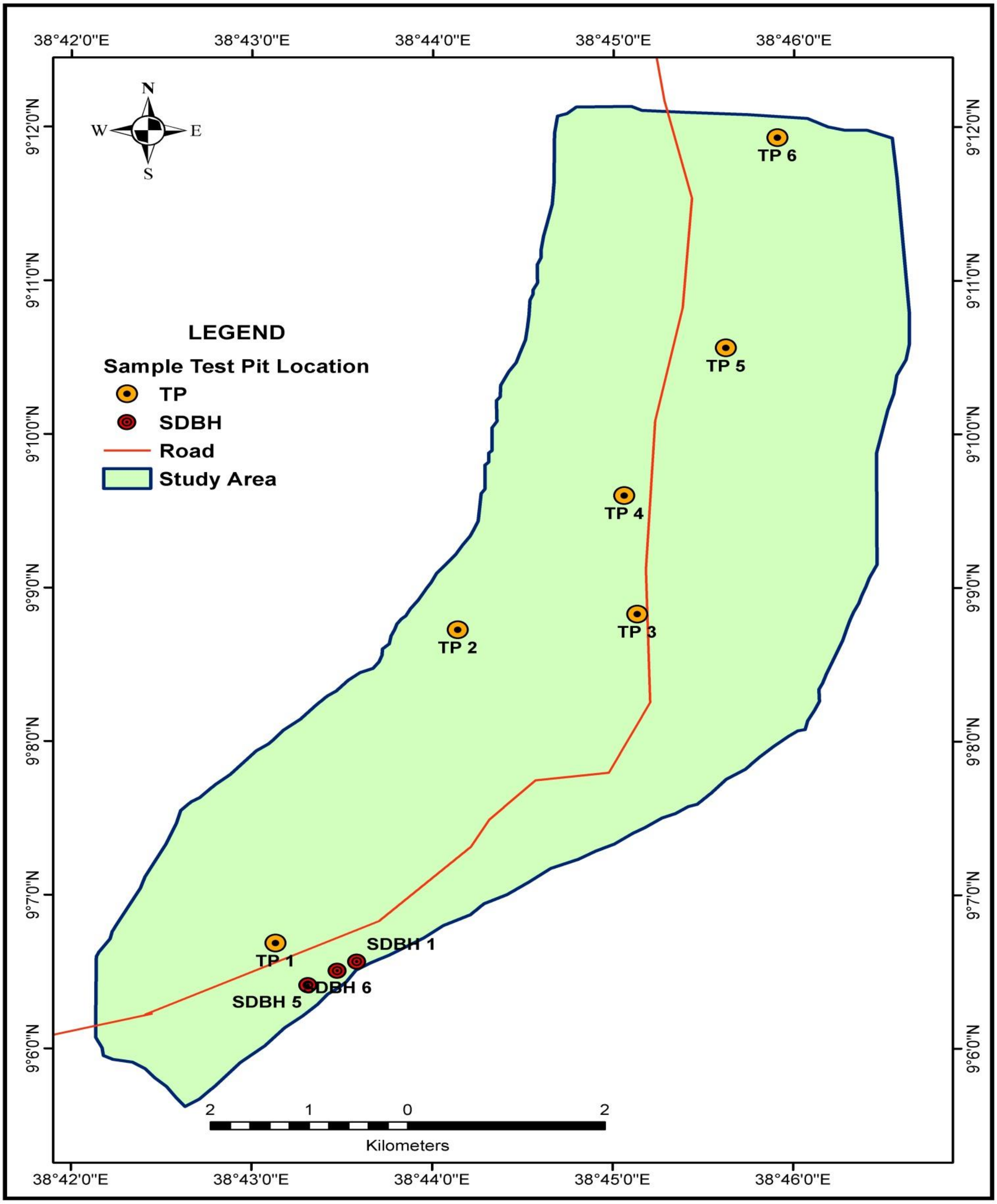


Fig.4.1 Location Map of Test pits

4.3 Post field work

Table 4.2 Laboratory soil tests conducted on disturbed and undisturbed samples

Test conducted	Type of sample	Standard followed	Number of sample
Natural moisture content	Disturbed	ASTM D 2216	11
Grain size Analysis	Disturbed	ASTM D 422	11
Atterberg Limits	Disturbed	AASHTO T90-89	11
Specific gravity	Disturbed	ASTM D 854-00	11
Free swell test	Disturbed		11
Direct shear test	Undisturbed	ASTM D3080	4
Consolidation test	Undisturbed	AASHTO T-236	4

- Engineering soil classification using AASHTO and USCS classification schemes
- Engineering soil mapping using Arc map 10.3 software
- Presentation and discussion of results
- Conclusion and Recommendations are drawn from the results

The methods and work efforts outlined in this study are consistent with analyses used in literatures.

CHAPTER FIVE

5. DATA PREPARATION, ANALYSIS, RESULTS AND DISCUSSIONS

5.1. General

For characterization of the soil of Sululta town for engineering practices firstly field visual investigation was carried out to select the place from where sample to be collected. The selection of site for test pits depends on topography variation, drainage, distance. Then six test pits excavated to a maximum depth of 3m and sample collected for laboratory tests. The soil of the study area characterized based on laboratory index tests results. The coordinates of sampling sites were collected. Based on the field description, the soil of study area is characterized by fine grains and low to very high plasticity behavior. Furthermore, the soils show color variation with depth within each test pits and grain size difference also seen in the same test pit with depth. These variations within depth of each test pits were the reason for collection of different sample for the same test pit. In addition to primary data, secondary data for six boreholes up to depth of 3 m were collected from Geological survey of Ethiopia and analyzed.

5.2 Field Textural Description of Soils

The soils of the study area was described at field based on their color, particle size, plasticity, grading and on the basis of these description the soils' field name was given.

Table 5.1 Field soil profile description of Sululta tow

Locality	Depth (m)	Sample code	Color	Grain size	Plasticity	Grading	Soil field name
Mizan	0-2.25	TP11	Light reddish	Fine grained	Low plastic	Uniformly graded	Silt with trace sand
	2.25-3.0	TP12	Light reddish	Fine grained	High plastic	Uniformly graded	Clayey SILT
Elemtu	0-2.0	TP21	Light reddish	Fine grained	Slightly plastic	Poorly graded	Silty CLAY
	2.0-2.5	TP22	Dark gray	Fine grained	Slightly plastic	Uniformly graded	Slightly plastic silt
Ashawa	0-2.0	TP31	Black	Fine grained	High plastic	Gap graded	Clay with minor sand
	2.0-2.5	TP32	Light reddish brown	Fine grained	Slightly plastic	Gap graded	Clay with some sand
Kajima	0-2.6	TP41	Light gray	Fine grained	Very high plastic	Uniformly graded	Clay of Very high plasticity
	2.6-3	TP42	Pinkish gray	Fine grained	High plastic	Uniformly graded	Slightly sandy CLAY
Laga dim	0-1.65	TP51	Dark gray	Fine grained	High plastic	Uniformly graded	Clay with minor sand
	1.65-2.6	TP52	Light gray	Fine grained	High plastic	Poorly graded	Clay with some sand
Bircuko Fabrica	0-2.20	TP6	Light reddish	Fine grained	Slightly plastic	Poorly graded	Clayey SILT

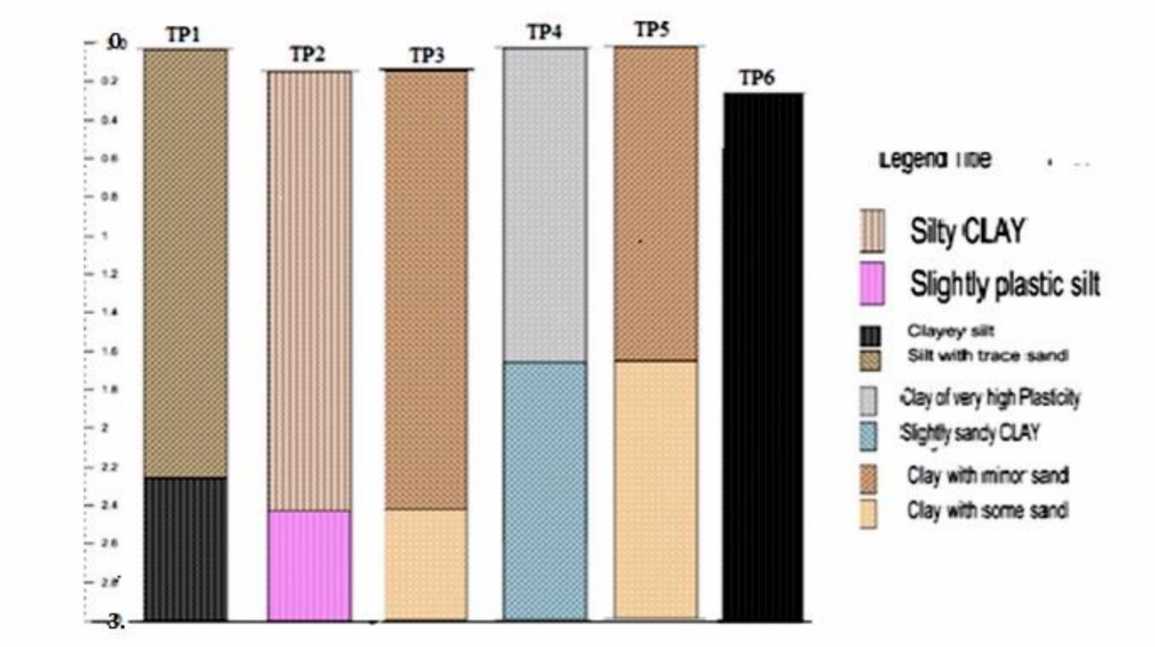


Fig .5.1 Soil profile logging of test pits

5.3 Laboratory Tests on Disturbed Samples

5.3.1 Natural Moisture Content (NMC)

Natural Moisture Content has effect on soils behavior when used for construction purposes and foundation of structures. Moisture content affects settlement condition (consolidation), shear strength and suitability of soil for compaction. Natural Moisture content used to predict degree of consolidation of soils. The Natural moisture content of the soil is determined using ASTM D 2216 Procedure.

$$W = \frac{\text{Weight of water}}{\text{Weight of solid soil}} \qquad 5.1$$

For coarse and fine-grained soils, water content can have a significant effect on the soils behavioral properties when used for construction purposes and foundations. Moisture content affects the settlement (consolidation) condition. Moreover, the swelling-shrinkage condition of a particular soil is related to its moisture content and its change with time. Consistency of a fine grained soil also depends largely on its moisture content. The Moisture content of the soil of the study area ranges from 23.27 to 65.48.The laboratory moisture content test result of the soils of the study area are presented in table 5.2.

Table 5.2 Natural moisture content of the soil of the study area.

Locality	Depth	Sample code	Natural moisture content
Mizan	2.25	TP11	23.27
	3.0	TP12	28.02
Elemtu	2.0	TP21	45.20
	2.5	TP22	46.23
Ashawa	1.4	TP31	43.93
	2.5	TP32	37.10
Kajima	2.6	TP41	65.48
	3	TP42	43.07
Laga dima	1.65	TP51	51.24
	2.6	TP52	43.67
Bircuko Fabrica	2.20	TP6	40.73
Mizan	1	SDBH11	44.78
	3	SDBH13	46.23
	1	SDBH21	37.37
	3	SDBH23	34.56
	1	SDBH31	38.82
	3	SDBH33	44.75
	1	SDBH41	19.1
	2	SDBH52	43.28
	3	SDBH53	40.65
	2	SDBH62	33.01

5.3.2 Grain-size Analysis

The grain size of the study area soil was determined based on ASTM D 422 Standard test method. In the study area for different localities and depth variation of identical test pit the grain size analysis using both sieve and hydrometer analysis was carried out to determine the range in which the representative soil sample falls (see Fig.5.3 below). After completion of grain size analysis the relative proportion of different size in each sample was determined. The range of the size was especially required for the purpose of soil classification and also to get the relative proportion of clay sized soil in order to determine the expansion potential of the soil of the study area. From grain size analysis it was concluded that the soil of the study area can be characterized as fine grained. And the clay sized particles varies within each sample. Accordingly, the soil in the study area

- Gravel : 0- 2.58
- Sand : 3 - 28.9
- Silt : 44.1 – 83.1
- Clay : 16.1 – 40

The results are presented in table 5.3.

Fig.5.3 Hydrometer Analysis for fine grained soils of the study area

Table 5.3 Grain size distribution of the soil of the study area

Locality	Depth	Sample code	Gravel (%)	Sand (%)	Silt (%)	Clay (%)
Mizan	2.25	TP11	0	2.12	68	29.88
	3.0	TP12	0	3	63	34
Elemtu	2.0	TP21	0	2.02	57.98	40
	2.5	TP22	0	2.28	57.72	40
Ashawa	2	TP31	0.57	2.36	74	23.07
	2.5	TP32	0	7.35	62.65	30
Kajima	2.6	TP41	0	0.44	69.56	30
	3	TP42	2.58	1.47	71.1	24.85
Laga dima	1.65	TP51	0	2.36	83.1	14.54
	2.6	TP52	0.2	5.55	69.9	24.35
Bircuko Fabrica	2.20	TP6	0	3.1	74.9	22
Mizan	1	SDBH11	0.4	27.3	44.5	27.8
	3	SDBH13	0	28.9	46.4	24.7
	1	SDBH21	0	21.3	57.7	21
	3	SDBH23	0	26.8	46.4	26.9
	1	SDBH31	0	24.1	47	28.9
	3	SDBH33	0	17	58.4	24.6
	1	SDBH41	0	27.4	44.1	28.5
	2	SDBH52	0	19.3	60.1	20.6
	3	SDBH53	0	27.7	56.2	16.1
	2	SDBH62	0	17	50.54	32.6

5.3.3 Atterberg (consistency) limits

This test is conducted in order to characterize the soils of the study area related to their plasticity. Plastic index was used in classifying fine-grained soils and to the Casagrande plasticity chart. Limits were determined for the soil samples finer thanNo.200sieve. Atterberg limit test was conducted in this research for the purpose of obtaining the basic index information and plasticity of the fine grained soils used to identify the soils and to classify them. The test procedures are outlined in AASHTO material testing manual. In the present study the Atterberg limit tests follow AASHTO T90-89 procedure.

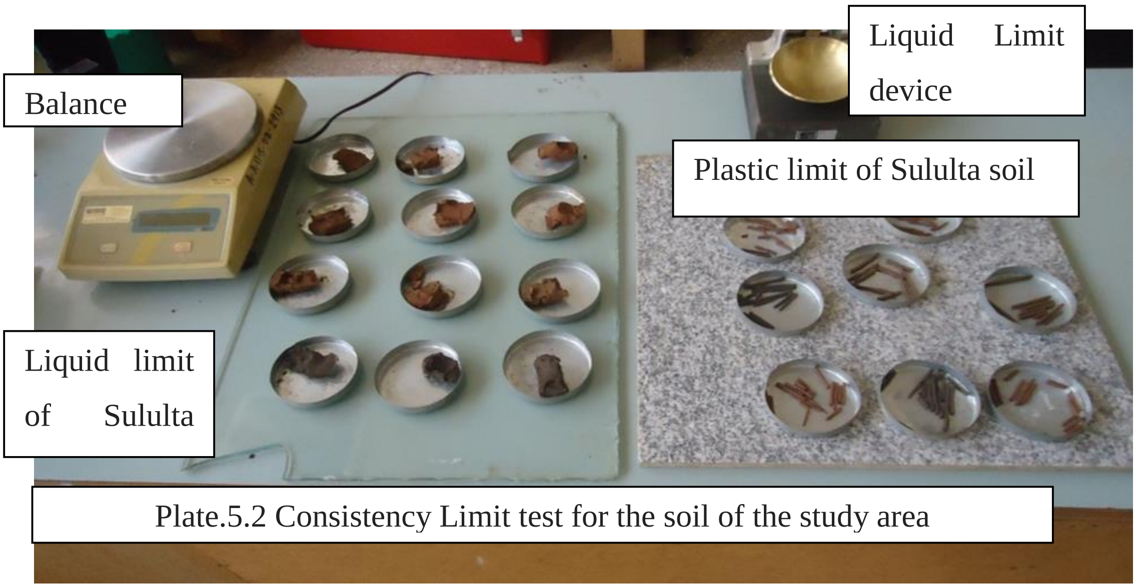


Plate.5.2 Consistency Limit test for the soil of the study area

Plasticity Index

The soils of study area are cohesive soils.

$$PI = LL - PL \quad (5.2)$$

The plasticity index of the soil of the study area is low to medium in Sandy silt soils and medium to very high in Elastic silt soils.

Consistency Index

The consistency index indicates the consistency of a soil. It shows the nearness of the water content of the soil to its plastic limit. A soil with a consistency index of zero is at the liquid limit. It is extremely soft and has negligible shear strength. On the other hand, a soil at a water content equal to the plastic limit has a consistency index of 100%, indicating that the soil is relatively firm. A consistency index of greater than 100% shows that the soil is relatively strong.

Mathematically, the equation expressed Szechy and Vargi (1978)

$$CI = \frac{LL - W}{PI} \quad (5.3)$$

The consistency index of the soils of the study area ranges from 20.3% (very soft) to 157.9 %(very stiff).

Liquidity Index

Liquidity index indicates the nearness of its water content to its liquid limit. When the soil is at its liquid limit, its liquidity index is 100% and it behaves as a liquid. When the soil is at the plastic limit, its liquidity index is zero. Negative values of the liquidity index indicate water content smaller than the plastic limit.

Mathematically, it can be described as

$$LI = \frac{W-PL}{PI} \qquad 5.4$$

The liquidity index value of the study area soils varies from -57.97(semisolid state) to 79.65(plastic). Atterberg limit test results of Sululta town soil presented in the following table 4.5

Table 5.5Atterberg limit test results of the Sululta town soils

Locality	Depth	Sample code	LL	PL	PI	CI (%)	LI (%)
Mizan	2.25	TP11	41.8	30.07	11.73	157.9	-57.97
	3.0	TP12	52.8	30.81	21.99	112.6	-12.69
Elemtu	2.0	TP21	56.65	41.90	14.75	77.6	22.37
	2.5	TP22	48.90	35.78	13.12	20.3	79.65
Ashawa	2	TP31	66.84	44.76	22.08	103.7	-3.76
	2.5	TP32	48.8	33.84	14.16	82.6	23.02
Kajima	2.6	TP41	91.5	46.91	44.59	58.3	41.65
	3	TP42	70.25	43.35	26.9	101.04	-1.04
Laga dima	1.65	TP51	62	42.53	19.47	55.2	44.74
	2.6	TP52	67.5	38.19	29.31	81.3	18.70
Bircuko Fabrica	2.20	TP6	47.3	35.67	11.63	56.5	43.50
Mizan	1	SDBH11	51	34.86	16.14	38.53	28
	3	SDBH13	65	43.54	21.46	87.46	6.17
	1	SDBH21	51	39	12	113.58	-4.17
	3	SDBH23	66	38.41	27.59	113.95	-10
	1	SDBH31	58	37.64	20.36	94.20	3.13
	3	SDBH33	66	43.72	22.28	95.37	2.35
	1	SDBH41	54.6	36.9	17.7	200	-48
	2	SDBH52	49	31.16	17.84	32	38.89
	3	SDBH53	52	37.82	14.18	80	7.48
	2	SDBH62	41	29.71	11.29	61.91	14.97

In general, Atterberg Limit tests of the soil of the study area showed that:

LL ranges from 41.8 to 91.5, PL varies from 30.07 to 46.91 and PI ranges from 11.63 to 44.59; from medium plasticity to very high plasticity. The consistency index ranges from 20.3% to 200%, so the soil consistency ranges from soft to very stiff.

Table 5.4 Swelling characteristics of the soil of the study area.

Locality	Depth	Sample code	PI	Swelling potential of soils
Mizan	2.25	TP11	11.73	Medium
	3.0	TP12	21.99	High
Elemtu	2.0	TP21	14.75	Medium
	2.5	TPP22	13.12	Medium
Ashawa	1.4	TP31	22.08	High
	2.5	TP32	14.16	Medium
Kajima	2.6	TP41	44.59	Very high
	3	TP42	26.9	High
Lagadima	1.65	TP51	19.47	Medium
	2.6	TP52	29.31	High
BircukoFabr	2.20	TP6	11.63	Medium
Mizan	1	SDBH11	16.14	Medium
	3	SDBH13	21.46	High
	1	SDBH21	12	Low
	3	SDBH23	27.59	High
	1	SDBH31	20.36	High
	3	SDBH33	22.28	High
	1	SDBH41	17.7	Medium
	2	SDBH52	17.84	Medium
	3	SDBH53	14.18	Low
	2	SDBH62	11.29	Low

5.3.4 Activity (Ac) of the Soils

Skempton (1953) proposed Activity of soil is as the ratio of the plasticity index and the percentage of clay fraction (finer than 2μ).

$$A_c = \frac{PI}{\%\text{ clay fraction}} \qquad 5.5$$

The activity of the soil of study area was determined by using the plasticity index and grain size analysis results of the soils using Skempton's description of activity of soils and the clay minerals contained in the soils identified using activity values.

Table 5.6 Activity characteristics of the soil of the study area.

Locality	Sample code	Depth	PI	% Clay	Ac	Remark	Clay mineral contain
Mizan	TP11	2.25	11.73	29.88	0.39	In active	Kaolinite
	TP12	3.0	21.99	34	0.65	Inactive	Illite
Elemtu	TP21	2.0	14.75	40	0.37	Inactive	Kaolinite
	TP22	2.5	13.12	40	0.33	Inactive	Kaolinite
Ashawa	TP31	1.4	22.08	23.07	0.96	Normal	Illite
	TP32	2.5	14.16	30	0.47	Inactive	Kaolinite
Kajima	TP41	2.6	44.59	30	1.5	Active	Ca-Montmorillonite
	TP42	3	26.9	24.85	1.08	Normal	Kaolinite
Laga dima	TP51	1.65	19.47	14.54	1.34	Active	Illite
	TP52	2.6	29.31	24.35	1.20	Normal	Illite
Bircuko Fabric	TP6	2.20	11.63	22	0.53	Inactive	Kaolinite
	SDBH11	1	16.14	27.8	0.58	In active	Illite
	SDBH13	3	21.46	24.7	0.86	Normal	Illite
	SDBH21	1	12	21	0.57	In active	Illite
	SDBH23	3	27.59	26.9	1.02	Normal	Illite
	SDBH31	1	20.36	28.9	0.7	In active	Illite
	SDBH33	3	22.28	24.6	0.9	Normal	Illite
	SDBH41	1	17.7	28.5	0.62	In active	Illite
	SDBH52	2	17.84	20.6	0.86	Normal	Illite
	SDBH53	3	14.18	16.1	0.88	Normal	Illite
	SDBH62	2	11.29	32.6	0.34	In active	Kaolinite

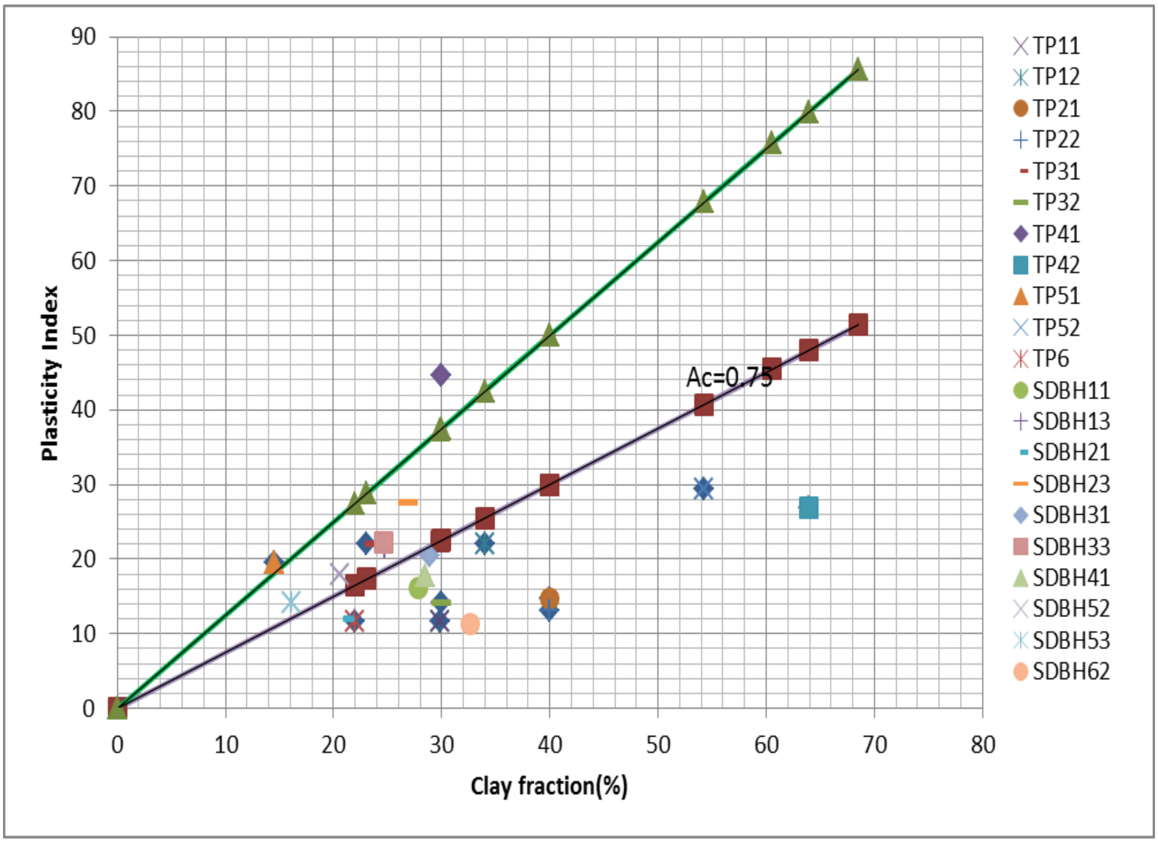


Fig.5.2 Activity chart of the soil of the study area

The behavior of fine grained soils depend the characteristics of the clay minerals contained in the soils. The most considerable properties of clay depend on the type of mineral which is important for particles less than 2 micron size. The study of clay minerals is crucial for understanding clayey soils. Generally, soil of the study area mostly contains two types of clay minerals (Kaolinite &Illite).

5.3.5 Free Swell

Free swell test consists of placing a known volume of dry sample passing No.200 sieve into graduated cylinder filled with water and measuring the swelled volume after it has completely settled. According to Chen (1975), free swell is the difference between initial and final volume, expressed as initial volume.

$$\text{Free swell} = \frac{\text{Final volume} - \text{Initial volume}}{\text{Initial volume}} x100 \qquad 5.5$$

This method is adapted to the swelling characteristics of the soil of the study area.

According to Holtz (1956), free swell values below 50% exhibit appreciable volume change even under lightly loaded structures. So, the soil for which their representative samples result in free swell of greater than 50% not appreciable under lightly loaded structures.

The free swell of the soil of the study area was calculated by following the free swell articulated by Chen (1975) and the result ranges from 30% to 80%. Hence for the samples with free swell of greater than 50%

consideration should be taken during design of civil structures to be founded on such soils because their free swell value exhibit the swelling potentiality behavior. Especially, TP-4&TP-5 show that high expansion potentiality characteristics. Swelling pressures of the soils of the study area showed that, direct relationship with their plasticity indices. This is because both free swell and plasticity index are measures of swelling characteristics of soils. In addition, the soil with highest degree of free swell implied that highest value of activity. From the implication from these three parameters, it concluded that, the degree of expansion of soils can be determined by using one of these parameters. In the present study, the soil found at Kajima site shows that highest degree of free swell whereas those from Mizan site shows lowest degree of free swell. For the soils with degree of free swell greater than 50% (Kajima, Ashawa, Laga dima) consideration should be taken during design of structures. The free swell test result of the soil of the study area presented in the following table 5.7.

Table 5.7 Free swells of the study area.

Locality	Depth	Sample code	Free swell
Mizan	2.25	TP11	30
	3.0	TP12	40
Elemtu	2.0	TP21	50
	2.5	TP22	45
Ashawa	2	TP31	65
	2.5	TP32	50
Kajima	2.6	TP41	80
	3	TP42	70
Laga dima	1.65	TP51	70
	2.6	TP52	70
Bircuko Fabrica	2.20	TP6	40
Mizan	1	SDBH11	50
	3	SDBH13	40
	1	SDBH21	40
	3	SDBH23	30
	1	SDBH31	30
	3	SDBH33	30
	1	SDBH41	40
	1	SDBH51	30
	2	SDBH52	30
	2	SDBH62	40

5.3.6 Specific Gravity (Gs)

Specific gravity of soil is the ratio of the unit weight of solid soil its unit weight of water. In Laboratory Specific gravity of soil is determined by putting a known weight of oven dried soil sample in a pycnometer which is then half-filled with distilled water. The air entrapped in the soil sample is removed by heating or means of vacuum pump. The pycnometer is then topped up with distilled water up to calibration mark and brought up to a constant temperature.

$$Gs = \frac{Unit\ weightofsoilsolidonly}{Unitweightofwater} \quad 5.6$$

In this research study, ASTM D 854-00 procedure is adopted for testing of the specific gravity of the soils of study area and the results are presented in the Table 5.8. The specific gravity of the study area varies from 2.08 to 2.68. The specific gravity test results of the soils of the study area are presented in Table 5.8.

Table 5.8 Specific gravity of the study area soil

Locality	Depth	Sample code	Specific gravity
Mizan	2.25	TP11	2.53
	3.0	TP12	2.24
Elemtu	2.0	TP21	2.68
	2.5	TP22	2.66
Ashawa	2	TP31	2.48
	2.5	TP32	2.45
Kajima	2.6	TP41	2.34
	3	TP42	2.44
Laga dima	1.65	TP51	2.42
	2.6	TP52	2.3
Bircuko Fabrica	2.20	TP6	2.43
Mizan	1	SDBH11	2.43
	3	SDBH13	2.41
	1	SDBH21	2.36
	3	SDBH23	2.15
	1	SDBH31	2.49
	3	SDBH33	2.49
	1	SDBH41	2.51
	1	SDBH51	2.46
	2	SDBH52	2.08
	2	SDBH62	2.23

5.4 Laboratory tests on undisturbed samples

5.4.1 General

The soil must be capable of carrying the loads from any engineered structure placed upon it without a shear failure and with the resulting settlements being tolerable for that structure. It is necessary to investigate both base shear resistance and settlements for any structure. In many cases settlement criteria will control the allowable bearing capacity; however, there are also a number of cases where base shear (in which a base punches into the ground usually with a simultaneous rotation) dictates the recommended bearing capacity.

Depending on the laboratory classification tests the soils of the study area were classified in to two classes by using USCS classification system. Then, the consolidation and strength characteristics of the both classes were examined using direct shear test and one dimensional consolidation test. For both tests, two test pits, one with Sandy silt soil and the other with Elastic silt (TP-1 &TP-4 respectively)were selected as classified in this research. In addition, from the secondary data that was gained from the Geological Survey of Ethiopia of six bore holes one is selected for consolidation and bearing capacity characteristics analysis. The reason why one borehole data selected for analysis is because the investigation was done at a single site.

5.4.2 Direct shear test

Direct shear test is the simplest and the oldest type of shear strength test. Mohr (1900) presented a theory for rupture in materials that contended that a material fails because of a critical combination of normal stress and shearing stress Thus, the functional relationship between normal stress and shear stress on a failure plane can be expressed as:.

Direct shear test is conducted following ASTMD 3080 standard in this research work. The strength test result showed that:

Cohesion range from 34 to 74Kpa, Dry density range from 12.45 to 14.3 and Angle of shear resistance range from 2.29^0 to $27.89.^0$

Direct Shear result of the study area soils are presented in the table 5.9.

Table 5.9 Direct shear test result

Sample code	Depth(m)	C(Kpa)	Ø(°)	Dry density(KN/m^3)
TP11	1	47	27.89	14.3
TP13	3	74	16.05	13.3
TP41	1.5	34	6.56	14
TP43	3	43	2.29	14
SDBH31	1	44	13.28	12.74
SDBH33	3	40	10.86	12.45

Where,

C = cohesion

Ø = Angle of internal friction

5.4.2.1. Bearing capacity Analysis

Bearing capacity is the ability of soil to safely carry the pressure placed on the soil from any engineered structure without undergoing a shear failure with associated large settlements. Shear strength of soils is major structural property of soil which provides supporting ability or bearing capacity and permits slope to be stable. In this research work shear strength test is conducted in order to estimate bearing capacity of the soil. As a result, the shear strength parameters (cohesion and angle of shear resistance) of soils were determined by using direct shear test.

Estimation of bearing capacity of soil is required to have a safe structure built on that soil. In this study, bearing capacity of the soil of the study area was analyzed using computational sheet program developed by Raghuvanshi to simplify the Terzaghi, Hensen, Meyerhof, Vesic and EBSC-7 methods. By using these methods ultimate and allowable bearing capacity of six representative samples from three different sites were estimated. These three sites are Mizan from where TP11 &TP13 are taken, Kajima the site for TP4 in this study (location of TP41&TP43).And the third one was taken from the secondary data and analysis was carried out. The results of analysis presented in the tables.

Allowable Bearing Capacity

Allowable bearing capacity of the soils of the study area differs for the same footing while different methods applied. It refers that the variation in result from using different methods. Therefore during analysis of bearing capacity, it is more appropriate to take the average of the results from different methods. Allowable bearing capacity of the soil of the study area is presented in the table 5.10 below

Mizan site

For the analysis of bearing capacity of soils at Mizan site two samples were collected from TP1 at depth of 1m and 3m. And the analysis was carried out for square footing of 2x2, 2x2, 2.5x2.5, 3x3, 3.5x3.5, 4x4, 4.5x4.5, 5x5, 5.5x5.5 for the sample at depth of 1m and of 3x3, 3.5x3.5, 4x4, 4.5x4.5, 5x5, 5.5x5.5, 6x6, 6.5x6.5 for sample at depth of 3 m. The result of allowable bearing capacity of soils of Mizan site presented in the following table 5. 10 (a&b) and fig.5.4 (a&b).

Table 5.10 (a) Allowable bearing capacity of TP11

TP11 C(Kpa)= 47 , Ø(°) = 27.89 at Depth =1, length=width FS = 3						
Width	Terzaghi	Hensen	Meyerhof	Vesic	EBSC-7	Average
2	778.98	899.79	1052.59	923.45	751.86	881.334
2.5	793.21	879.34	1069.29	906.89	763.82	882.51
3	807.43	868.27	1085.99	899.76	775.78	887.446
3.5	821.65	862.56	1102.69	898.04	787.74	894.536
4	835.88	860.20	1119.40	899.68	799.69	902.97
4.5	850.10	860.07	1136.10	903.58	811.65	912.3
5	864.32	861.51	1152.80	909.05	823.61	922.258
5.5	878.55	864.08	1169.50	915.66	835.57	932.672

The average value of allowable bearing capacity of TP11 ranges from 881.334 to 932.672 Kpa.

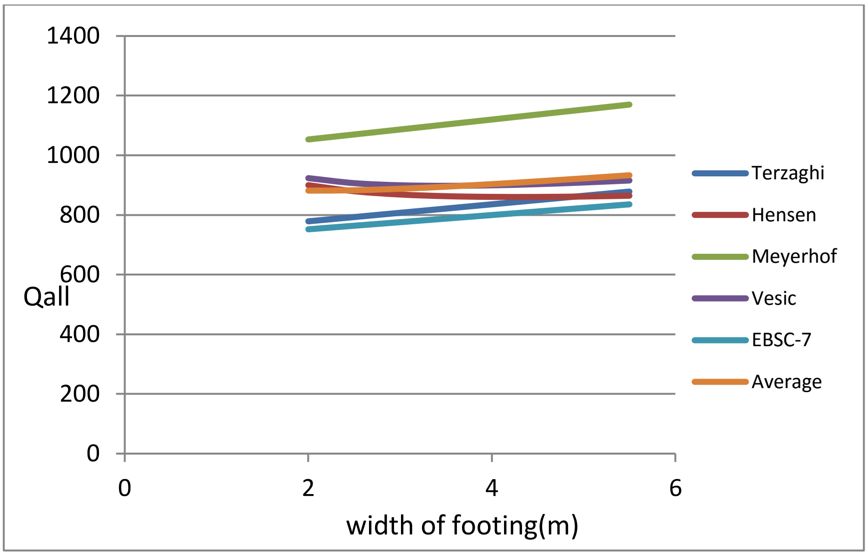


Fig.5.3 (a) Allowable bearing capacity of TP11

Table 5.10 (b) Allowable bearing capacity of TP12

TP12 C(Kpa)= 74 Ø(°) = 16.05at Depth = 3, length=width FS = 3						
Width	Terzaghi	Hensen	Meyerhof	Vesic	EBSC-7	Average
3	521.47	655.26	644.51	623.87	473.93	583.808
3.5	524.10	630.46	646.32	638.88	475.43	583.038
4	526.73	612.10	648.13	621.58	476.93	577.094
4.5	529.35	598.03	649.94	608.59	478.43	572.868
5	531.98	586.97	651.75	598.60	479.92	569.844
5.5	534.61	578.10	653.56	590.80	481.42	567.698
6	537.23	570.86	655.37	584.64	482.92	566.204
6.5	539.86	564.89	657.18	579.75	484.42	565.22

The average allowable bearing capacity of soils of TP12 ranges from 565.22Kpa to 583.808 Kpa.

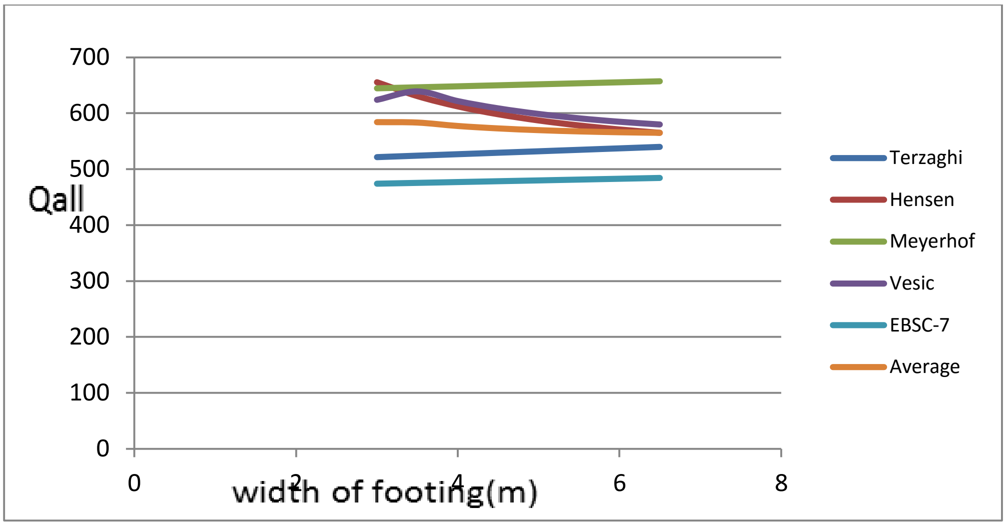


Fig.5.3 (b) Allowable bearing capacity of TP12

Kajima site

In the same manner with that of Mizan site**,** for the analysis of bearing capacity of soils at Kajima site two samples were collected from TP4 at depth of 1.5m and 3m. And the analysis was carried out for square footing of 2x2, 2.5x2.5, 3x3, 3.5x3.5, 4x4, 4.5x4.5, 5x5, 5.5x5.5 for the sample at depth of 1.5 m and of 3x3,3.5x3.5, 4x4, 4.5x4.5, 5x5, 5.5x5.5, 6x6, 6.5x6.5 for sample at depth of 3 m. The result of allowable bearing capacity of soils of Kajima site presented in the following table 5. 10 (c&d) and fig.5.4 (c&d).

Table 5.10 (c) Allowable bearing capacity of TP41

TP41 C(kpa) = 43 , Ø(°) =2.29 at Depth =1.5, length=width FS = 3						
Width	Terzaghi	Hensen	Meyerhof	Vesic	EBSC-7	Average
2	133.33	146.16	156.56	147.59	114.38	139.604
2.5	133.98	139.88	156.73	141.67	114.54	137.36
3	134.63	135.73	156.90	137.87	114.69	135.964
3.5	135.29	132.80	157.07	135.29	114.84	135.058
4	135.94	130.62	157.24	133.46	114.99	134.45
4.5	136.59	128.95	157.41	132.15	115.14	134.048
5	137.24	127.63	157.58	131.18	115.29	133.784
5.5	137.90	126.57	157.75	130.48	115.44	133.628

The average allowable bearing capacity of TP41 ranges from 133.628KPa to 139.604 Kpa.

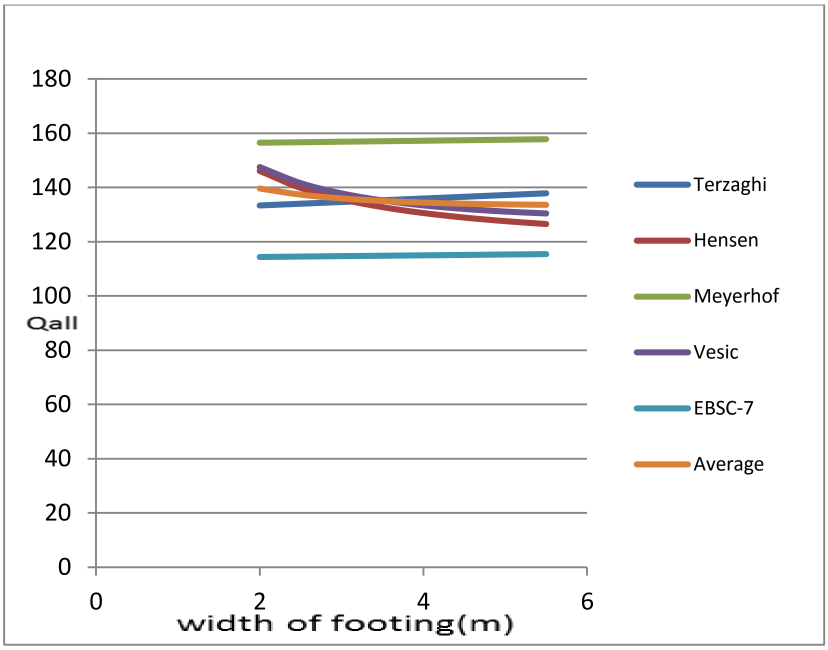


Fig.5.3 (c) Allowable bearing capacity of TP41

Table 5.10(d) Allowable bearing capacity of TP42

TP42 C(kpa)= 34 , Ø(°) =6.56 at Depth =3m, width(B) = length(L) FS = 3						
Width	Terzaghi	Hensen	Meyerhof	Vesic	EBSC-7	Average
3	137.85	158.44	159.91	150.31	117.37	144.776
3.5	138.05	152.58	159.93	153.39	117.39	144.268
4	138.24	148.19	159.94	149.11	117.40	142.576
4.5	138.44	144.77	159.96	145.81	117.42	141.28
5	138.64	142.04	159.98	143.20	117.43	140.258
5.5	138.83	139.81	159.99	141.08	117.45	139.432
6	139.03	137.95	160.01	139.34	117.46	138.758
6.5	139.22	136.38	160.03	137.88	117.48	138.198

The average allowable bearing capacity of TP11 ranges from 138.198 Kpa to 144.776 Kpa**.**

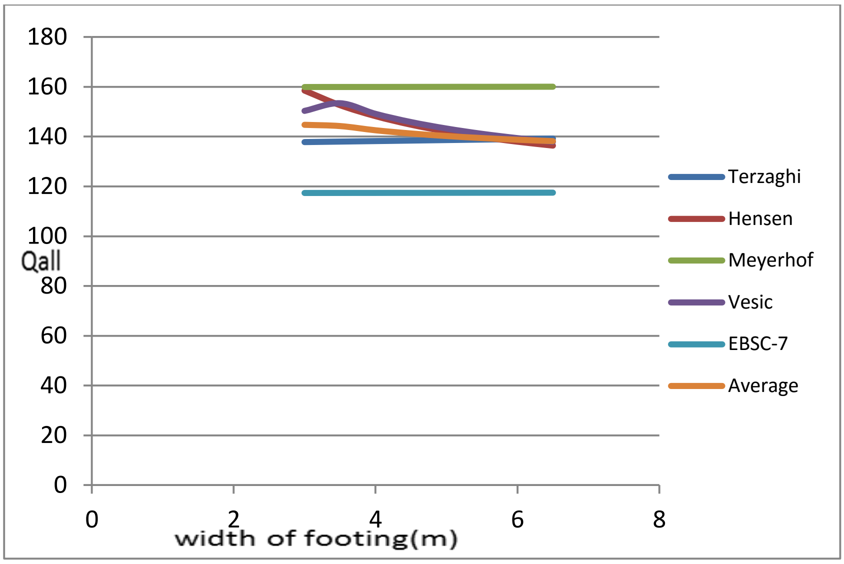


Figure 1 Fig.5.3 (d) Allowable bearing capacity of TP42

Mizan site from secondary data

For analysis of the bearing capacity of the soil at Mizan site for which data is taken from Geological survey of Ethiopia, the data for two samples were collected from SDBH3 at depth of 1m and 3m. And the analysis was carried out for square footing of 2x2, 2.5x2.5, 3x3, 3.5x3.5, 4x4, 4.5x4.5, 5x5, 5.5x5.5 for the sample at depth of 1 m and of 3x3, 3.5x3.5, 4x4, 4.5x4.5, 5x5, 5.5x5.5, 6x6, 6.5x6.5 for sample at depth of 3 m. The result of allowable bearing capacity of soils of Kajima site presented in the following table 5. 10 (e&f) and fig.5.4 (e&f).

Table 5.10(e) Allowable bearing capacity of SDBH31

SDBH31 C(Kpa)= 44 , Ø(°) = 13.28 at Depth =1, length=width FS = 3						
Width	Terzaghi	Hensen	Meyerhof	Vesic	EBSC-7	Average
2	243.95	256.36	294.77	259.50	214.66	253.848
2.5	245.68	248.59	295.74	252.50	215.48	251.598
3	247.40	243.59	296.71	248.27	216.30	250.454
3.5	249.13	240.16	297.68	245.62	217.12	249.942
4	250.85	237.73	298.65	243.96	217.95	249.828
4.5	252.58	235.95	299.63	242.96	218.77	249.978
5	254.31	234.94	300.60	242.42	219.59	250.372
5.5	256.03	233.66	301.57	242.21	220.41	250.776

The average allowable bearing capacity of SDBH31 ranges from 250.776 Kpa to 253.848 Kpa.

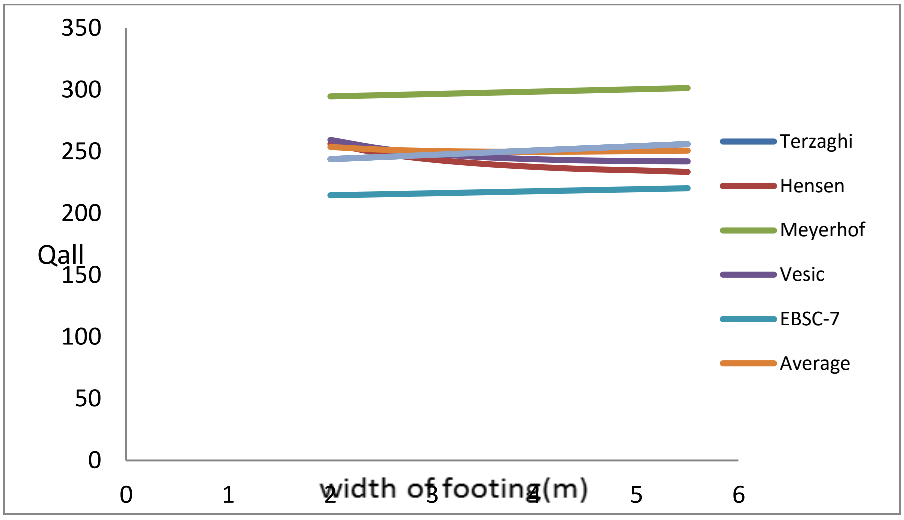


Fig.5.3 (e) Allowable bearing capacity of SDBH31

Table 5.10(f) Allowable bearing capacity of SDBH33

SDBH33	C(Kpa)= 40 , Ø(°) = 10.86 at Depth = 3, length=width					FS = 3
Width	Terzaghi	Hensen	Meyerhof	Vesic	EBSC-7	Average
3	218.43	264.34	261.84	261.84	193.85	240.06
3.5	219.61	254.52	262.38	262.38	194.32	238.642
4	220.80	247.23	262.92	262.92	194.79	237.732
4.5	221.99	241.62	263.46	263.46	195.25	237.156
5	223.18	237.20	264.00	264.00	195.72	236.82
5.5	224.37	233.64	264.54	264.54	196.19	236.656
6	225.56	230.72	265.09	265.09	196.65	236.622
6.5	226.75	228.29	265.63	265.63	197.12	236.684

The average allowable bearing capacity of SDBH33 ranges from 236.684 Kpa to 240.06 Kpa.

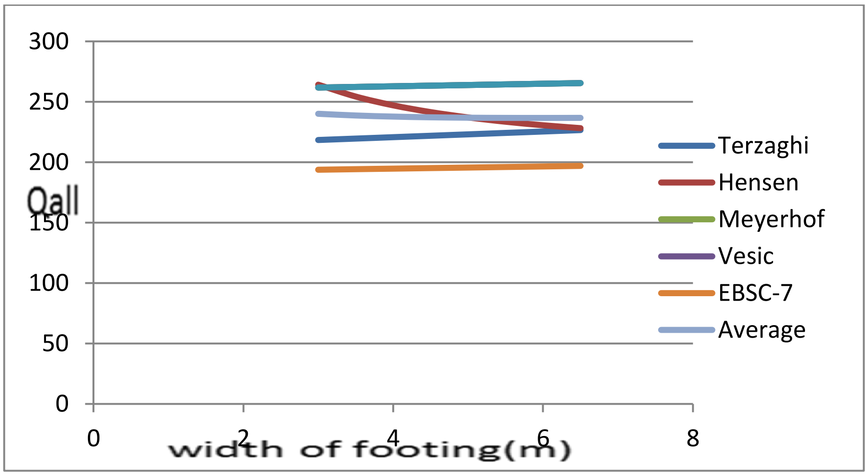


Figure 2 Fig.5.3 (f) Allowable bearing capacity of SDBH33

The analysis of bearing capacity of the soils conducted for square footing(at depth of 1 m and 2 m respectively) of the study area implies that, average allowable bearing capacity of the soils ranges from 133.6 to 253KPa for Elastic silt soils where as it ranges from 572 to 932Kpa for sandy silt soils. From all the tests performed the sandy silt soil show that, their strength is higher than those of Elastic silt. In case of their bearing capacity also it indicated higher value. The bearing capacity of the soils found at Mizan site showed that highest value relating to the other sites**.** The highly plastic soil in this study, found at Kajima site result in lowest bearing capacity from than the other sites. The main end result from the bearing capacity analysis of two different soil types implied that, the highly plastic, high water content, with high expansion potential resulted in low bearing capacity and vice versa.

5.4.3 Consolidation Characteristics

5.4.3.1 One Dimensional Consolidation Test

Laboratory determination of the consolidation characteristics of clay soils is usually carried out on saturated soil using an Odometer. The swelling characteristics of soils can also be determined conveniently using an Odometer. In Odometer test, only one dimensional consolidation and swelling characteristics of the soil are determined.

The objective of consolidation test is to obtain soil data which is used in predicting the rate and amount of settlement of structures founded on clay and to know whether the amount of settlement determined will be acceptable or not. The compressibility characteristics of a soil relating to both the amount and rate of settlement are usually determined from the one-dimensional consolidation test. Terzaghi (1925) proposed the first theory to consider the rate of one-dimensional consolidation for saturated clay soils. The theory considers the rate at which water is squeezed out of an element of soil and can be used to determine the rate of:

- Volume change of the soil with time
- Settlement at the surface of the soil with time
- pore pressure dissipation with time

In consolidation test, coefficient of consolidation (C_v) value can be obtained based on one of the following two methods:

(1) Taylor's square root of time fitting method

The Root Time Method utilizes the early settlement response which theoretically should appear as a straight line in a plot of dial gauge reading (settlement) vs. square root of time. By using this method, C_v calculated as

$$C_v = \frac{T_{v90*H^2}}{t_{90}} = 0.848 * (\frac{H}{2})^2/t_{90} \quad 5.10$$

(2) Casagrande logarithm of time fitting method

$$T_v = \frac{c_{vt}}{H^2 dr}$$

$$C_v = \frac{T_{v50*H^2}}{t_{50}} = 0.196 * (\frac{H}{2})^2/t_{50} \quad 5.11$$

The one-dimensional compression and swelling characteristics of a soil of the study area measured in the laboratory using the odometer test. A cylindrical specimen of soil enclosed in a metal ring is subjected to a series of increasing static loads, while changes in thickness are recorded against time. From the changes in thickness at the end of each load stage the compressibility of the soil is observed, and parameters measured such as Compression Index (Cc), Swell index(C_s), coefficient of consolidation (C_v) and swell pressure (Kpa) were determined using oedometer test result.

The consolidation test results presented in the following table 5 .11

Table 5 .11(a) Consolidation test result of the soils of the study area

Sample code	Depth(m	Pressure(kpa	Void ratio (%)	$C_v, mm^2/min$ $0.197 * H^2/t_{50}$)
TP11	1	100	0.778	34.08
		200	0.769	2.03
		400	0.736	14.71
		800	0.686	10.30
		1600	0.620	12.58
TP12	3	100	0.924	34.08
		200	0.868	0.99
		400	0.798	0.35
		800	0.704	0.19
		1600	0.599	0.32
TP41		100	0.848	8.53
		200	0.822	2.82
		400	0.787	3.48
		800	0.744	5.34
		1600	0.702	4.24
TP43		100	0.918i	3.79
		200	0.898	19.75
		400	0.867	19.11
		800	0.827	19.69
		1600	0.792	7.58
SDBH31		100	0.848	8.53
		200	0.822	2.82

		400	0.787	3.48
		800	0.744	5.34
		1600	0.702	4.24
SDBH33		100	0.918	3.79
		200	0.898	19.75
		400	0.867	19.11
		800	0.827	19.69
		1600	0.792	7.58

Table 5.11(b) Consolidation test result of the study area

Sample code	Depth(m)	Compression index(Cc)	Swelling index(Cs)	Swelling pressure(kpa)	compressibility
TP11	1	0.22	0.04	14	High
TP12	3	0.35	0.04	48	Very high
TP41	1.5	0.32	0.03	66	Very high
TP42	3	0.26	0.02	14	High
SDBH31	1	0.14	0.02	14	Medium
SDBH33	3	0.12	0.06	20	Medium

Prediction of Primary settlement in the soils

Times when 50% and 90% respectively of the final settlement will take place in the soils is predicted.

$$T_V = C_v t / d^2$$

$$t_{50} = \frac{T_{50} H^2}{c_v} = \frac{0.197 H^2}{c_v}$$

$$t_{90} = \frac{T_{90} H^2}{c_v} = \frac{0.848 H^2}{c_v}$$

Table 5.12 predicted 50% and 90% of the final settlement in the soils.

Sample code	H(m)	$C_{v,} mm^2/min$	$t_{50}(year)$	$t_{90(year)}$
TP11	0.8	14.74	0.016	0.07
TP12	1.5	7.19	0.12	0.5
TP41	0.8	1.44	0.17	0.72
TP42	2	2.12	0.7	3.04
SDBH31	0.85	4.88	0.056	0.24
SDBH32	2	13.98	0.1	0.46.

CHAPTER SIX

6. SOIL GENESIS AND GEOTECHNICAL SOILMAPPING

6.1 Soil Genesis

According to literatures reviewed on soil formation, soils found in flood plain are result of topography, drainage, flooding, climate and time. In view of that, there are rivers such as Orogogo, Dima and Billo drain from the surrounding ridges to Sululta Town. Sululta Town is known by flooding that wear the plain area in summer season. Therefore, the soils in the town are transported (alluvial soil).These transported soils are originated from the geology from where they are transported by water (flooding, river). In addition to the direction of river flow and topography, the mineral composition also was used for identification of soils parent material in this study. In order to determine the genesis of soil in the area the composite map of geology, drainage and topography was prepared and the study sites were plotted on the map. If the soil of the study area were residual soils, their genesis could be described by the underlying rock type. But this approach cannot be adopted for soils found in flood plains.

From the analysis of stream flow direction and topography change, it is understandable that from where to where the transportation of the soil took place. In addition, the agricultural soil map of the town was produced to compare the result of the present study with that soil map and the clay minerals were identified in the soils used to recognize the genesis of the soils. The soil of the study area had stratified layers due to their formation time gap. In the study area, the alluvial soils are transported from its original place of formation (parent material) by drainages and flooding. Streams in the study area flows from the places of higher elevation of the surrounding to lower elevation. The places within low elevation are the deposition positions for the coming soils carried by streams and flooding. The Sululta Town found in plain area that is suitable for deposition of the transported soils from the surrounding highlands. Therefore, the soils of the study area are alluvial deposits. Arora (2000) stated that alluvial soil found as uniform all over their deposition plain. The probable parent materials for these soils are mostly volcanic rocks since the area is mostly covered by basaltic rock. Superficial sediments found in gentle slope from where it cannot transported to other place. So, it was not considered as parent material for soils in the town. According to Arora (2000) Montmorillonite is resulted from weathering of volcanic ash; Kaolinite and Illite is end product of weathering of feldspar. In addition, Cheleka basalt is documented as it is constituted of feldspar by Oromia Water, Mineral and Energy as discussed in local geology of this study.

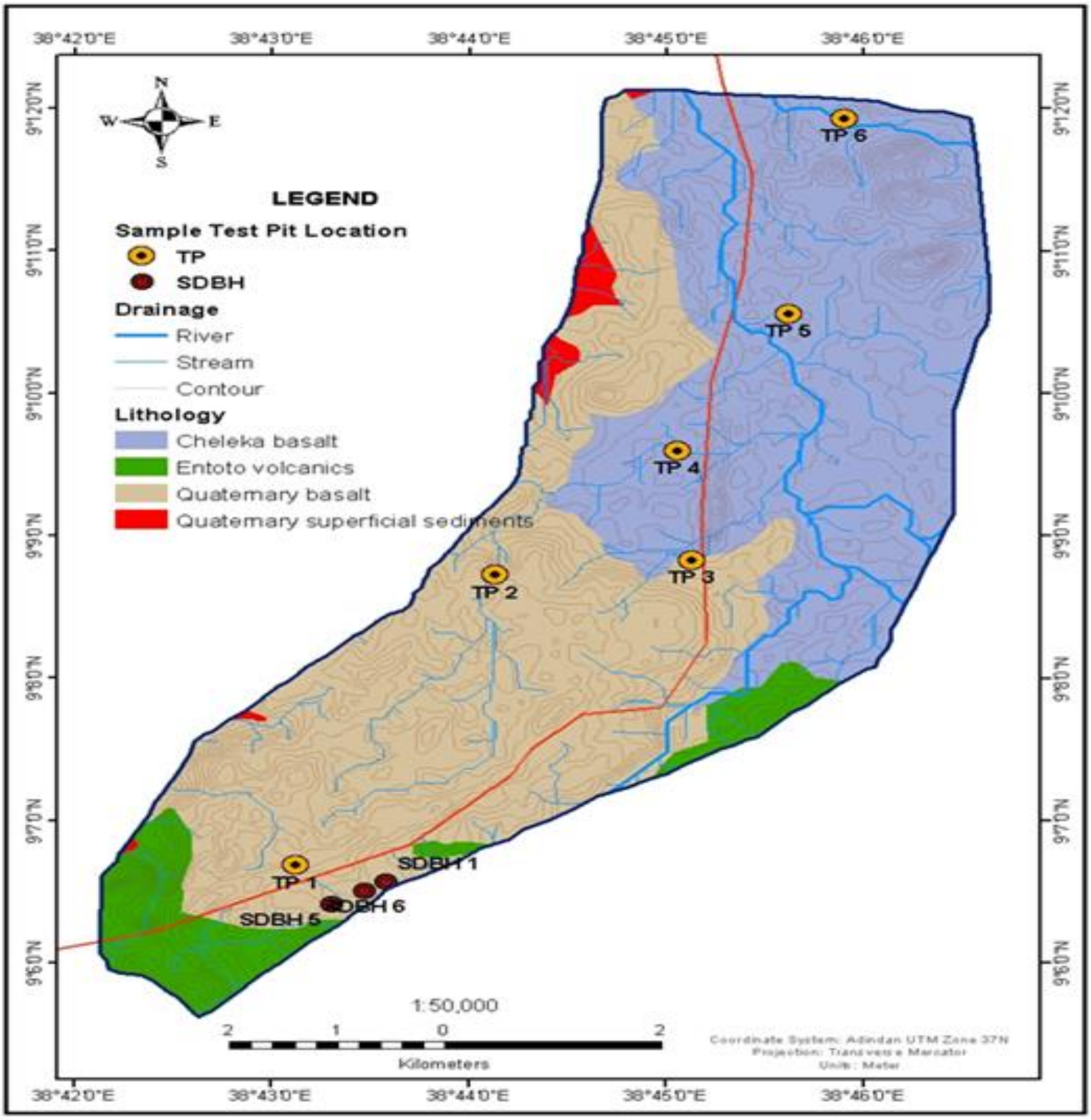


Fig.6.1 Soil Genesis Map (Combination of Geology, Topography, Drainage).

Depending on literatures reviewed on genesis of soil and clay minerals, clay minerals identified in this study, topography of the study area and drainage patterns of the study area the genesis of the soil of Sululta Town discussed below as presented in the table 5.1 below

Table 6.1 Genesis of soil of the study area

Locality	Parent Rock
Mizan	Entoto volcanic
Elemtu	Quaternary basalt
Ashawa	Cheleka basalt
Kajima	Entoto volcanic
Laga dima	Cheleka basalt
Bircuko Fabrica	Cheleka basalt

6.2 Soil classification

Soil classification is like a language to communicate between geotechnical engineers and engineering geologists. It communicates their probable engineering behavior and allows engineers access to the accumulated experience of other engineers by giving general behavior of the soil. Unified Soil Classification System (USCS) and American Association of State Highway and Transportation Officials (AASHTO) are common classification systems used in engineering practice. In this research both AASHTO and USCS Soil classification schemes are adopted for classification of the soils of the study area. Both the classification schemes depend on the result from grain size analysis and Atterberg limits. In case of AASHTO classification system the soil is regarded as coarse grained if more than 35% retained on No.200(0.075mm) and fine grained if more than 35% passes No.200 while retaining of more than 50% on No.200 sieve is coarse grained and passing of more than 50% on No.200 is fine grained in USCS.

6.2.1 AASHTO Classification

Based on plasticity and amount of particle size passing through No.200 sieve discussed in chapter four the soil of the study area classified. And the AASHTO classification scheme uses Group Index (GI) to classify the soil within a group. All the soils of the study area fall under A-7-5 by AASHTO classification. A-7-5 soil type is clay soil and such soil is poor for construction purpose. The lower the GI value, the better the sub grade material. According to Bowles (1992), as GI value goes 20 and above, it is not suitable for sub grade material. Most of the soil of the study area has GI value of greater than 20. Accordingly, the soil of the study area those with GI value greater than 20 (TP-1-3m, TP-2-2m, TP-3-2m, TP-4, TP-5) indicates that as these soils are not suitable for sub grade material. Afterwards, in terms of its group index the soil of the study area is characterized as poor sub grade material except those with GI less than 20. Specifically; TP-4 and TP-5 are worst for sub grade material. All the soil samples falls below the line of equation $PI = LL - 30$ which separates A-7-5 fom A-7-6. The soil of the study area ranges in the same group by AASHTO classification system. The AASHTO classification of the soils of the study area are presented in Table 6.1 and fig.6.2.

Table.6.1 Classification of the soils of the study area by using AASHTO classification system

Locality	Depth	Sample cod	F_{200}(%	LL	PI	GI	AASHTO Soil classes
Mizan	2.25	TP11	97.16	41.8	11.73	14	A-7-5(14)
	3.0	TP12	97.88	52.8	21.99	27	A-7-5(27)
Elemtu	2.0	TP21	97.72	56.65	14.75	22	A-7-5(22)
	2.5	TP22	97.98	48.90	13.12	18	A-7-5(18)
Ashawa	2	TP31	90.93	66.84	22.08	28	A-7-5(28)
	2.5	TP32	92.65	48.8	14.16	17	A-7-5(17)
Kajima	2.6	TP41	99.56	91.5	44.59	59	A-7-5(59)
	3	TP42	95.95	70.25	26.9	35	A-7-5(35)
Laga dima	1.65	TP51	97.64	62	19.47	27	A-7-5(27)
	2.6	TP52	94.25	67.5	29.31	35	A-7-5(35)
Bircuko Fabrica	2.20	TP6	96.9	47.3	11.63	16	A-7-5(16)
Mizan	1	SDBH11	72.3	51	16.14	13	A-7-5(13)
	3	SDBH13	71.1	65	21.46	18	A-7-5(18)
	1	SDBH21	78.7	51	12	12	A-7-5(12)
	3	SDBH23	73.3	66	27.59	22	A-7-5(22)
	1	SDBH31	75.9	58	20.36	18	A-7-5(18)
	3	SDBH33	83	66	22.28	24	A-7-5(24)
	1	SDBH41	72.6	54.6	17.7	14	A-7-5(14)
	2	SDBH52	80.7	49	17.84	16	A-7-5(16)
	3	SDBH53	72.3	52	14.18	12	A-7-5(12)
	2	SDBH62	83.14	41	11.29	10	A-7-5(10)

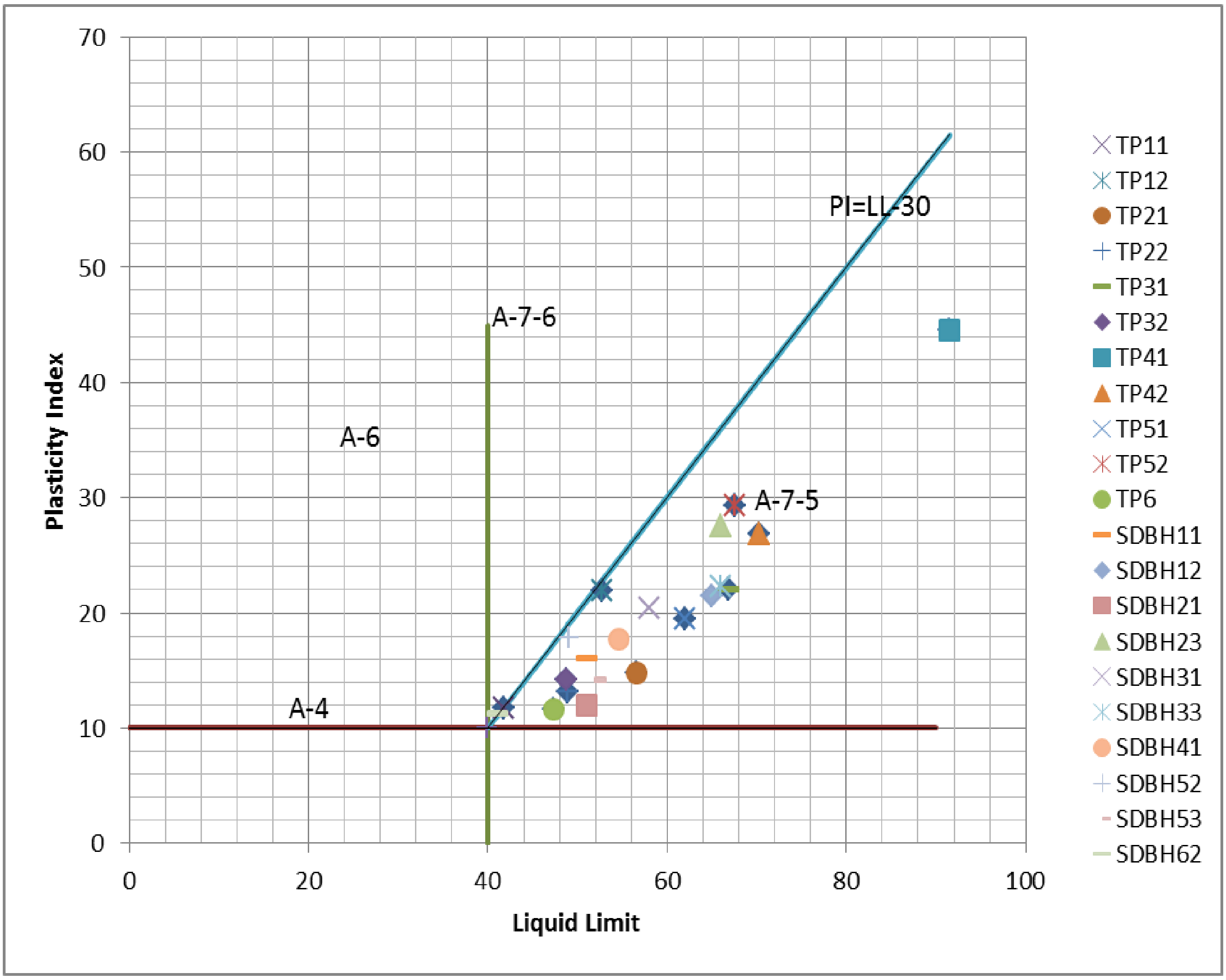


Fig.6.2 AASHTO Classification chart

6.2.2 Soil Classification Using Unified Soil Classification System (USCS)

This classification system was used in this study based on laboratory results of grain size analysis and Atterberg limits. All of the representative soil samples of the study area were classified as cohesive soil by USCS classification while greater than 50% pass No.200 sieve. All of the soils fall below A-line that indicate that the soils of the study area are silt soils. Based on their liquid limit they have two classes (Low plastic silt & High plastic silt symbolized as ML and MH respectively. The soils with liquid limit less than 50 were classified as ML where as those with liquid limit of greater than 50 were classified as MH (Table 6.2 and Fig.6.2.below)

Table 6.2 Classification of the soil of the study area using USCS

Locality	Depth	Sample code	Gravel (%)	Sand (%)	LL	USCS soil Class	Soil Name
Mizan	2.25	TP11	0	2.12	41.8	ML	Sandy Silt
	3.0	TP12	0	3	52.8	MH	Elastic Silt
Elemtu	2.0	TP21	0	2.02	56.65	MH	Elastic Silt
	2.5	TP22	0	2.28	48.90	MH	Elastic Silt
Ashawa	2	TP31	0.57	2.36	66.84	MH	Elastic Silt
	2.5	TP32	0	7.35	48.8	ML	Sandy Silt
Kajima	2.6	TP41	0	0.44	91.5	MH	Elastic Silt
	3	TP42	2.58	1.47	70.25	MH	Elastic Silt
Laga dima	1.65	TP51	0	2.36	62	MH	Elastic Silt
	2.6	TP52	0.2	5.55	67.5	MH	Elastic Silt
Bircuko Fabrica	2.20	TP6	0	3.1	47.3	MH	Elastic Silt
Mizan	1	SDBH11	0.4	27.3	51	MH	Elastic Silt
	3	SDBH13	0	28.9	65	ML	Sandy silt
	1	SDBH21	0	21.3	51	MH	Elastic Silt
	3	SDBH23	0	26.8	66	MH	Elastic Silt
	1	SDBH31	0	24.1	58	MH	Elastic Silt
	3	SDBH33	0	17	66	MH	Elastic Silt
	1	SDBH41	0	27.4	54.6	MH	Elastic Silt
	2	SDBH52	0	19.3	49	MH	Elastic Silt
	3	SDBH53	0	27.7	52	MH	Elastic Silt
	2	SDBH62	0	17	41	MH	Elastic Silt

The USCS plasticity chart shows that the soil under investigation lies below A-line in the region of inorganic silt and inorganic elastic silt. That means inorganic silt with low to high plasticity.

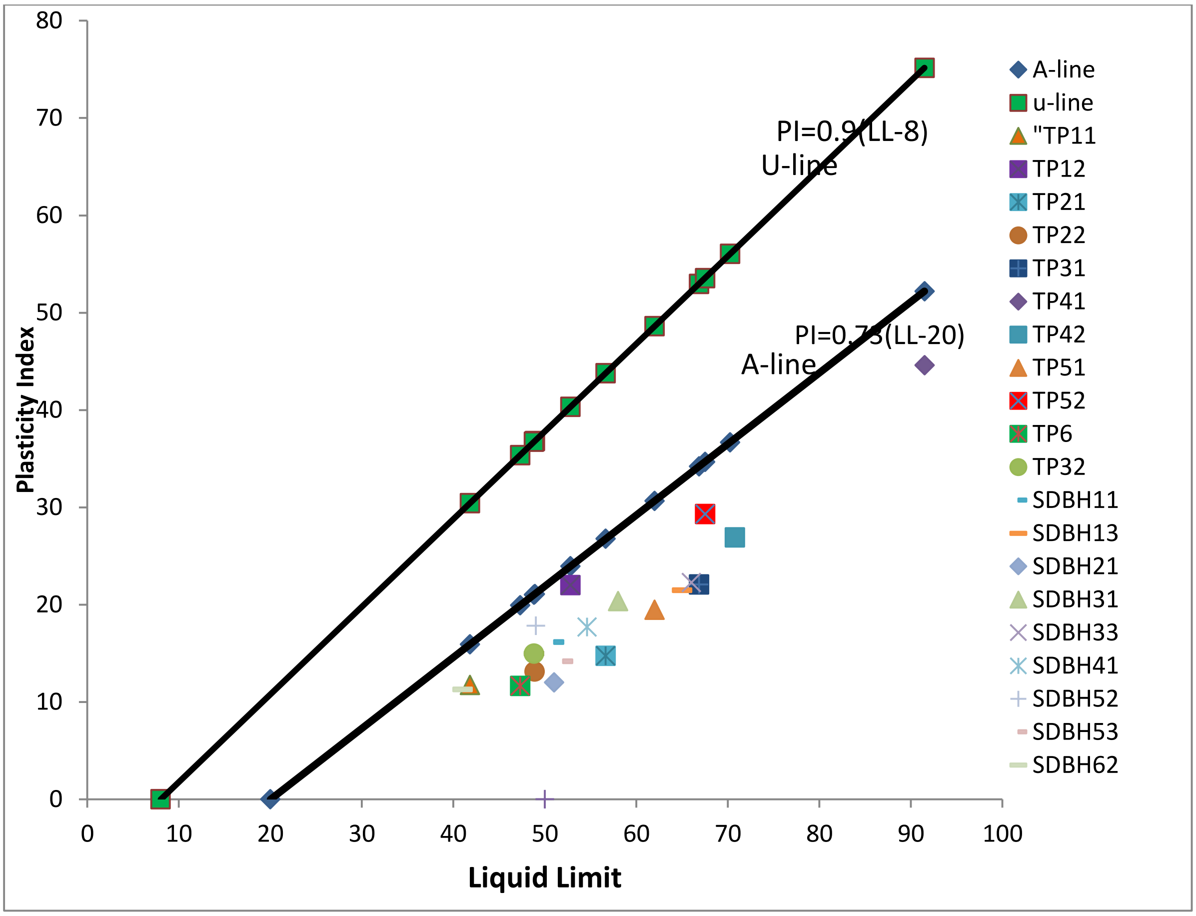


Fig.6.3 USCS Soil classification plasticity chart

6.3 Geotechnical soil map of the study area

In this research study, the soil engineering map was carried out by using laboratory test results and classification of the soils of the study area based on laboratory index test values. The soil type of the study area were identified and located on the map using GPS reading of the location of representative samples and ArcGIS10.3 software. The soil types identified in the town are:

Elastic silts (MH): Mostly the soil of the town was characterized by Elastic silt soil. These are mainly characterized by light reddish, black and gray soils with low to high degree of expansiveness. Mostly the study sites are characterized by Elastic silt soils of varying color and free swell property.

Sandy silt (ML): Around Mizan (top layer) and Elemtu (bottom layer) resulted in sandy silt soil type in classification. The laboratory test result showed that, representative samples collected from different places and at different depth within each selected sampling location except the top layer of Mizan and bottom layer of Elemtu, the other place characterized by uniform soil type MH (Refer the fig.6.4 below).

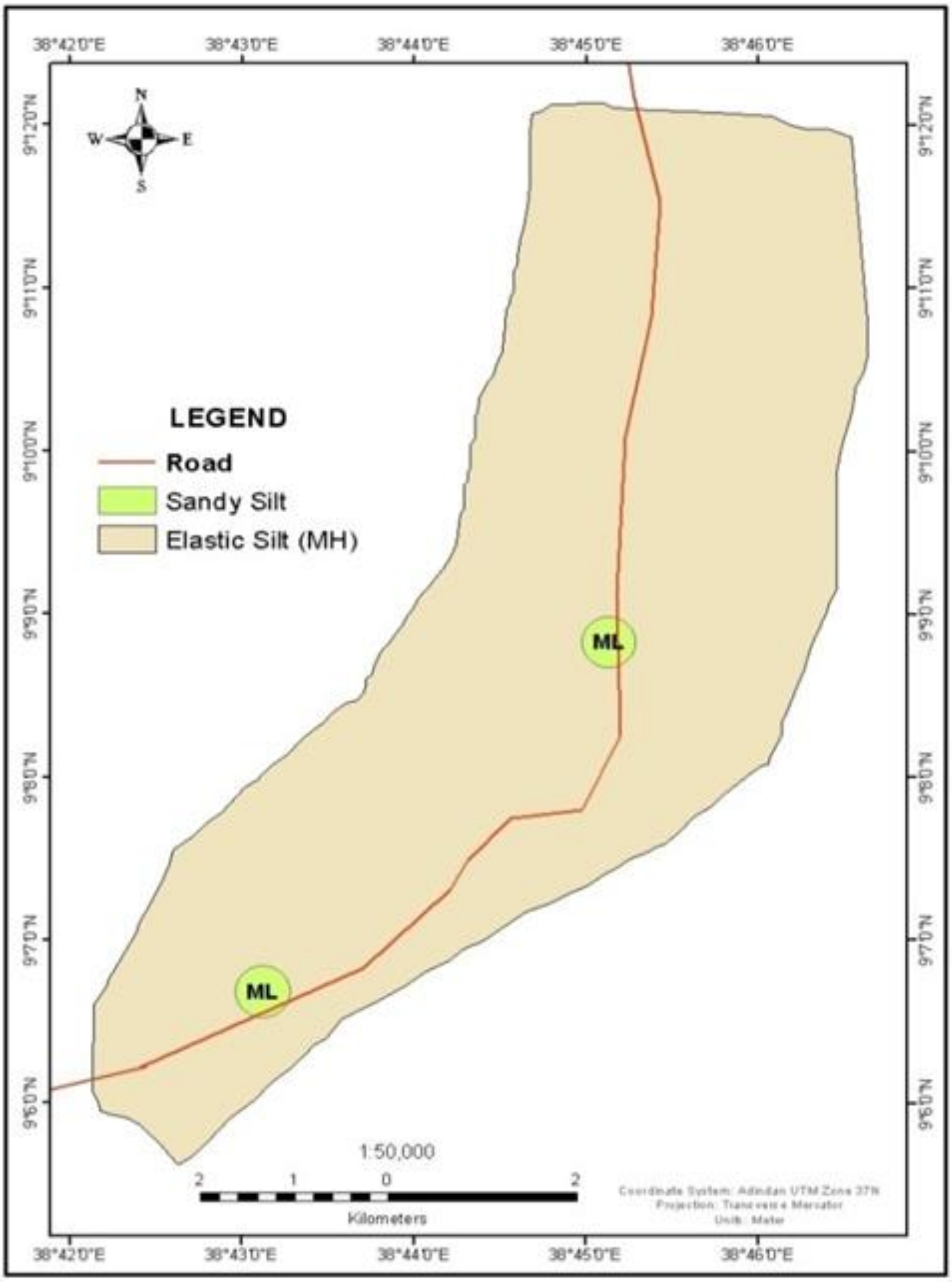


Fig.6.4 Geotechnical Soil Map of the study area

CHAPTER SEVEN

7. CONCLUSION AND RECOMMENDATION

7.1. CONCLUSION

Based on field observation of geological features and laboratory test results of the representative samples of the area the following conclusions are drawn:

Geological units found in the area dominated by basaltic rocks. The ground water of the study area is found at shallow depth. Moisture content of the soils varies from 23.27 to 65.48.Grain size analysis of the soils shows that, the soil of the town is fine grained soils. Atterberg limit test for the soil of the study indicates that Liquid Limit ranges from 41.8 to 91.5, Plastic Limit varies from 30.07 to 46.91, Plasticity Index ranges from 11.63 (medium plasticity) to 44.59 (very high plasticity). Similarly, specific gravity of the soils of the study area ranges from 2.24 to 2.68. Free swell of the soils of the study area shows that the values range from 30(non-expansive) to 80(expansive). The free swell and consistency test results of the study area shows that the soils are not expansive according to Ethiopian classification of expansive soil. The clay minerals in the soil of the study area are Kaolinite, Illite and Ca-Montmorillonite. The soils of the study area were classified as A-7-5 which is clayey in case of AASHTO classification system and also classified within group by their GI values. GI values of the soils are mostly greater than 20 that are not suitable for sub grade material. Soils of the town are almost uniform. The classification was also conducted using USCS and the soil classified as ML and MH silty soil with low plasticity and high plasticity respectively.

Engineering soil map of the study area was produced at a scale of 1:50,000. Large seasonal fluctuations in ground water table in the town can adversely influence bearing capacity of soil. From strength test and bearing capacity analysis it is concluded that, the soil of the study area was within low bearing capacity characteristics. Allowable bearing capacity of the soil of the study area is calculated using different bearing capacity estimation equations and the average was taken. Genesis of soils of the study area was discussed using soil forming factors and clay minerals identified in the soils. The test results show that ML soil has swelling pressure of 14kPa, whereas MH soil has swelling pressure of the 48–66kPa. The consolidation swell (one – dimensional) test on these samples has indicated that the compression index of the soil of the study area is within the range of 0.12-0.35. For consolidation to take place, the soil should be subjected to a pressure greater than the swelling pressure.

7.2 RECOMMENDATION

- It is recommended that further researches can be conducted with increased number of samples from same areas and additional areas that are not included in this research of Sululta town.
- Depth to the water table and pore water pressure distributions should be known to determine the influence of soil weight and surcharge on the bearing capacity.
- Flooding in the area is may cause damage to residential buildings unless consideration taken during design.

REFERENCES

AASHTO (2001). Standard Specification for Transportation Materials and Methods of Sampling and Testing, part II tests. American Association of State Highway and Transportation Officials, Washington, DC.Washington, D.C.

Alemayehu Teferra and Mesfin Leikun (1999). Soil Mechanics, AAU Printing Press, Addis Ababa, Ethiopia

Alemayehu Regassa, K. Van Daele, P. De Paepe, M. Dumon, J. Deckers, Asfawossen Asrat and E. Van Ranst(2014).Characterizing weathering intensity and trends of geological materials in the Gilgel Gibe catchment, southwestern Ethiopia. Journal of African Earth Sciences **99** (2014) 568-580

American Society for testing and Materials (2007).Annual Book of ASTM standards, vol.04, 08, West Konshohoken

Ashenafi Tamirat (2013). Study on Index Properties and swelling pressure of Expansive soils found in Dukem, Unpublished Msc thesis, Addis Ababa University, Addis Ababa, Ethiopia.

ASTM, D.422-63 (2007). Standard test method for particle-size analysis of soils. *Annual Book of ASTM Standards*, *4*.

ASTM, D. 4318(2005). *Standard test method for liquid limit, plastic limit, and plasticity index of soils, ASTM Standard*, *4*, 1-13.

ASTM, D. (1994). 3080-90: Standard test method for direct shear test of soils under consolidated drained

ASTM, D. 854-00. Standard Test Method for S" pecific Gravity of Soil Solids by Water.

Arora, K.R. (2004). Soil Mechanics and Foundation Engineering. Standard publishers Distributors, New Delhi

ASTM(1996).Annual Book of ASTM standards. Soils and Rocks, Building stones.vol.4,08.American Society for Testing and Materials, Philadelphia

Barnes, J. W. (1997). Basic Geological Mapping.3rdEdition. John Wiley & Sons, Chichester

Belay Desta. (1983).Geological Map of Goba sheet (NB 37-7)1:250,000 scale. EIGS, Addis Ababa, Ethiopia.

Belay Hunde (2014). Investigation on some of engineering properties of soils Found in Ambo town, Ethiopia, Unpublished Msc thesis, Addis Ababa University, Addis Ababa, Ethiopia.

Bell, F.G. (2007). Engineering Geology.2^{nd}ed., Butterworth-Heinemann, Burlington

Bowles, J.E. (1996). Engineering Properties of Soils and Their measurement.4^{th} ed.McGraw-Hill Book Company, New York.

Bowles, J. E. (1970). *Engineering properties of soils and their measurement* (No. 187 pp).

Bowles, J.E. (1992).Foundation Analysis and Design, 5^{th} ed, McGraw-Hill Companies,

Inc. New York.

Casagrande, A.(1948).Classification and Identification of soils,Transactions,ASCE,vol.113,901-930pp

Chamberlin, T.C(1882).General maps of the soils of Wisconsin. Wisconsin Geological Survey. Beloit

Chen F.H (1975), *Foundations on expansive Soils*, elsevier publishing company, AmsterdamChen, F.H. (1988). Foundations on expansive soils, Elsevier Scientific publishing Company, Amsterdam.

Dagnachew, D. (2011). *Investigation on some of the engineering characteristics of soils in Adama town*, Msc thesis, Addis Ababa University, Addis Ababa, *Ethiopia*

Dubroeucq, D., Geissert , D., Quantin ,P.(1998).Weathering and soil forming processes under semi-arid conditions in two Mexican volcanic ash soils. Soil science.**86:**99-122

Dokuchaiev.(1879).Abridged historical and critical examination of the principal soil classifications existing (Russian), Trans. Soc. Naturalists, St. Peters.

Dow, D.B., Beyth, M. and TsegayeHailu (1971). Paleozoic Glacial Rocks Recently Discovered in Northern Ethiopia. Geol. Mag, 108(l), p.53-60.

Dye,P.I(1979).Feasibility of Reclaiming and Improving sodicsoils, Rhodesian AgricJ.**76** (2):65-68

ESB (1998).Georeferenced Soil Database for Europe, Manual of Procedures ver. 1.0. European Soil Bureau, Scientific Committee. European Soil Bureau Research Report No.5. EUR 18092 EN, 184pp. Office for the Official Publications of the European Communities, Luxembourg

EIGS (Ethiopian Institute of Geological Survey) (2010). Engineering Geological Map of Addis Ababa, Unpublished report, Addis Ababa, Ethiopia

FAO (2001). Lecture notes on the major soils of the world. World Soil Resources Reports, Rome. Pp 334

Fookes. (1997). Geology for engineers: the geological model, prediction, and performance. Quarterly Journal of Engineering Geology, 30, 293-424.

Fookes, P. G. 1969. Geotechnical mapping of soils and sedimentary rock for engineering purposes with examples of practice from the Mangla Dam project.Geotechnique, 19, 52-74

Franzen, D.W.,Cihacek, V.L. Hofman and L.J. Swenson. 1998. Topography-based sampling compared with grid sampling in the Northern Great Plains. Journal of Production Agriculture. 11: 364-370

Gebremedhin Berhane. (2010).Engineering Geological Soil and Rock characterization in the Mekelle town, Northern Ethiopia: Implications to Engineering practice, Mekele University,

Grim, R.E.(1968) .Clay Mineralogy,2nd Ed., Mc Gram Hill ,New York,596P

Heinzen, R.T. and Arulanandan, K.(1977).Factors Influence Dispersive Clays and Methods of Identification. In: Dispersive Clays related Piping and Erosion in Geotechnical Projects, ASTM STP 623:202-213

Holmgren, G .G .S. and Flanagan, C.P.(1977) .Factors affecting spontaneous dispersion of soil materials as evidenced by crumb test .In: Dispersive Clays related Piping and Erosion in Geotechnical Projects, ASTM STP,623:218-239

Holtz, W. G., & Gibbs, H. J. (1956). Engineering properties of expansive clays. *Transactions of the American Society of Civil Engineers*, *121*(1), 641-663.

Holtz, R.D. and Kovacs, W.D.(1981).An Introduction to Geotechnical Engineering, Prentice-Hall

ISRM.(1981).Rock Characterization Testing And Monitoring. Pergamon press, Great Britain.

Jenny, H.(1941). Factors of Soil Formation. McGraw-Hill, New York, NY, 281 pp

Kezdi, A. (1980). *Handbook Of Soil Mechanics-Volume 2. Soil Testing* (Vol. 2, No. Monograph).

Krishna R. (2002), Engineering Properties of Soils Based on Laboratory Testing, UIC.

Lambe, T. W. (1951). *Soil Testing for Engineers* (Vol. 72, No. 5, p. 406). LWW.

Lee R. K.,Susan L. B., and Michael A. A (2000). Chemical weathering, atmospheric Co2, and climate. Earth Planet. Sc. **28**:611–67.

Mengesh Tefera, Tadiwos Cherinet, and Worknesh Haro.(1996). Explanation of the geological map of Ethiopia, Ministry of Mines and Energy, EGS, Bull. No 3,Addis Ababa.

Merga Mekonnen, (2012) Evaluation of Land Use Planning and Management With Respect to Environmental Issues in Sululta Town, Msc Thesis, Addis Ababa University, Addis Ababa, Ethiopia.

Meyerhof, G. G. (1963). Some recent research on the bearing capacity of foundations. *Canadian Geotechnical Journal*, *1*(1), 16-26.

Mock, R.G. and Pawlak, S.L. (1983). Alluvial Fan Hazards at Glenwood Springs, Geological Environment and Soil Properties. In: *Proceedings of ASCE Conference*, pp. 221-233. Houston, Texas

Munsell Color (2000). Munsell soil color charts. Gretagmacbeth.New Windsor, NY.

Obaje, S. O., Omada, J. I. and Dambatta, U. A. (2013).Clays and their Industrial Applications: Synoptic Review. International Journal of Science and Technology.**3**:264-270

OUPI, (2006); Structural plan of Sululta Town. Addis Ababa, Ethiopia

OWMEB (Oromia Water, Mines and Energy Bureau) (2014).Environmental Impact Assessment (EIA) study for Basalt Gravel Aggregate Production project in Sululta, Addis Ababa, Ethiopia.

Paton, T.R., 1978. The Formation of Soil Material. Allen and Un win, London, 143 pp

Phanikumar .B.R. (2009). Expansive soils problems and remedies. Guntur, India, 907 PP

Pregitzer, K. S., King. J. S., Burton, A. J. and Brown, S. E. (2000). Responses of tree fine roots to temperature. New Phytologist 147, 105–115. 30.

Rollins, K.M. and Rogers, G.W. (1994). Mitigation Measures for Small Structures on Collapsible Alluvial Soils, Journal of Geotechnical Engineering, 1533-1553.

Kazmin V. (1980). Report on the Geological Map of the Ethiopian Rift Valley. EIGS, Addis Ababa.

Mengesha Tefera, Tadiwos Cherinet and Workneh Haro (1996). Explanation of the Geological map of Ethiopia, Ministry of Mines and Energy, EIGS, Bull. No 3, AA.

National Meteorological Agency of the Federal Democratic Republic of Ethiopia, 2009. Daily Precipitation and Temperature data Ethiopian Government, Addis Ababa, Ethiopia

Peck, R., Hanson, W. and Thornburg, T.H. *Foundation Engineering*, John Wiley & Sons, 1953.

Pregitzer, K. S., King, J. S., Zak, D. R. and Holmes, W. E. (2000). Elevated atmospheric CO2, fine roots and the response of soil microorganisms: a review and hypothesis. *New Phytologist*, *147*(1), 201-222.

Quideau, S. A., Chadwick, O. A., Benesi, A., Graham, R. C., & Anderson, M. A. (2001). A direct link between forest vegetation type and soil organic matter composition. *Geoderma*, *104*(1), 41-60.

Ranjan, G., Vlladkar, M. N.,and Sharma, R. P. (1993). Soil-structure interaction in the time domain. *Computers & structures*, *46*(3), 429-442.

Samuel, T.,(1989).Investigation into some of the engineering properties of Addis Ababa Reed clay soil, Unpublished Msc thesis, Addis Ababa University, Addis Ababa

Shakoor, A.(1991). *Characterization of Geologic Materials*. Kent, USA.

Singh, M.,& Rao, K. S. (2005). Bearing capacity of shallow foundations in anisotropic non-Hoek–Brown rock masses. *Journal of geotechnical and geoenvironmental engineering*, *131*(8), 1014-1023.

Skempton, A. W. (1953). The colloidal activity of clays. *Selected Papers on Soil Mechanics*, 106-118.

Solomon Tale (2000). The Extent of Surface and Groundwater Pollution in Addis Ababa. M.Sc.Thesis, Addis Ababa University, Addis Ababa.

Sululta City Administration (2006).Social Status Profile of Sululta City, Sululta City Administration, Sululta, Ethiopia.

Terzaghi and peck, R. B. (1948). Soil Mechanics in Engineering Practice, Wiley, New York.

William, D. B.(200). Engineer Manual No. 1110-1-1905, U.S. Army Corps of Engineers, Washington, DC.

Wilding, L. P and Dress, L. R.(1983). Spatial Variability in Pedology, pp 83-113. indication of good drainage (Periaswamy and Ashaye, 1982).

Schmertmann, J. H. (1955). The undisturbed consolidation behavior of clay. In *From Research to Practice in Geotechnical Engineering:* (pp. 1-33). ASCE.

Wang, Jung, Projietu, Vaug Quil and Liding Chen (2001), Soil nutrients in relation to land use and landscape position in the semi-arid small catchment on the loess plateu in China- Journal of Arid. Environment Vol. 48: 537-550. 42.

Szechy, k. and Varga, L. (1978).Foundation Engineering-Soil Exploration and Spread Foundation, Akademiai, Kiado. Budapest, Hungary

Wilding, L. P., & Dress, L. R. (1983). Application of geostatistics to spatial studies of soil. *Advances in Agronomy. Trangmar, BB, RS Yost, and G. Uehara (eds.)*, *38*

Wilson, M.J., 1975. Chemical weathering of some primary rock-forming minerals. Soil Sci. 119, 349–355