**Shrink swell susceptibility zonation of Addis Ababa**

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**A Thesis Submitted to School of Earth Science**

**Presented in partial fulfillment of the requirements for the degree of master of Science (Engineering Geology)**

**Addis Ababa University,**

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## DECLARATION

I hereby declare that this thesis is my original work that has been carried out under the supervision of Dr. Zemenu Geremew, School of Earth Sciences, Addis Ababa University during the year 2020 as part of the Degree of Master of Science Program in Engineering Geology in accordance with the rule and regulation of the institute. I further declare that this work hasn't been submitted to any other University or Institution for the award of any degree or diploma and all sources of materials used for the thesis have been duly acknowledged.

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## Abstract

The present study was carried out in Addis Ababa. The main objective of this study is to carry out shrink swell susceptibility mapping of Addis Ababa.
Clay soils are found in many parts of Ethiopia, especially southern, south eastern and south western part of Addis Ababa. Damages due to the shrink swell phenomenon has been frequently reported.

Swell potential of such soil can be predicted by both direct and indirect methods. By combining direct and indirect methods of swell potential measurements that predict shrink–swell behavior, a susceptibility map has been established for Addis Ababa. This map shows sensitive areas toward shrink and swell phenomenon.

The adopted methodology has been modified from French Bureau of geological and mining research (BRGM) approach. This procedure allowed the identification and spatial variation of shrink swell potential of soil in the study area. Then, they were classified and rated based on their volume changing potential as per given standard.

The criterions used to establish susceptibility map are the lithological (plasticity and free swell), geotechnical (clay fraction and thickness of expansive soil) and mineralogical parameters. Each criterion and or parameters was rated, combined and sum together. This summation was divided by the number of the layers (plasticity index, free swell, clay fraction, lithological thickness and percentage of swelling mineral) to get the mean.

Finally shrink swell susceptibility map has been produced based on the mean. The formations have been classified in to three classes and represented by tarragon green, yellow and red colors representing low, medium and high susceptibility to shrink swell respectively.

The shrink swell susceptibility map shows that 30% (159km$^2$) of the study area has a 'high shrink swell potential', 38% (196km$^2$) of the study area has 'medium' shrink swell potential. Whereas, the areas that account for 'low shrink swell potential' and 'non clay or rock formations' are 18% (96km$^2$), 14% (76km$^2$), respectively. Thus, the shrink swell susceptibility map can be used as a regulatory tool in land use and planning procedures.

# CHAPTER 1 INTRODUCTION

Expansive soils are those containing clayey materials which shrink as their moisture content decreases and swell as their moisture content increases. The moisture increase in soil may come from rain, leaks in water pipes or sanitary sewer lines and decrease in moisture content can be caused mainly by change in atmospheric temperature, relative humidity and periodic sun drying (Subba and Satyadas,1987). Swell/shrink is not an inherent property of the clay soil, but a result of interaction between suction (the affinity for water to enter the soil mass) and soil property intrinsic expansiveness. The swell/shrink phenomenon is governed mainly by the kind of clay mineralogical compositions (e.g. smectite, kaolinite, illite and chlorite), quantity, shape, size and the adsorption capacity of the soil particles (Mitchell, 1993, Chen, 1998, Coduto, 2001, Day, 2001 and Lucian et al., 2006 as cited by Charles Lucian, 2008). The direct consequence of swell-shrink behavior is associated with soils containing clay mineral smectite (montmorillonite). The problem of shrink/swell is compounded by the large climate variability from season to season (Bell, 1983). Coastal belt of the tropics in the semi-arid regions of East Africa, experiences two main seasons: the dry and the rainy seasons (Lucian,2008). Shrinkage cracks develop in soils during the dry season due to the stifling heat of the tropics. During the rainy season, the expansive clay minerals attract a great amount of water, mainly through shrinkage cracks, resulting into massive change in volume. Swelling, or shrinkage or both may cause damages originating from differential heave to structures supported on expansive soil, especially light weight buildings. This leads to additional financial burden to owners for repair. Apart from the expansive soil and poor materials, the defects may originate from inadequate design and poor job-site construction or a multiple of the factors. The structures most susceptible to swelling/shrinkage on expansive soils are those with foundations located at shallow depths within the active zone (Chen,1988). Damages experienced by these structures include cracks in the foundation and walls and jammed doors and windows. The degree of damage based on observed cracks ranges from hairline cracks, severe cracks, very severe cracks to total collapse.

Mostly the cracks appear in the weakest points of the structures such as around the door and window openings and in the joints where the wall and ceiling meet or where wall and floor meet (Lucian,2008).

This problematic soil in Ethiopia, covers large surface area. South, south east and south west part of the capital Addis Ababa is covered with this soil, where many constructions are being constructed and damage has been reported (Affework Sisay, 2004, Tewodros Alene, 2010).

This research aims at Susceptibility zonation of expansive soil of Addis Ababa to mitigate the damage due to shrink swell. For this to be achieved, field survey, different laboratory soil tests from private and governmental organizations were collected, processed and analyzed during the course of this research.

## 1.1 Background

Expansive soils exist all over the world and cause damages to foundations and associated structures (Kariuki, 2004, as cited by Charles Lucian, 2008).

It has been ascertained that expansive clays cause billions of dollars damage every year in the USA, more than all other natural hazards combined (Jones and Holtz, 1973 and Chen, 1988).

The problem is also extensive in some areas of Addis Ababa but little statistics is available. The shrink-swell phenomenon is controlled by different factors like mineralogical; soils containing more than 20% montmorillonite (Ravina, I,1973, as cited by Alemayehu and Solomon,1986), lithological and geotechnical. Soils sensitivity to shrinkage and swelling can be evaluated by considering the above factors. The heterogeneity nature of soil makes it very difficult to conclude on the behavior of soil without some fundamental geotechnical investigation. Observations show variations in properties from point to point on the ground is because of inherent differences in composition and consistency during formation.

There are a number of research works related to the behavior of expansive soils in Addis Ababa. Alemayehu and Solomon, (1986), Daniel Teklu (2003), Affework Sissay, (2004), Fikerte Arega, (2006), Abdshekur Kemal, (2015), Hailemariam Girma, (2016), Tesfalem G/Mariam, (2018), Zemene Muche, (2019) and etc. These studies focused on soil deformation, permeability, strength and stress-strain behavior, correlation between critical state soil parameters, index properties, swelling pressure, Damage assessment of the expansive soil in and around Addis Ababa.

## 1.2 Problem Statement

Despite the large coverage of expansive soils in Ethiopia, there is no systematic research on susceptibility zonation of such volume changing and problematic soil.

Studying the engineering characteristics of soils and evaluating their behavior with respect to degree to pose damage on engineering structures are very important.

Therefore, it is believed that identifying and zoning the level of susceptibility related to expansive soil is crucial for proper land use and planning and mitigating the effects of shrink swell.

## 1.3 Significance of the Study

The result and findings of these research work are expected to be utilized by urban planners and policy makers to mitigate the shrink swell susceptibility and minimize cost of additional site investigation.

## 1.4 Objectives of the Study

### 1.4.1 General Objective

The main objective of this research is to carry out shrink swell susceptibility mapping of Addis Ababa.

### 1.4.2 Specific objectives

To achieve the general objective, the following specific objectives were followed.

- To collect existing geological, mineralogical, and geotechnical data.
- To develop methodology for the shrink swell susceptibility mapping.

- To produce shrink swell susceptibility map of Addis Ababa at a scale of 1:50,000.

**1.5 Methodology**

The following methodology has been followed to produce the shrink swell susceptibility map of Addis Ababa.

Different data has been collected from governmental and non-governmental organizations, published text books and journals for better understanding on the characteristics of the expansive soil in study area.

In a first step, Engineering geological map published by Ethiopian Institutes of Geological survey covering most of the study area have been used to know different formations, their areal extent and distribution. Groupings were carried out in a second step, according to lithological natures having different behaviors of shrink-swell.

Lithological, mineralogical and geotechnical characterization of formation has been done through understanding of the proportion of clay material present in the formation and its thickness, which constitutes its lithological characterization. Analysis of index properties has been utilized in defining indirectly the mineralogical characteristics of the selected formation and classification of proportion of swelling minerals belonging to the group of smectites (which includes montmorillonite).

Characterization of the geotechnical behavior of the clay formations of the study area was essentially established on the basis of collection of different relevant data.

Finally, susceptibility map has been produced from mean of lithological, mineralogical and geotechnical parameters.

$$\text{Mean}= \frac{\boldsymbol{Lithological}(\boldsymbol{CF}<\mathbf{0.002}\boldsymbol{mm\ and\ EST})+\boldsymbol{Swelling\ Mineral}\ (\%)+\boldsymbol{Geotechnical}(\boldsymbol{PI\ and\ FSW})}{\boldsymbol{Number\ of\ layers}\ (\mathbf{5})}$$

Where; CF- Clay fraction
EST- Expansive soil thickness
PI- Plasticity index
FSW- Free swell

The average of these scores is calculated to get a degree of general susceptibility toward the shrinkage–swelling phenomenon, included between one and four at scale of 1:50000. The susceptibility map has been done with the help of ArcGIS software, DEM (Digital Elevation Model with 30m x30m resolution Source: Shuttle Radar Topography Mission (SRTM), Local IDW (inverse distance weighted), and Strater Demo 4 soft wares.

**1.6 Scope of the study**

- This study particularly focuses on the shrink- swell susceptibility mapping of the soil in study area based on lithology, mineralogy and geotechnical behavior based on collected data from the study area.

**1.7 Limitations**

- This research study has to undergo some limitations during the process of data collection. The secondary data sources were unable to provide the researcher crucial data for the study, and the secondary data lack well organized geo-database system.

In addition to this, limitations of very important laboratory tools especially X-ray diffraction (XRD) were observed.

- The collected data from different organization has been tested under different engineering procedure and standard, as per their project aim.
- The soil has been sampled from various depth which affects engineering test result.

**1.8 Thesis Outline**

- **Chapter 1**: Gives a general introduction, includes background of the study, problem statement, objectives of the study, significance of the research, scope of the study, general methodology, and outline of the thesis.
- **Chapter 2**: Reviews wide and detail literatures regarding to expansive soils. This comprises a brief description about expansive soils, identification and discusses previous works relevant to the present research.
- **Chapter 3**: Provides an overview of the study area including location, climate, geology and hydrogeology.
- **Chapter 4**: Provides detail of point data used to produce the susceptibility map from the average values of lithological, mineralogical and geotechnical parameters.
- **Chapter 5:** Provides an overview of susceptibility map with different class, result and discussion, methods of preventing damage due to shrink swell, appropriate design for expansive soil and remedial measures.
- **Chapter 6:** Focuses on the conclusions and recommendations forwarded through the present research work.

# CHAPTER 2 LITRATURE REVIEW

## 2.1 Background

The term ‘soil’ in soil engineering is defined as an unconsolidated material, composed of solid particles produced by disintegration of rocks. The void space between the particles may contain air, water, or both (Arora,2004). It can be classified as gravel, sand, silt and clay. Expansive soils or active soils are those containing clayey materials which shrink as their moisture content decreases (as they dry out) and swell as their moisture content increases (when they get wet). Expansive soils exist all over the world and cause damages to foundations and associated structures (Kariuki, 2004 as cited by Lucian,2008). It has been known that expansive clays cause billions of dollars damage every year in the USA, more than all other natural hazards combined (Jones and Holtz, 1973 and Chen, 1988). The problem is also extensive in some areas of Ethiopia but no detail statistics are available. Geotechnical engineers did not recognize damages associated with buildings on expansive soils until the late 1930s. The U.S. Bureau of reclamation made the first recorded observation about soil heaving in 1938 (Chen, 1988). Since then a number of researchers have pioneered researches into expansive soils. Apart from increased research in expansive soil, design of shallow foundations to support lightweight structures on expansive soils is a potential problem than design of foundations for heavy loads (Meehan and Karp, 1994).

Problem of expansive soils throughout the five continents results from a wide range of factors; (1) shrinkage and swelling of clay soils resulting from moisture change (2) type of the clay size particles (3) drainage– rise of ground water or poor surface drainage (4) compression of the soil strata resulting from applied load. Other factors include (5) pressure of the backfill soil, (6) soil softening (7) weather (8) vegetation and (9) the amount of aging (Lucian, 1996, Chen, 1988 and Day, 1999 as cited by Lucian,2008). All these should be considered to come out with the choice of appropriate design criteria for careful selection of the proper type of foundation, type of structure and type of construction materials. With proper knowledge of the above indicatives, the potential for structural damage could be mitigated.

This chapter summarizes a brief review of the methodologies, techniques and observations of some of the previous studies to provide useful knowledge on clay mineralogy, soil structure and swell investigation tests in order to provide comprehensive review of the existing research results.

## 2.2. Mechanics of swell

Soil volume change result from an imbalance in internal energy of the system (soil/ water/ plants/ air). Energy imbalances important in engineering result from moisture movement caused by loads, desiccation, and temperature changes. Response to a specific set of conditions are determined by the composition, structures, and geologic history of the soil. The largest component of volume change is that of the clay micelle which surrounds the individual clay particles in the soil. Water is forced out of the micelle by loads, desiccation, or temperature along energy gradient and reduction in volume results. When these influences are removed, the energy gradients are reversed, the available water is forced into the clay micelle and swell is produced (Mckeen, 1976, as cited by Daniel Teklu,2003).

The natural micro scale mechanisms, which contribute the major portion of volume changes in expansive soils, are (Snethen, 1975, as cited by Daniel Teklu,2003).

- Osmotic repulsion: it is a pressure gradient developed in the double-layer water due to variations in the ionic concentration in the double layer.
- Clay particle attraction: as clay particles possess a net negative charge on their surfaces and edges which result in attractive forces for various cations and in particular for dipolar molecules such as water.
- Cation hydration: it is physical hydration of cations substituted into or attached to the clay particles.
- Capillary imbibition: it is a movement of water into a mass of clay particles resulting from surface tension effects of water and air mixtures in the pores of the clay mass.

### 2.3 Identifications of expansive soil

Identification of potential swelling or shrinking subsoil problems is an important tool for selection of appropriate design and methods of construction (Van Der Merwe, 1964 and Hamilton, 1977). Despite the lack of standard definition of swell potential (Nelson and Miller, 1992), there exist various geotechnical methods to identify the swelling potential of soils.

#### 2.3.1. Field identification

Some of the important field identification method that indicate the potential for expansiveness of a soil are the following (chen, 1966, as cited by Ayenew,2004):

- A shiny surface is easily obtained when a partially dry piece of the soil is Polished with a smooth object such as the top of a finger nail.

- The wet samples of the soil are sticky and it will be relatively difficult to clean the soil from the hands.

- The appearance of cracking in nearby structures.

- They usually have a color of black and gray.

- In the regions where there is seasonal moisture variation

- Open or closed fissures, (a joint or similar discontinuity) or desiccation crack on surface textures of the soil (Fig.2.1)
- Shattering or micro-shattering, (presence of fissures forming granular fragments of clayey soils).

Fig.2.1. Expansive soil showing cracks

### 2.3.2 Laboratory identification

Generally, there are three different methods of identifying expansive soil in the laboratory.

**I. Mineralogical identification**

This method is used for identifying the mineralogy of clay particles such as characteristic crystal dimensions, characteristic reaction to heat treatment, size and shape of clay particles and charge deficiency and surface activity of clay particle. These properties are a fundamental factor controlling expansive soil behavior. The various techniques under these methods are:

-X-ray diffraction

-Differential thermal analysis

-Dye absorption

-Electron microscope

-Cation exchange capacity, etc

But these methods are not suitable for routine tests because of the following reason; they are time consuming, require expensive test equipment and, the results are interpreted by specially trained technicians (Sridharan and Prakash,2016).

**II. Indirect methods**

These methods try to link some of the index properties of fine-grained soils with the soil clay mineralogical composition and hence, to estimate their swell potential (Sridharan and Prakash,2016). The commonly used test here is the Atterberg limit. In this method, measurement of the plasticity and the shrinkage characteristics of the soil is conducted for identification of soils and provide a wide acceptable means of rating by using liquid limit, plastic limit, shrinkage limit, free swell tests, colloid content test, etc.

**Liquid limit:** Liquid limit of a soil is regarded as the water holding capacity of the soil, which in turn has been taken as a measure of soil swell potential. Degree of soil swell potential based on the liquid limit of fine-grained soils (Holtz and Gibbs, 1956) (Table.2.1)

Table.2.1 Expansive soil classification based on shrinkage limit (Holtz and Gibbs, 1956)

| Classification of potential swell | Liquid limit (LL, %) (Holtz and Gibbs, 1956) |
|---|---|
| Low | 20-35 |
| Medium | 35-50 |
| High | 50-70 |
| Very high | >70 |

**Plasticity Index**: It is the difference between the liquid limit and plastic limit of fine-grained soils. Higher the plasticity index, more plastic the soil is and higher will be the soil swell potential. Degree of soil swell potential based on the plasticity index of the soils are given in Table 2.2 (BRGM,2009).

Table2.2 Expansive soil classification based on plasticity index (BRGM,2009)

| Classification of potential swell | Plasticity index |
|---|---|
| Low | <12 |
| Medium | 12-25 |
| High | 25-40 |
| Very high | >40 |

**Particle size**: Many researchers have proposed criteria based on percentage clay size fraction (i.e., <0.002 mm size) or colloid content (i.e., content of particles of size less than 0.001 mm) to predict the swell potential of fine-grained soils, as per the scheme given in Table 2.3 (Chen 1965).

Table 2.3. Expansive soil classification based on clay fraction (Chen,1965)

| Degree of swell potential | Percent clay size fraction | Rating |
|---|---|---|
| Low | <30 | 1 |
| Medium | 30-60 | 2 |
| High | 60-95 | 3 |
| Very high | >95 | 4 |

**Activity:** Activity is the ratio of plasticity and clay fraction finer than 2μm in %.

$$\text{Activity} = \frac{PI}{<0.002\%\ clay}$$

Skempton, established useful empirical relationships between expansion potential and physical properties of soils such as colloids contents (clay contents), soil activity, plasticity index etc.

Table 2.4: Chart for evaluation of potential expansiveness (Skempton,1953)

| Activity | Nature of soil | Swell potential |
|---|---|---|
| <0.75 | In active | Low |
| 0.75 – 1.25 | Normal | High |
| >1.25 | active | Very high |

**Free swell test**: The free swell is defined as the ratio of the increase in volume of the soil from a loose dry powder form to the equilibrium sediment when it is poured into water, expressed as the percentage of the original volume.

The percent of free swell is expressed as:

$$\text{Free swell percent} = \frac{\Delta V}{V} * 100\%$$

where $\Delta V = V_f - V$= change in initial volume (V) of a specimen and

V = initial volume (10 $mm^3$) of the specimen

$V_f$ = final volume of the specimen

Soils with free swell less than 50% are not likely to show expansive property, while soils with free swell in excess of 50 percent could present swell problems. Value of 100% or more are associated with clay which could swell considerably, especially under light loadings (Subba and Satyadas, 1987).

Free swell is classified as per the guidelines given in Table 2.5.

Table .2.5 swell potential classification (Holtz and Gibbs,1956)

| Swell potential | FS value (%) |
|---|---|
| Low | <50 |
| Medium | 50 – 100 |
| High | 100 – 200 |
| Very high | >200 |

**iii. Direct measurement**

The most accurate and dependable method of determining the swelling potential (% swell) and swelling pressure of expansive clay is by direct measurement using oedometer testing technique.

$$\% \, swell = \frac{\Delta H}{H} * 100$$

**Consolidation or Swelling pressure test:** Swelling Pressure is the amount of pressure a soil exerts upon swelling or the pressure required recompressing the fully swollen sample back to its initial volume. Most of the structural damages occur when the swelling pressure is greater than the foundation pressure, assessing the swelling pressure is an important task in dealing with expansive soil (Alemayehu and Mesfin, 1999).

The oedometer testing techniques have become popular and are extensively used. The different types of techniques under these methods are: Constant Volume Method, Swell-Consolidation Method, Different Pressure Method, Double-Odometer Method (Alemayehu and Mesfin, 1999).

**2.4 Factors Influencing Swelling and Shrinking of a Soil**

The factors influencing the shrink swell potential of a soil can be considered in three different groups (Nelson and Debora,1992 as cited by Abdirshkur Kemal, 2015).

I. Soil characteristic that influence the basic nature of the internal force field. These includes: -

- Clay mineralogy (Kaolinite, Montmorillonite and Illite)
- Plasticity
- Dry density
- Soil suction
- Soil water chemistry
- Soil structures and fabrics

II. The environment factor that influence the changes that may occur in the internal force system. These include;

- Initial moisture condition
- Moisture variation
- Climate (Ground water, Drainage and manmade water source, Vegetation, Permeability, Temperature)

III. State of stress, which include

- Stress history
- Surcharge load

- Soil profile

**Effect of Clay mineralogy**

The swell/shrink phenomenon is governed mainly by the kind of clay mineralogical compositions (e.g. Kaolinite, Montmorillonite and Illite). Soils containing higher proportion of montmorillonite possess swell/shrink phenomenon than other group (Lucian et al.,2006).

**Effect of plasticity**

In general, soils that exhibit plastic behavior over wide ranges of moisture content and that have high liquid limits have greater potential for swelling and shrinkage.

Plasticity is an indicator of swell potential (Subba and Satyadas,1987).

**Effect of initial moisture content**

Naturally expansive soils with low or no moisture content have higher tendency for water than the soil profile with more water content.

Conversely, water lose occurs swiftly in a soil profile at higher water content on exposure to drying effects and shrink more than a relatively desiccated profile (Budhu,2010).

**Effect of moisture variation**

When the soil profile experiences changes in its water content in the active zone near the upper part of the profile, swelling occurs. The largest variation in moisture content and volume changes of expansive soils occurs in those layers (Budhu,2010).

**Effect of active zone**

The swelling-shrinkage potential depends mainly on the thickness of the active zone and the degree of saturation (Coduto, 2001). Geotechnical soil properties alone do not adequately identify the depth of potential soil volume change. Generally, the depth of active zone (depth of desiccation) varies depending on soil type, soil structure, topography and climate, but it usually ranges between 1.0 m and 4.0 m. Since moisture content below the active zone depth can be accepted as constant, heaving would not occur in layers beneath active zone depth (Lucian et al., 2006). The relationship between climatic condition and depth of active zone is illustrated (Walsh et al., 1998 as cited by, Burt G. Look,2007) in table 2.6.

Table 2.6. Relationship between climate and active zone

| Climate description | Active zone depth (m) |
|---|---|
| Alpine/west coastal | 1.5 |
| Wet temperate | 1.8 |
| Temperate | 2.3 |
| Dry temperate | 3.0 |
| Semi-arid | 4.0 |

**Effect of climate**

Usually, climate change modifies rainfall, actual evaporation, generation of runoff, groundwater level and soil moisture storage.

Changes in both total seasonal precipitation and its pattern of variability are important in the prediction of alternate cyclic episodes of swelling and shrinking of expansive soils (Lucian,2010).

During the rainy periods that follow the dry spells, water penetrates the surface cracks generating swell in the soil around and under the foundation resulting in expansion and structural foundation problems.

In addition, the absorbed water increases the unit weight of the soil thus decreasing the resisting (shear) strength of the soil. With alternate cycles of wetting (swelling) and drying (shrinking), a progressive reduction of shear strength of expansive soil takes place. The problems caused by expansive soils are critical in areas of semiarid climate because of the broad change of climatic conditions (Lucian, 2010).

**Effect of ground water**

Shallow water tables provide source of moisture and fluctuating water tables contribute to moisture (Subba and Satyadas,1987).

**Effect of drainage**

Surface drainage features, such as ponding around a poorly graded house foundation, provide sources of water at the surface; leaky plumbing can give the soil access to water at greater depth (Subba and Satyadas,1987).

**Effect of topography**

Topographical conditions under which smectite is formed are entirely different from that of koalinite. Compared to others the formation of smectite requires low relief, which directly affects the shrink/swell phenomena of soil (Lucian, 2010).

**Effect of vegetation**

The roots of the trees and shrubs consume large amount of moisture from the soil, eventually causing the soil to shrink much faster in the root zone area than other soil areas not exposed to the plant roots. An area with decreasing moisture content is more prone to differential settlement than the surrounding soil (Lucian, 2010).

**Effect of permeability**

Soils with higher permeability, particularly due to fissures and cracks in the field soil mass, allow faster migration of water and promote faster rates of swell (Subba and Satyadas,1987).

**Effect of temperature**

Increasing temperatures cause moisture to diffuse to cooler areas beneath pavements and buildings and promote shrink swell phenomena (Subba and Satyadas,1987).

**Effect of Stress History**

An over consolidated soil is more expansive than the same soil at the same void ratio, but normally consolidated. Swell pressures can increase on aging of compacted clays, but amount of swell under light loading has been shown to be unaffected by aging. Repeated wetting and drying tend to reduce swell in laboratory samples, but after a certain number of wetting-drying cycles, swell is unaffected (Tripathy and Fredlund, 2002).

**Effect of loading**

Magnitude of surcharge load determines the amount of volume change that will occur for a given moisture content and density. An externally applied load acts to balance inter-particle repulsive forces and reduces swell (Tripathy and Fredlund, 2002).

**Effect of Soil Profile**

The thickness and location of potentially expansive layers in the profile considerably influence potential movements. Greatest movement will occur in profiles that have expansive clays extending from the surface to depths below the active zone. Less movement will occur if expansive soil is overlain by non-expansive material or overlies bedrock at shallow depth (Tripathy and Fredlund, 2002).

## 2.5 Shrink swell susceptibility mapping

Different countries like France and UK, where there is appreciable area coverage of volume changing soil and experiencing severe engineering damage have proposed different methodologies to tackle the problem. In UK shrink swell susceptibility mapping has been done based on lithological, mineralogical and modified plasticity index' (*Ip*') value.

IDW (inverse distance weighting) interpolation technique has been used to interpolate point data of study area.

Such plasticity parameters, being based on remolded specimens, cannot precisely predict the shrink–swell behavior of an in situ soil. However, they do follow properly laid down procedures, being performed under reproducible conditions to internationally recognized standards (Jones and Terrington, 2011). A 'Modified Plasticity Index' (*IP'*) was proposed in the Building Research Establishment Digest 240 (1993) for use where the particle size data, specifically the fraction passing a 425 µm sieve, are known or can be assumed as 100% passing (Building Research Establishment 1993).

The Modified IP' takes into account the whole sample and not just the fines fraction, it therefore, gives a better indication of the 'real' plasticity value of an engineering soil:

$$Ip' = \frac{Ip * \% < 425\mu m}{100}$$

where Ip' is 'Modified' Plasticity Index and *Ip* is 'Standard' Plasticity Index

Zonation has been done based on the following table 2.7:

Table.2.7 Classification of Volume Change Potential (BRE,1993)

| Classification | *IP'*(%) | VCP |
|---|---|---|
| A | <10 | Non plastic |
| B | 10 – 20 | Low |
| C | 20 – 40 | Medium |
| D | 40 – 60 | High |
| E | >60 | Very high |

In French shrink swell susceptibility mapping methodology has been developed by the French Bureau of geological and mining research (BRGM), from research expanded gradually by several authors (BRGM,2009). This qualitative approach depends on the establishment of a synthetic map of argillaceous and marl formations, these are later ranked according to their susceptibility to the shrinkage–swelling phenomenon. This ranking was established on the basis of their lithological properties, their mineralogical criterions, and their geotechnical behavior (BRGM,2009). The lithological criterion is used to characterize the dominant materials in the formation, and to distinguish clayey soil.

This criterion also includes the thickness, continuity, and the heterogeneity of the formations. The maximum rate is assigned to thick and continuous layer (BRGM,2009). The minimum is attributed to a heterogeneous, thin, and discontinuous formation without predominant clay (table 2.8.1).

Table 2.8.1 Conventional scale used to distinguish the different lithological classes

| Type of formation | Susceptibility | Rating |
|---|---|---|
| Formation not containing clay but present locally | Low | 1 |
| Formations with not predominantly clayey | Average | 2 |
| Formation predominantly clay and very thin | High | 3 |
| Continuous formation mainly clay or marl, with thickness >3m | Very high | 4 |

The mineralogical criterion considered that the shrinkage–swelling occurs preferentially in the presence of the Smectite (Montmorillonite, Beidellite, Saponite, Sauconite) and the interstratified phyllosilicates group. To characterize susceptibility of formation, a rating is awarded to each clay formation, depending on the Smectite and interstratified swelling minerals contained in the clay (Table 2.8.2).

Table 2.8.2 Mineralogical criterion scale applied for the susceptibility assessment

| Average swelling minerals (%) (BRGM,2009) | Susceptibility | Rating |
|---|---|---|
| <25 | Low | 1 |
| 25-50 | Medium | 2 |
| 50-80 | High | 3 |
| >80 | Very high | 4 |

A geotechnical evaluation of the susceptibility is based on the soil identification tests. This quantitative characterization of the material particle size and its reactivity through the methylene blue test value, linear shrinkage, (Ls) and plasticity index (PI) seem to be the most representative geotechnical measurements of the phenomenon (BRGM,2009). The measure of the methylene blue quantity (in grams) adsorbed per 100g of fine soil provides an idea of the clay content of the material and the nature of clays via its specific surface. The evaluation of the susceptibility of soil to shrinkage–swelling according to moisture variation can be established from this criterion (BRGM,2009). The sensitivity of clay material toward the phenomenon according to methylene blue test is described in Table 2.8.3.

Table 2.8.3. Geotechnical susceptibility marks according to methylene blue value

| Methylene blue test Blue value | Susceptibility | Rating |
|---|---|---|
| <2.5 | Low | 1 |
| 2.5 -6 | Average | 2 |
| 6 -8 | high | 3 |

The evaluation of the susceptibility of shrinkage–swelling clay depending on the PI is indicated in table 2.8.4.

Table 2.8.4. Geotechnical marks according to the PI

| PI | Susceptibility | Rating |
|---|---|---|
| <12 | Low | 1 |
| 12-25 | Medium | 2 |
| 25-40 | High | 3 |
| >40 | Very high | 4 |

**Linear shrinkage:** The linear shrinkage value is the way of quantifying the amount of shrinkage likely to be experienced by clayey material. Initially, the soil is saturated with water.

When the water content decreases, its total volume decreases, then stabilizes. This process of decreasing the water content results in two successive phases. During the first, the grains constituting the soil come closer, but the soil remains always saturated: the variation in soil volume is therefore proportional to the decrease in water content.

During the second, the grains are in contact and can no longer getting closer, removing water can no longer changes the volume of the soil, but results desaturation.

The water content corresponding to this level is called the withdrawal. The lower this value, the greater the variation in volume and the greater the settlement induced in the event of drying (Mastchenko, 2001, as cited in GRGM,2009).

$$linear\ shrinkage(\%)\ = \frac{Initial\ length - Oven\ dried\ length}{Initial\ legth} * 100$$

The sensitivity of clay material toward swell shrink phenomenon according to Ls is described in Table 2.8.5.

Table 2.8.5. Geotechnical marks according to linear shrinkage

| Linear shrinkage (Ls) | Susceptibility | Rating |
|---|---|---|
| <0.4 | Low | 1 |
| 0.4- 0.65 | Medium | 2 |
| 0.65 – 0.75 | High | 3 |
| >0.75 | Very high | 4 |

The shrink swell mapping of study area has been modified from French methodology based on availability of the data. Different data like plasticity index (PI), Liquid limit (LL), free swell index value (FSI), oedometer (one dimensional consolidation) value (Kpa), clay fraction (%), mineralogical composition (%), and thickness of soil profile (lithology) has been utilized. Finally, those values and rating fall under different susceptibility (low, medium, high and very high) susceptibility map has been produced.

**2.6. Distribution of expansive soil in Ethiopia**

In Ethiopia the occurrence and spatial distribution of expansive soil is significant and it covers about 10% of total surface area of the country (Mekonen, 2004; Leuseged,1990 as cited by Fekerte Arega 2009) Fig 2.2. This soils are observed in area such as central Ethiopia, following the major trunk road like Addis Ababa - Ambo, Addis Ababa- Weliso,

Addis Ababa - Debere Berehan, Addis Ababa - Gohatsion, Addis Ababa - Mojo.
Also cover towns like Mekelle, Bahirdar, Gambela, Arba Minch and most of Southern, South-west and southeast part of the capital Addis Ababa. These areas are where most of major recent construction are being carried out (Affework Sisay, 2004; Tewodros Alene, 2010).

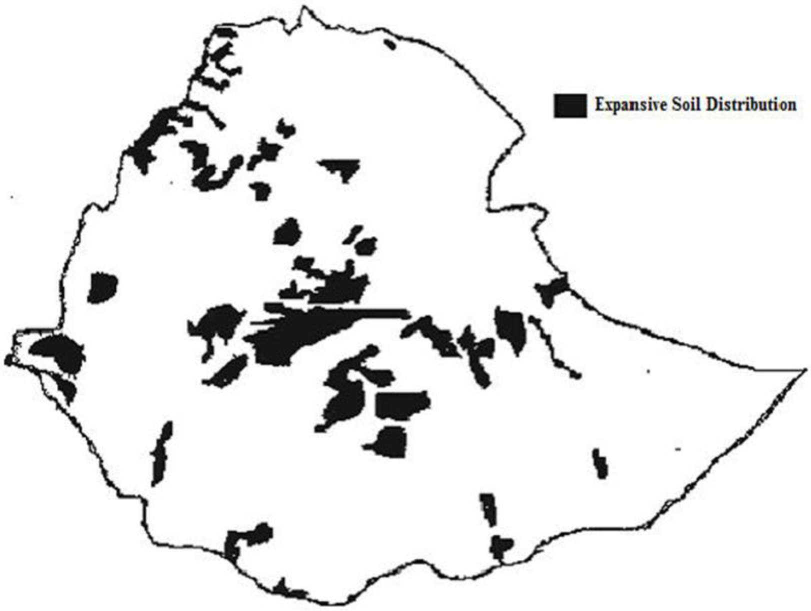



Figure 2.2. Distribution of Expansive Soils in Ethiopia

**2.7 Problems due to expansive soil in Ethiopia**

Engineering problems due expansive soil have remained one of the biggest challenges in construction sector of Ethiopia. Even if there is few statistics on the cost consequence and the amount of damage caused by this problem, there have been a serious economic losses and substantial increase in the cost of construction which in many times exceed initial cost estimate of construction projects (Fekerte Arega, 2009). This soil cause damage on structures in different parts of the country.

Differential settlement creates serious of bumps or corrugations, potholes, and patches on different road section and this problem is reported on main road connecting Addis Ababa –Jimma town and Bole international airport (Nettterberg,2001 as cited by Fekerte Arega 2009). Due to cut slopes (erosion, heaving, and slumping) Ethiopia road authority has been allocating additional cost for clearing and maintenance (Ethiopian road authority, 2001 as cite by Fekerte Arega 2009). Investigation conducted by Afewerk Sisay (2004), showed that 64% of surveyed 96 buildings found in different localities namely (Bole, Olompian and Nifas silk, Lafto, old airport, Mekanisa, Gerji and Bole Bulbula) are affected adversely. 72 % of the affected buildings are due to the consequence of heave or shrinkage of the soil. According to Alemayehu and Solomon (1986), Case studies of 35 structures all located within the regions of expansive soils, typical damages are observed on those structures.

**2.8 Previous Works related to the research**

A number of researches on the engineering properties of soils found in Addis Ababa have been carried out in.

Some of the researches conducted and utilized in this thesis are summarized as follows.
Alemayehu Teferra and Solomon Yohannes (1986), investigating on the expansive soil of Addis Ababa (old airport, Bole road, Near civil aviation, AMCE, Yared church, EBCA); stated percentage of montmorillonite present in the black and grey soils ranges from 45 to 87 percent, liquid limit rages from 87 to 123, plasticity index ranges from 72 to 93, natural moisture content ranges from 30.2 to 40, free swell ranges from 90 to 170, clay fraction ranges from 40 to 70, and activity ranges from 1.3 to 1.8. According to Medhanit Akalu (2017), investigating the of Engineering characteristics of Red soil in the Western Addis Ababa; Clay fraction ranges from 27 to 53, Activity ranges from 0.11 – 0.7, liquid limit ranges from 32 to 60, plasticity index ranges from 13 to 23 and free swell ranges from 50 to 70.

Lulseged Ayalew (1990), investigated engineering properties of Bole area; the study showed that the clay fraction ranges from 46.4 to 84.7. Plasticity index ranges from 26.6 to 80.1. Free swell ranges from 8-130%. Swelling pressure ranges from 0.36 Mpa to 0.18 Mpa and the dominant clay mineral in the study area is montmorillonite.

According to Zemene Muche (2019), investigating the soils engineering properties of Akaki Kality sub city, the moisture content ranges from 12 to 68.5, the percentage of fine and coarse fractions ranges from 5.0 to 99.9 % and 0.1 -95.9 % respectively, liquid limit ranges from 25 to 113, plasticity index ranges from 4 to 74 and free swell ranges from 20 to 280.

According to Daniel Teklu (2003), examining the swelling pressure of Addis Ababa expansive soil indicated that, moisture content ranges from 33.2 to 44.3, liquid limit ranges from 96 to 121, plasticity index ranges from 26 to 47, clay fraction ranges from 50 to 81 and swelling pressure ranges from 108 to 420 Kpa.

According to Hailemariam Girma (2016), study on foundation of different buildings constructed on expansive soil of Addis Ababa showed that, moisture content ranges from 30 to 46, liquid limit ranges from 68 to 115, plasticity index ranges from 34 to 69, free swell ranges from 78 to 205 and swelling pressure ranges from 148 to 391 Kpa.

According to Lamesgen (2014), the thickness of red clays in Addis Ababa ranges from 2m to 13m, the maximum thickness was found in boreholes sunk around Atanatera. Similar thickness ranges (2m to 13m) were obtained for expansive soils too (Fig. 2.3).

The maximum thickness of expansive soils in Addis Ababa was recorded in Bole sub-city, around Bole Medhanialem Church. The average LL, PI and free swell values of expansive soils in Addis Ababa are 92%, 44% and 143%, respectively. The compression index of ‘light to dark grey’ soils ranging from 0.166 to 0.319 showing a moderate to very high degree of compressibility. The swelling pressure of ‘light to dark grey’ soils in Addis Ababa are in the range of 100 to 180Kpa.

# CHAPTER 3 DESCRIPTION OF STUDY AREA

Addis Ababa lies at an altitude of 2,300 meters (7,500 feet) a.s.l. and located at $9^0$5'40'' latitude and $38^0$76'36'' longitude. The city is divided into ten sub cities and 99 weredas Fig.3.1. The study area covers about 527 $km^2$, with a population of 3,384,569 according to 2007 population census with annual growth rate of 3.8%.

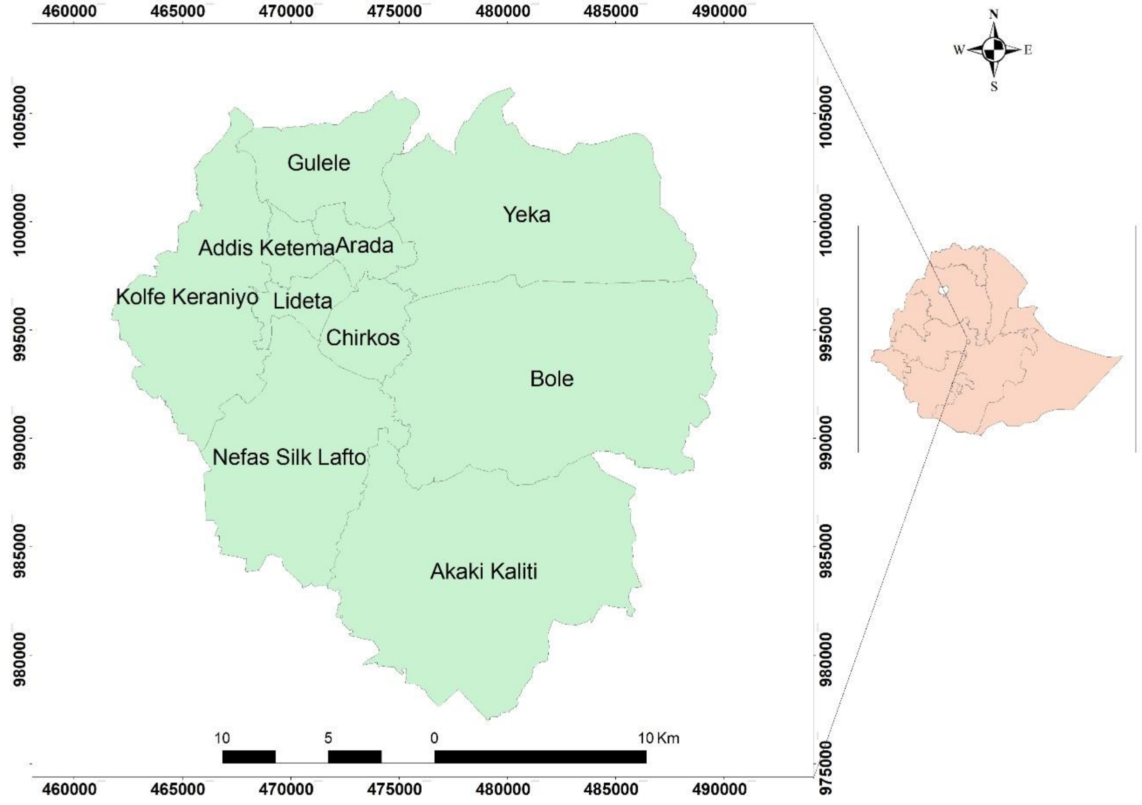



Fig 3.1 Location Map of the Study Area

## 3.1 Climate

The climate is one of the most important factors in soil profile development. It helps to change parent material into soil. Climatic factors, such as precipitation, wind and sunlight/ temperature, accelerate the formation of the basic material of soil. Soil is a mixture of rock fragments, minerals, air, water, and organic materials. Soils differ depending on how much of these different ingredients they contain, and climate contributes to those differences. For example, the climatic conditions under which smectite is formed are entirely different from that of koalinate. The formation of smectite require low rainfall and low temperature. In these conditions, the environment offers itself extreme disintegration, strong hydration and restrained leaching appropriate for the formation of smectite rich expansive soils (Tourtelot, 1973 and Azam et al., 1998 as cited in Lucian,2008). In contrast, high temperature, strong hydrolysis by high permeability and high rainfall intensities favour the formation of kaolinite (Tourtelot, 1973 and Weaver, 1989 as cited in Lucian,2008).

In Addis Ababa the dry season ranges from mid-September to May. In the mid December there is uncommon low rainfall while in March and April there is intermediate rain fall. The rest of the months are characterized by high rain fall. Accordingly, the amounts of rainfall during these months are varied from year to year (Tamiru et al., 2003).

### 3.1.1 Rainfall

Addis Abeba has three distinct seasonal periods with seven main rainy months from March to September. The dry season (Bega) is between the months of October to February, the short rain season is between March to May and the big rainy season is between the months of June to September (Feven Solomon, 2007). In Addis Ababa rainfall intensity variation is attributed to the differences in topography. The high elevated areas such as the Entoto receive relatively greater precipitation than lowland areas around the study area. According to the data obtained from National Meteorological Services Agency (NMSA), the annual mean rainfall of Addis Ababa Bole station, Addis Ababa Observatory Tekelehaimanot station, Intoto station and Akaki Beseka stations are 1053 mm,1248 mm,1315 mm and 1011 mm respectively.

Thus, the city receives mean annual rainfall of about 1157 mm as shown in table 3.2a. These stations are located at an elevation of 2354m, 2386m, 2903m, 2057m a.s.l. respectively.

Table. 3.2a. Mean Monthly Rainfall (mm) in four stations of Addis Ababa (1988 to 2018)

| Stations | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Annual Total Rain fall (mm) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Bole station | 11.32 | 24.48 | 55.77 | 84.91 | 77.32 | 114.7 | 237.19 | 263.91 | 137.78 | 33.03 | 4.91 | 7.73 | **1053** |
| A.A observ | 13.98 | 31.10 | 56.91 | 86.55 | 78.12 | 145.71 | 282.56 | 305.42 | 192.42 | 35.86 | 10.2 | 9.65 | **1248** |
| Intoto station | 12.81 | 31.91 | 54.37 | 80.11 | 81.69 | 161.92 | 334.94 | 353.15 | 153.02 | 28.88 | 13.46 | 9.00 | **1315** |
| Akaki station | 11.19 | 25.04 | 51.21 | 85.12 | 70.78 | 112.24 | 245.06 | 255.39 | 122.21 | 20.1 | 6.14 | 5.85 | **1011** |
| Mean monthly Rain fall (mm) | **12.32** | **28.13** | **54.56** | **84.17** | **76.97** | **133.64** | **274.93** | **294.46** | **151.35** | **117.87** | **8.67** | **8.05** | **1157** |

*(Source: National Meteorological Services* Agency)

From 30 years' data of mean monthly rain fall, the heaviest amount of rain falls occur in the month of August, While the minimum amount of rainfall occurs in December. Furthermore, Addis Ababa Observatory which is located at a higher elevation than Addis Ababa Bole and Akaki Beseka stations, records greater amounts of mean annual rainfall (1205 mm). This shows that there is a variation in the amount of rainfall within Addis Ababa with differences in altitude.

### 3.1.2 Temperature

Under normal conditions, air temperature decrease with increasing altitude at a mean rate of 0.7ºC for every 100m (Fetter, 1994 as cited in Hana Tibebu, 2008). The mean monthly maximum and minimum temperature records of National Meteorological Services Agency (NMSA) stations in Addis Ababa located at, Addis Ababa Bole, Addis Ababa Observatory and Intoto stations for the years between 1988 and 2018 were utilized to calculate monthly and annual average temperature. The computed average maximum and minimum temperature is presented below.

Table 3.2b. Monthly and Annual Temperatures of Addis Ababa (1988-2018)

| Stations | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Annual Total Temp (°C) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Bole station | 23.05 | 25.14 | 25.74 | 25.29 | 25.47 | 23.76 | 21.38 | 21.13 | 22.84 | 23.24 | 23.30 | 19.80 | **23** |
| A.A observ | 25.09 | 23.06 | 24.11 | 24.03 | 24.48 | 22.44 | 19.65 | 19.36 | 20.55 | 21.67 | 21.59 | 20.93 | **20** |
| Intoto station | 19.73 | 20.79 | 20.95 | 20.30 | 20.42 | 17.27 | 16.03 | 15.87 | 16.63 | 18.28 | 18.73 | 19.01 | **18** |
| Mean monthly Temp (°C) | **22.62** | **22.99** | **23.60** | **23.20** | **23.45** | **21.15** | **19.02** | **18.78** | **20.00** | **21.18** | **21.20** | **19.91** | **21** |

*(Source: National Meteorological Services Agency)*

As can be observed in table 3.2b, the highest monthly average maximum temperature occurs in the months of March with 23.6$^0$C and the lowest is in the month of August with 19 $^0$C. The monthly average record of temperature shown for each station indicates that the average annual temperature at Addis Ababa Bole, Addis Ababa Observatory, and Intoto stations were 23$^0$C, 20$^0$C, and 18$^0$C, respectively. Thus, the city is characterized by an about of 21 $^0$C mean annual temperature. Furthermore, Entoto station which is located at a higher elevation records smallest amount of average annual temperature. On the contrary, being at lower elevation, Bole station records the highest amount of average annual temperature. This shows that, like the rainfall, there is also variation in the amount of temperature within Addis Ababa with differences in altitude.

## 3.2 Topography and Drainage

Topography, hydrological conditions, environmental conditions, and geology govern the formation and behaviour of soils. Topographical conditions under which smectite is formed are entirely different from that of koalinate. The formation of smectite requires low relief (Tourtelot, 1973 and Azam et al., 1998 as cited in Lucian, 2008).

Flowing water/stream is one of the most important agents of transportation of soils. Swift running water carries a large quantity of soil either in suspensions or by rolling along the bed. Water erodes the hills and deposits the soils in the valleys. The size of soil particles carried by water depends upon the velocity. The swift water can carry the particles of large size such as boulders and gravels. With a decrease in velocity, the coarse particles get deposited. The finer particles are carried further downstream and are deposited when the velocity reduces. A delta is formed when the velocity slows down to almost zero at the confluence with a receiving body of still water such as a like, a sea or an ocean. (Arrora, 2004, as cited in Zemene,2019).

The city was founded at the southern flank of Intoto ridge (3199m a.s.l.) and expanded in all directions. This ridge marks the northern boundary of the city following the east-west trending major fault (Ambo-Kassam fault). Prominent volcanic features surrounding the city are Mt. Wochacha in the west (3385m a.s.l.), Mt. Furi (2839m a.s.l.) in the southwest and Mt. Yerer (3100 a.s.l.) in the southeast and characterized by rugged landscapes and steeper slopes (Belayneh Desta, 2009). The general inclination of the slope becomes lower towards the southern part of the city (Tamiru Alemayehu et al., 2006, as cited by Lamesgen Melese,2014).

The center of the city lies on an undulating topography with some flat land areas, while gentle morphology and flat land areas characterize the southern and southeastern parts of the city.

Akaki river and four water reservoirs, namely Legedadhi, Gefersa, Dire and Abba Samuel, represent the main surface water bodies within and in the vicinity of Addis Ababa. Basically the Akaki river has two main branches: The Big Akaki (which covers eastern part of the city) and Little Akaki River (which covers western parts of the city). The big Akaki river has many tributaries among which Ginfile, Kebena, Kechene, Kurtume and Yekka (Tamiru Alemayehu,2001) (Fig.3.2).

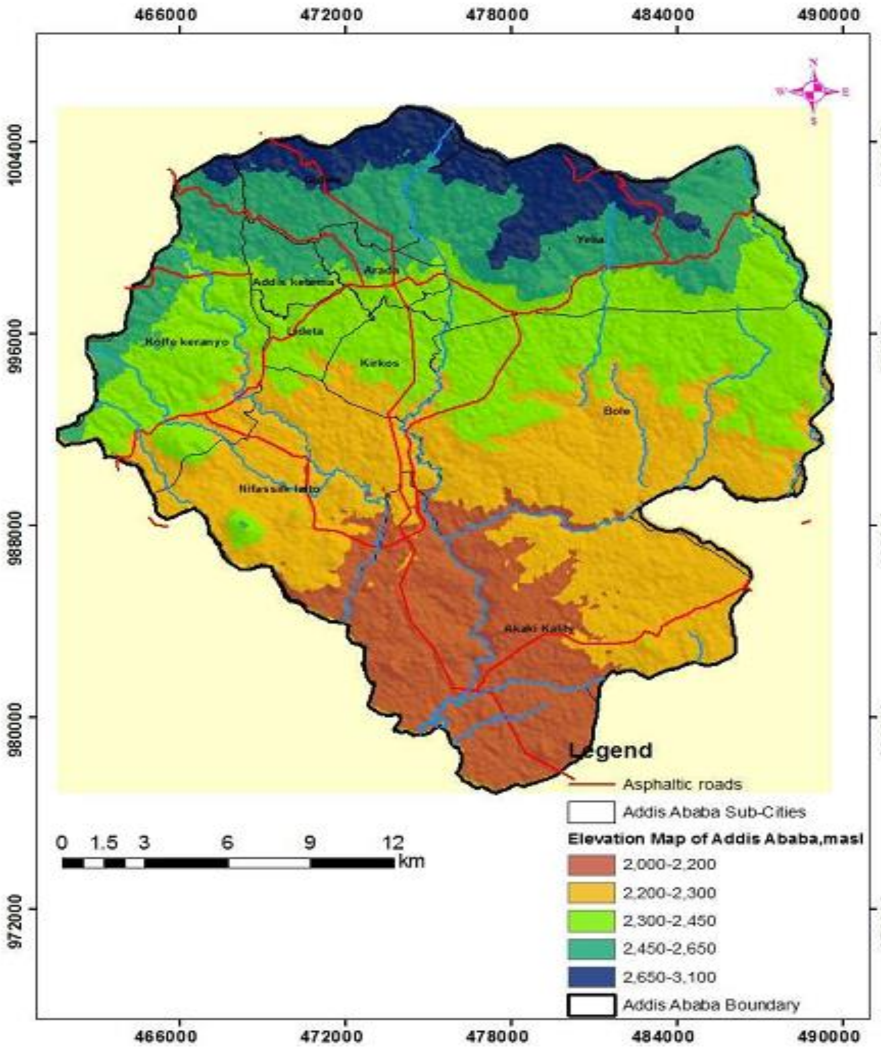



Fig 3.2. Elevation & Drainage Map of the Study Area (Lamesgen,2014)

**3.3 Land use land cover of the study area**

Land use land cover has an important role to know the main land use pattern in the city. The main land use pattern in the city embraces residential areas, market quarters, industrial zone, agricultural areas, forest and etc. The central part of the city includes residential quarters, governmental offices, churches, schools and universities, airports, parks, sport grounds, and various sized market. For the present research land use land cover of the study area is classified in to three classes namely bare land, forest and built up area.

They are represented by gray, green and red colors respectively. The maps show much construction are being taking place in south, south western and south eastern part of the city fig 3.3 (a, b, c).

Vegetation is one of the predisposing factor to the phenomenon of shrink swell. Accordingly, southern, south western and south eastern part of the study area is less and sparsely covered by vegetation. Therefore, susceptibility to shrink swell phenomenon due to vegetation is less than northern, northern western and northern eastern part of the city.

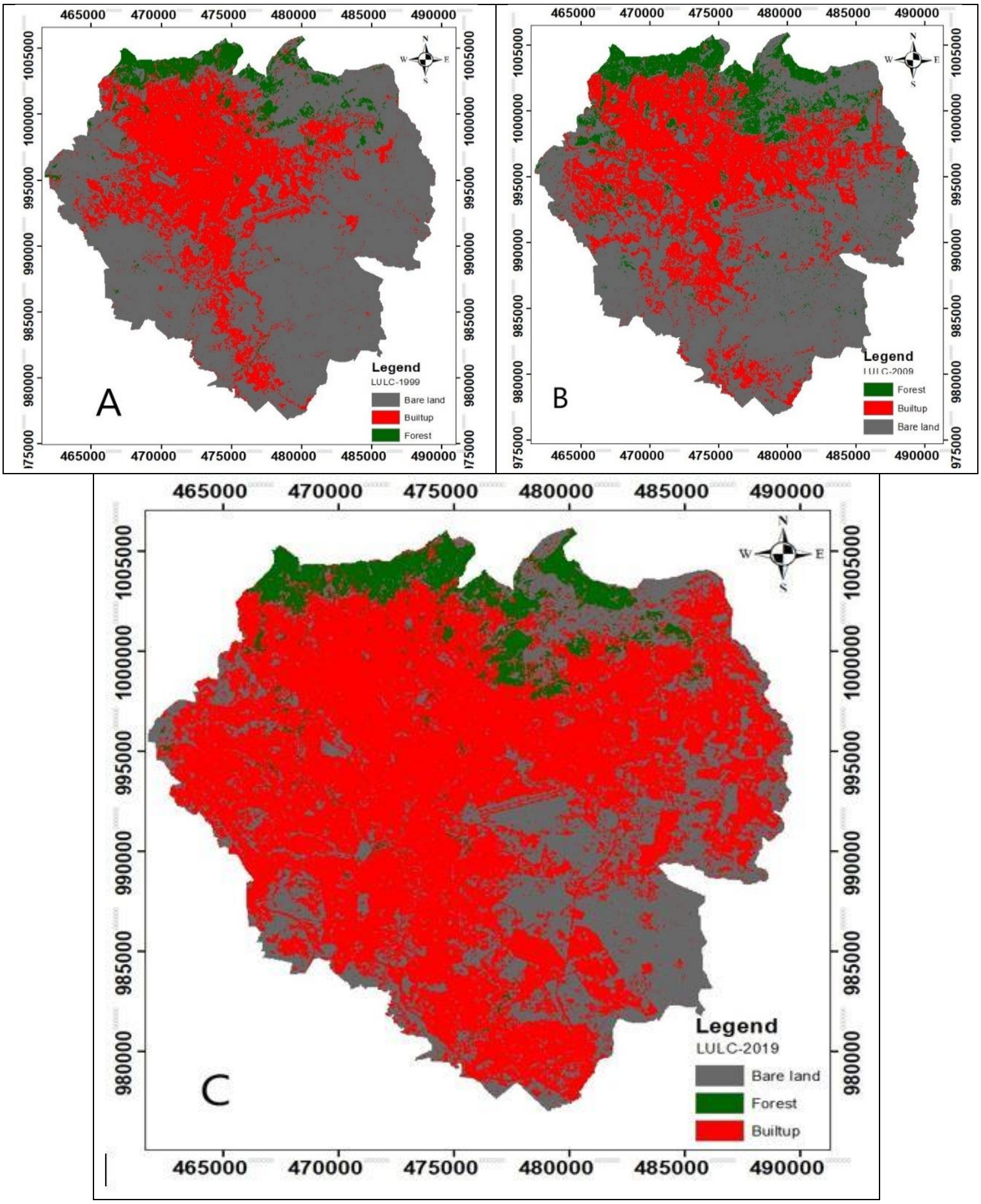



Figure 3.3 (a,b,c). Land use land cover of the study area

### 3.4 Regional Geology

The cenozoic volcanic rocks of Ethiopia are divided in to the Trap series and Aden series by Mohr (1962, as cited in GSE, 1996). The term Trap series is still widely used to represent the whole pile of the Tertiary flood basalt sequence with intercalation of silicic rocks which form the northwestern and southwestern plateaus and attain a thickness of up to 3km. The name Aden series was used for post rift volcanic rocks of the Main Ethiopian Rift (MER), Afar depression and some parts of the Ethiopian plateaus. Later studies have enabled to distinguish several volcanic episodes in both the Trap series and Aden series. (GSE, 1996). Uplift of the horn of Africa occurred on an immense scale following sub-horizontal nature of the uplifted strata. Rapid major uplift occurred with eruption of the trap series. The upraised and uparched land, fissuring under tension permitted the ascension of magma to form the trap series. (Hailesellassie Girmay and Getaneh Assefa,1989 as cited in Habtamu Solomon, 2010).

The Tertiary Ethiopian volcanism occurred in three main stages. These are; the pre-Oligocene stage (Ashagi formation), the Oligocene-Miocene stage (Aiba, Alaji and Tarmaber formations) and the Miocene- Pliocene stage (Fursa, Balchi and Bishoftu formations) (Zanettin, B, B. and Justin, V.E. (1974), as cited in Zeleke Tadesse, 2013).

According to Kazmin (1979, as cited in GSE, 1996), early volcanic events gave Ashangi basalts and initial opening of the southern red sea from east-west trending extensional fractures. The second cycle gave Aiba basalts. Alaji basalts being the third volcanic activity are related to rifting in the red sea and Gulf of Aden.

Extensive areas of the highlands of Ethiopia on both sides of the rift valley are covered by Tertiary (Trap series) volcanic rocks which are mainly basalts with subordinate acidic rocks. In the rift valley, subsequent to the formation of the rift valley, the Trap series were overlain by a variety of younger volcanic rocks of basalts, ignimbrites and rhyolites. (Tesfaye Chernet, 1988 as cited in Tamiru Alemayeyu et al., 2006).

### 3.5 Geology of Addis Ababa

Because of its location at the western margin of the Main Ethiopian Rift (MER), the geological history of the studied area is an integral part of the evolution and development of the Ethiopian Plateau and the Rift system. The area is covered by different volcanic rocks with both acidic and basic compositions and overlain by fluvial and residual soils varying in thickness from a few cm to about several meters in which black cotton soil is the predominant type (Morton, 1979). The geology of Addis Ababa compiled by Haileselassie Girmay and Getaneh Assefa (1989, as cited in Habtamu Solomon, 2010), Assegid Getahun (2007), Efrem Beshawered (2009) and WWDSE (2008) comprises Tarmaber basalts, Intoto silicics, Wachecha Trachyte, Addis Ababa basalts, Nazaret group (Addis Ababa Ignimbrite), and Akaki (Bofa) basalts. These are briefly discussed in the following sections. The geological map of the study area is given in Fig.3.4.

#### 3.5.1 Tarmaber Basalts

This unit is found in the northern portion of the city. It is dark grey in fresh samples, but reddish brown in weathered specimens. It is fine-grained volcanic rock composed of plagioclase, pyroxene, and opaque minerals (WWDSE, 2008 as cited in Lamesgen,2014).

### 3.5.2 Intoto Silicics (Intoto Formation)

The unit is unconformably overlain by Addis Ababa basalt on the foothills of Entoto and is composed of rhyolites and trachytes with minor amount of welded tuff and obsidian. The rhyolitic lava flows outcrop on the top and the foothills of the Entoto ridge, predominantly in the western side. It also outcrops in the eastern part of the town around Kokebe Tsebah School. The thickness is quite variable as it frequently forms dome structure. The thickness becomes maximum on the top of Intoto ridge and thin both towards the plateau and the plain east of Addis Ababa. (Hailesellase Girmay and Getaneh Asefa, 1989 as cited in Habtamu Solomon, 2010). The rhyolites are overlain by porphyritic trachytes and underlain by a sequence of tuffs and Ignimbrites. Tuffs and Ignimbrites are welded and characterized by columnar jointing. The trachytic lava flows outcrop on the top of Entoto Ridge and its foothills. The trachyte and the alaji aphanitic basalts are separated by paleosoil indicating time gap.

### 3.5.3 Wachecha Trachyte

This unit mainly covers relatively elevated areas of the study area. Volcanic mountains such as Wachecha in southwest, Furi in southern part and Yerer in Southeastern part of Addis Ababa are mainly trachyte in composition (Kebede Tsehayu et al., 1990). According to Efrem Beshawered (2009), this unit is composed of trachyte and pyroclastic material. It is light to dark grey, aphanitic to medium grained in texture with vesicular varieties mostly at its lower part. At some places it shows layering and its base is dominated by trachy basalt to basalt rock type (Assegid Getahun, 2007 as cited in Lamesgen Melse,2014).

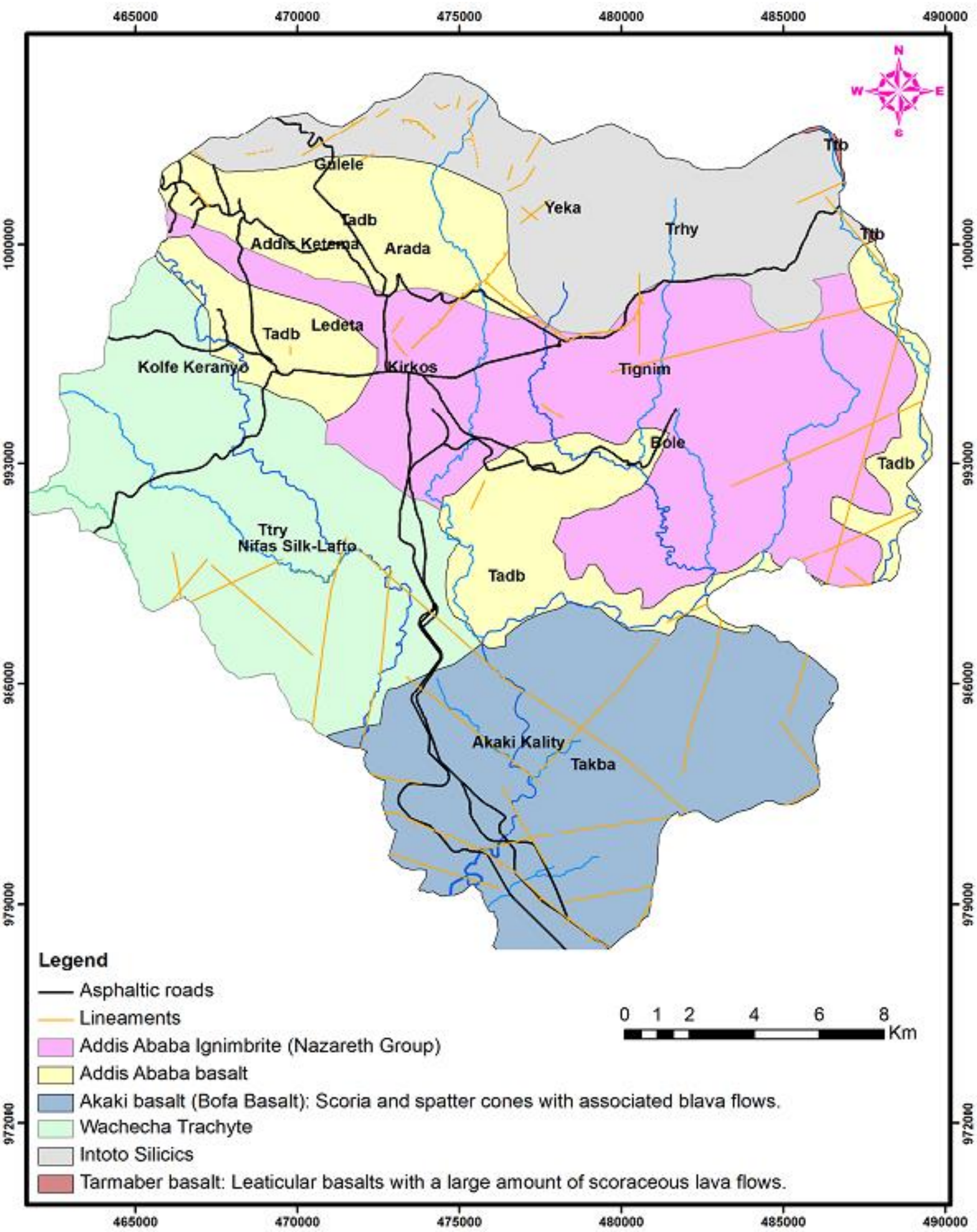



Fig.3.4 Geological Map of Addis Ababa (after WWDSE. 2008)

### 3.5.4 Addis Ababa Basalt

This unit, which is mainly present in the central part of the town, is underlain by the Entoto silicics and overlain by Lower Welded Tuff of the Nazaret group. The maximum thickness exceeding 130 m was found at ketchene stream. Olivine porphyritic basalts outcrop in the central part of the town that includes Mercato, Teklehaymanote and Sidist Kilo. The distribution of plagioclase porphyritic basalt is almost the same as that of the olivine prophyritic basalt.

It outcrops in an area, which includes Sidist Kilo, General Winget School and French Embassy. The Lower Welded Tuff overlies both types of basalt nearby the Building College, the Kolfe Police School, the Kokobe Tseba School and YekaMariam Church (Hailesellase Girmay and Getaneh Asefa, 1989 as cited in Habtamu Solomon, 2010).

### 3.5.5 Nazareth Group (Addis Ababa Ignimbrite)

The lithological units identified in this group are lower welded tuff, aphanitic basalt and upper welded tuff. The group is underlain by Addis Ababa basalt and overlain by Bofa basalts. The rocks outcrop mainly south of Filwoha fault and extended towards Nazareth. (Hailesellase Girmay and Getaneh Asefa, 1989 as cited in Lamesgen Melses, 2014).

Lower welded tuff outcrops as small discontinuous body in Filwoha, western parts of Addis Ababa and Sululta. Generally, it is overlain by the aphanitic basalt and underlain by the olivine and plagioclase porphyritic basalt. The age of this unit overlaps with the period of the activity of wechecha trachyte volcanoes. Aphanitic basalt covers the southern part of the city, especially the area of Bole International Airport and Lideta Old Airfield. The rock body shows vertical curved columnar jointing together with sub-horizonal sheet jointing. Along the course of Akaki River large amygdales of calcite occur in this basalt. Kaolinite lenses are present at the contact with the younger ignimbrite. Upper welded tuff outcrops all over the southern part of the city including Bole, Nefas Silk and Railway Station; nevertheless, it is also present in the central and northern part of the city. It is gray colored, vertically and horizontally jointed and composed of sanidine, anortoclase, rebekite, quartz, pumice and unidentified volcanic fragments (Hailesellasie Girmay and Getaneh assefa, 1989 as cited in Lamesgen Melese,2014). The welded tuff is underlain by aphanitic basalt and overlain by young olivine basalts.

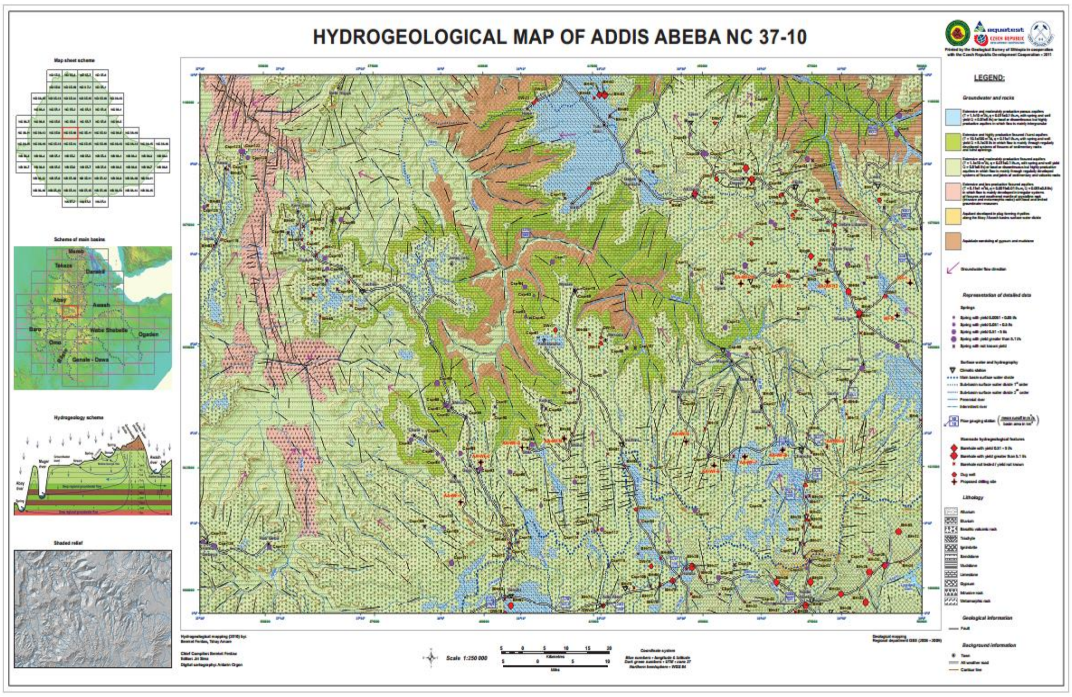
### 3.5.6 Bofa Basalt (Akaki Basalt)

Bofa Basalts outcrop southward from Akaki River where they appear in the form of boulders reaching a thickness of 10 meters. They are restricted and dominated in the southeastern part of the city. This rock is characterized by big vesicles that are filled by calcite. This basalt is underlain by the tuffs which cover the welded tuff (Hailesellasie Girmay and Getaneh assefa, 1989 as cited in Habtamu Solomon,2010). It is coarse grained porphyritic olivine basalt. It is highly vesicular basalt and at places the vesicles were filled by carbonate minerals. It is consisting of scoria and spatter cones with associated lava flows (WWDSE, 2008 as cited in Lamesgen Melese, 2014).

## 3.6 Hydrogeology

According to a study conducted by Tamiru Alemayehu et al. (2006), the major ground water aquifers in Addis Ababa are basalts, rhyolities, trachytes, scoria, trachy basalts, welded tuffs, unwelded tuffs and the unconsolidated materials of volcanic origin. The main aquifers in Addis Ababa area can be categorized in to three groups which include shallow aquifers of the weathered volcanic rocks and alluvial sediments along the river courses, deep aquifers of the fractured volcanic rocks that tap fresh ground water and thermal aquifers along Filwoha fault (Kebede Tsehayu et al. 1990).

Most of the aquifers are confined below the clay (paleosoil) and hence storage coefficient is very low (Kebede Tsehayu et al. 1990). Avery shallow ground water occurrence is revealed at the depressed area of around Filwoha, Ghihon Hotel, Stadium and Legehar (Kebede Tsehayu et al. 1990). The dug wells in the Filwoha area tap ground water from a depth of 12-18m under confined condition (Kebede Tsehayu et al. 1990).



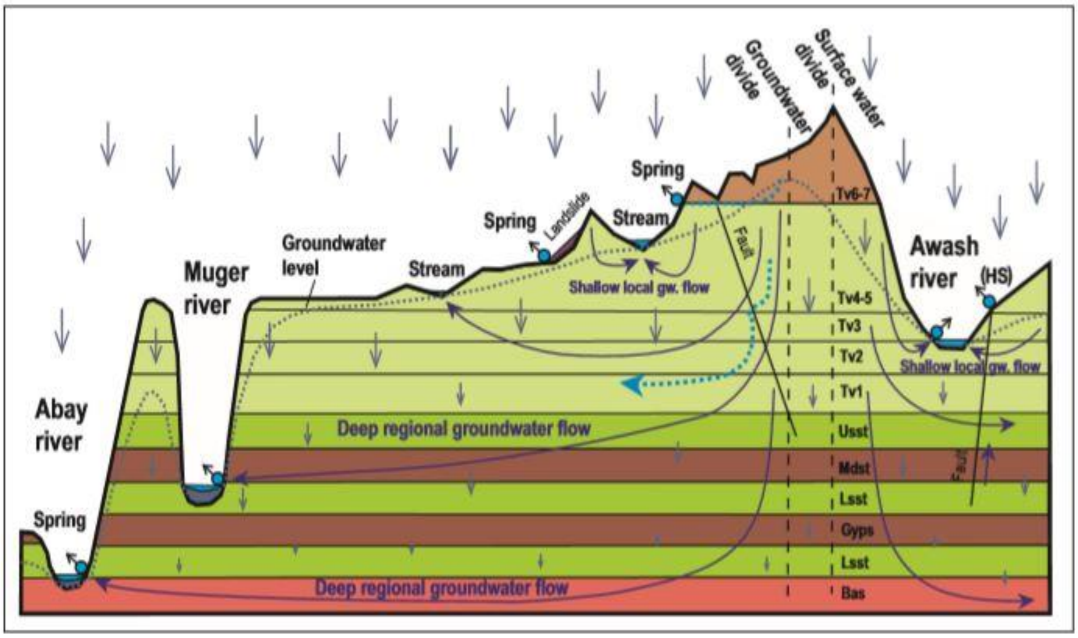




Fig.3.5 Hydrogeological map and Conceptual hydrogeological model of Addis Ababa area (GSE,2011)

### 3.7 Soil classification

The soil development in Addis Ababa area is mostly due to the physical disintegration and chemical decomposition of volcanic rocks. The weathering products are either remaining in places and form residual soils or transported and deposited in the low lying flat lands and depressions (Tamiru Alemayehu et al, 2006). The differences observed in the type and development of soils in the city depends mostly on the topography, parent rock and the degree of weathering. Although there is significant difference in the degree of weathering on the slopes, mostly soils are highly eroded and result in thin soil cover. The parent materials of expansive soils may be classified into two groups (Chen, 1975, as cited in Alemayehu and Solomon, 1986). The first group comprises of basic igneous rocks. Here feldspar and pyroxene minerals of the parent rocks decompose to form montmorillonite the predominant mineral of expansive soil and other secondary minerals. The second group comprises of sedimentary rocks that contain montmorillonite. The expansive soils of Ethiopia are derived from both groups.

The soil units of Addis Ababa are classified as alluvial, alluvial fan, colluvial, residual and lacustrine soils based on their origin (Kebede Tsehayu and Tadese Hailemariam, 1990) (Fig.3.6).

The alluvial soils which include channel and terrace deposits are found in some places along Akaki River in the west and southwestern parts of Addis Ababa and along Kebena River north of Bole area. The alluvial soils consist of more or less stratified deposits of gravel and clay transported by streams. The study indicated that sample taken from terrace deposits near Bole consists >80% fine and 20% sand and classified as ML in USCS system.

Alluvial fan is deposited where there is a decrease in gradient from a hill to a plain along a river section. It is coarser near the mouth of the river and become finer outwards and found in the Intoto region dissected by deep gullies (Kebede Tsehayu and Tadese Hailemariam, 1990).

Residual soils developed in situ by the decomposition of rocks are mainly located in Gulele and Kolfe area and consist of 62% clay, 33% silt and 5% sand (Kebede Tsehayu and Tadese Hailemariam,1990).

Bole and Mekanisa area consist of 76% clay, 22% silt and 2% and MH (rarely CH) according to USCS (Kebede Tsehayu and Tadese Hailemariam, 1990).

Low lying areas of Addis Ababa are dominated by black cotton soils. These soils have extremely high plasticity and very high degree of swelling as compared to the other identified soil types found in Addis Ababa (Kebede Tsehayu and Tadese Hailemariam, 1990).

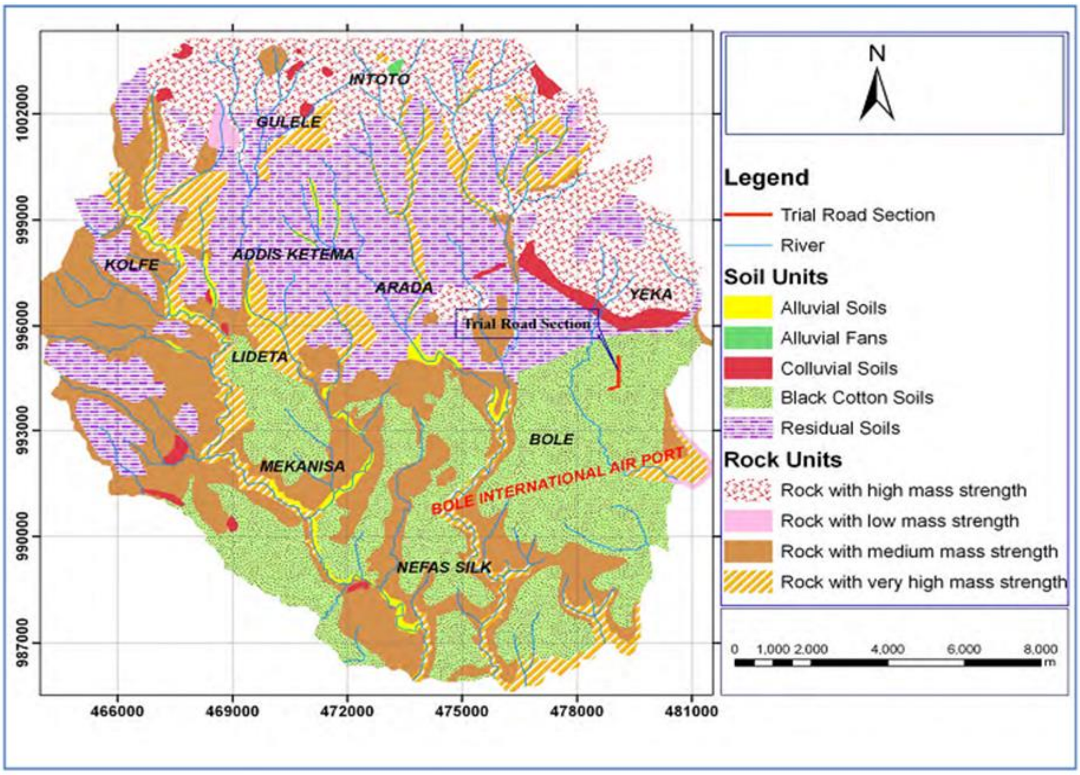



Fig 3.6. Engineering Geological Map of Addis Ababa (Kebede Tsehayu and Tadese Hailemariam, 1990)

In areas where there is great contrast in the topography colluvial soils are found. These are loos and incoherent deposits, consisting of fine to coarse grain particles.

Colluvial soils are mainly located at the foot slopes of northeastern part of Entoto silicics and other few places (Kebede Tsehayu and Tadese Hailemariam, 1990).

According to Kebede Tsehayu and Tadese Hailemariam (1990), in localities where the topography is relatively gentle, there is thick soil profile.

The thickness of black cotton soil around Bole varies from 2m to 10m. While, at Gabriel Meda and Beklo Bet the thickness is 10m and 5m sequentially. In some localities reddish brown soil with a thickness of more than 10 meter is commonly seen. According to Lamesgen (2014) of bed rock topography, the thickness of total soil profile reaches up to 45m in northern part of Nifas Silk lafto sub city (Fig 3.7).

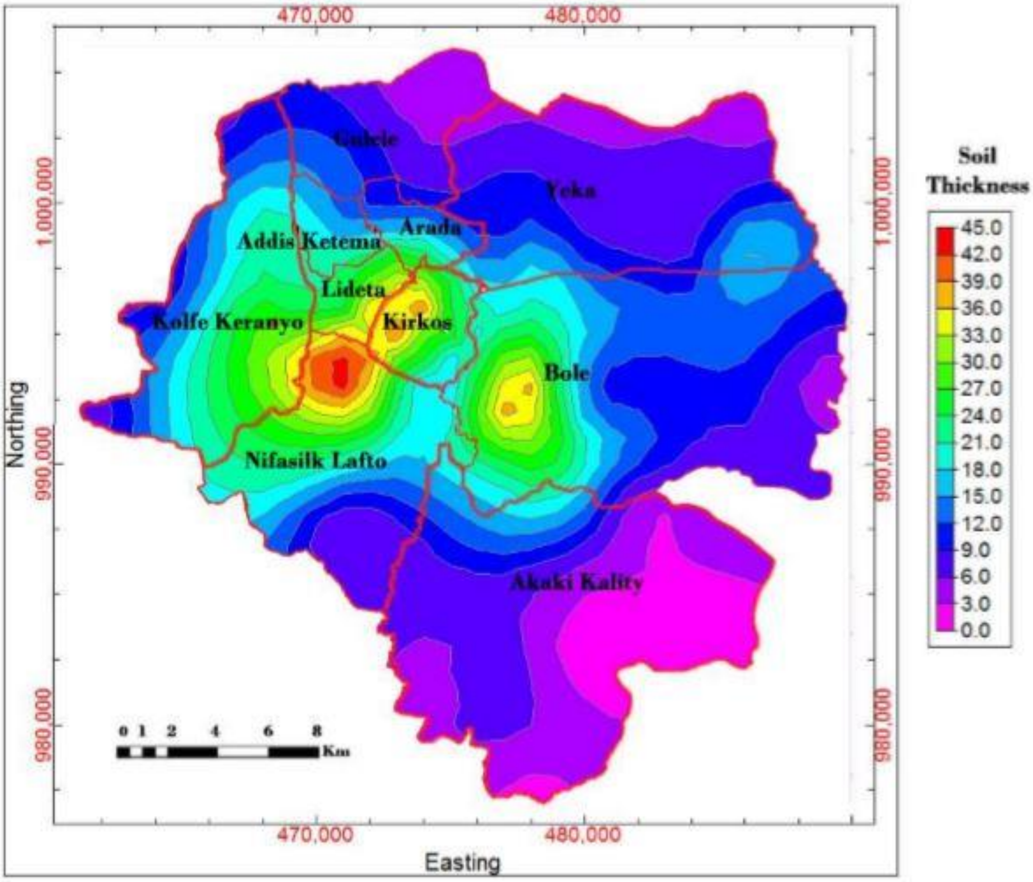



Figure .3.7. Soil thickness map of Addis Ababa (Lamesgin, 2014)

# CHAPTER 4 METHODOLOGY

The methodology followed to produce the susceptibility map to the phenomenon of shrinkage-swelling concerns the lithological nature of the outcropping to sub-surface formations, the mineralogy of the clay and the geotechnical behavior of soil. The above three criteria have been directly taken in to account. Finally, the shrink swell susceptibility map has been delineated with the help of ArcGIS, DEM, IDW and strater demo software.

- Arc GIS; is a geographical information system (GIS) software that allows handling and analyzing geographic information by visualizing geographical statistics through layer building maps like climate data or trade flows.

- DEM (Digital Elevation Model with 30m x30m resolution Source: Shuttle Radar Topography Mission (SRTM); the land use land cover of the area is prepared by using satellite image, Google earth image and through field observations.
- Local IDW (inverse distance weighted); the inverse distance weighted is an interpolation method based on the distance among the measured points. IDW predict the unknown value based on the neighborhood measured values and the weight is a function of inverse distance or the influence of measured value decrease with increase of distance. IDW interpolation technique can be used when variables depend on the location.

  The Inverse Distance Weighting interpolator assumes that each input point has a local influence that diminishes with distance. It weights the points closer to the processing cell greater than those further away. A specified number of points, or all points within a specified radius can be used to determine the output value of each location. Use of this method assumes the variable being mapped decreases in influence with distance from its sampled location. Has the following drawback Cannot estimate above maximum or below minimum values, and not good for peaks or mountainous areas.
- Strater Demo 4 soft wares; Strater is a powerful and innovative well log, borehole and cross section plotting software. The software sometimes pinches out the formation which could not represent subsurface formation.

Hydrogeological, topography, vegetation or type of foundation of the building, has not been considered since these could be very local. Therefore; cannot be mapped at the desired level.

**4.1. Lithological criteria**

The clay fraction and thickness of volume changing soil is the main parameter to be considered in the susceptibility to shrink swell phenomena. The fraction of clay varies from one area to another which have strong relationship with degree of expansiveness (fig. 4.1a and b). As clay fraction becomes dominant potential expansiveness increases. The thickness of the formation also comes into line of account, since the thin clay formations have a less shrinkage or swelling potential than thick formation (BRGM,2009) (table.4.1).
Table 4.1. Conventional scale used to distinguish the different lithological classes.

| Type of formation | Susceptibility | Rating |
|---|---|---|
| Non clay/silt formations | Low | 1 |
| Formations with dominant non clay/silt but with clay/silt intercalated | Average | 2 |
| Formation dominantly clay/silt with thickness < 3m | High | 3 |
| Formation with dominantly clay/silt, with thickness >3m | Very high | 4 |

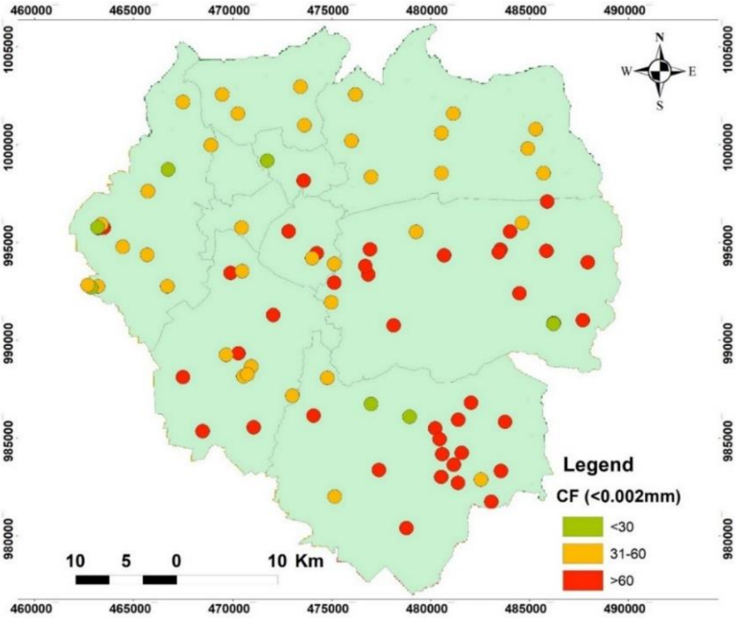



Fig.4.1a. Point distribution of clay fraction across the study area

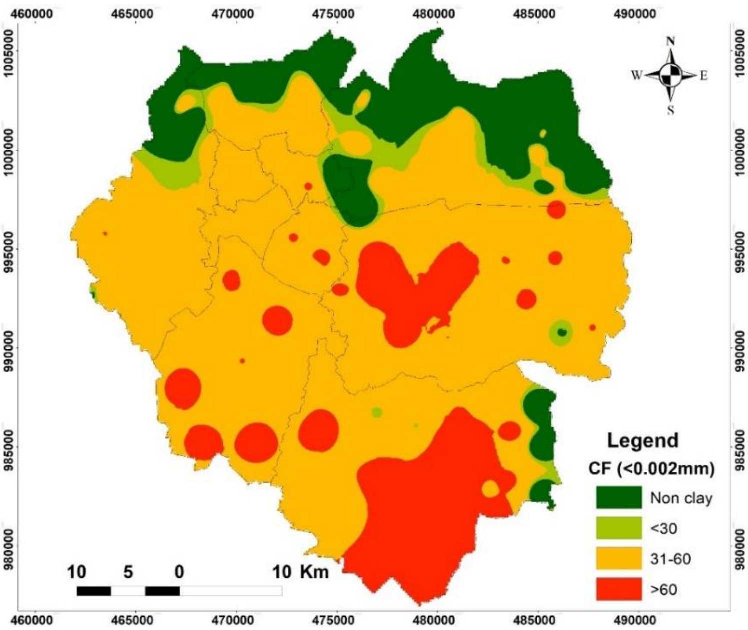



Fig 4.1b. IDW interpolation for all samples using clay fraction at each sample location of Addis Ababa.

**Cross section**

In this study different strati-graphic cross sections in different sub cities has been selected along bore holes and test pits mainly to over view the thickness of expansive soil profile for rating according to their thickness fig 4.2. But, the strater demo software of cross section plotting sometimes pinch out the formation, which is the drawback of the software.

Soil cross sections have been taken by connecting bore holes and test pits across the research area. Total of 3 cross sections have been taken. These sections are selected in a way that could help to see the variation of soil layers and thickness.

The study area is characterized by different formations with different thickness. Thus, area with formation of dominantly clay/silt, with thickness >3m has been rated 4, area with formation of dominantly clay/silt with thickness < 3m has been rated 3, area with formations of dominantly non clay/silt but with clay/silt intercalated has been rated 2 and area with non-clay/silt formations has been rated 1.

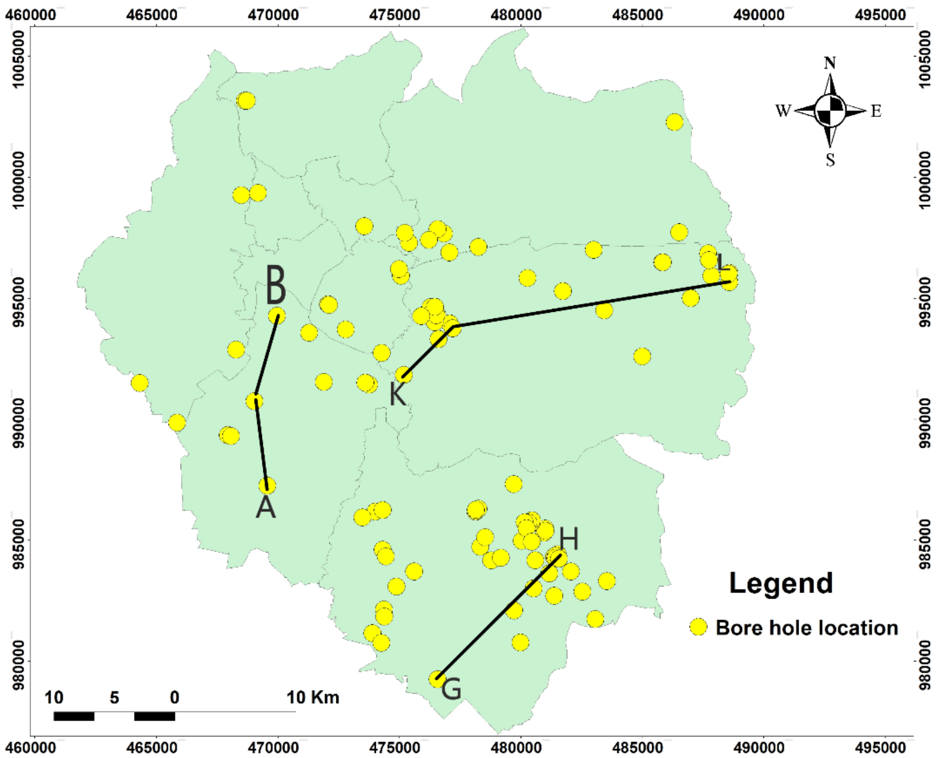



Fig 4.2. Distribution of bore hole data (BH) collected and Cross-section profile layout across Addis Ababa

**Section A - B (S1, S2, S3)**

The first layer along this section is dark highly plastic silty CLAY (black cotton) soil with a thickness of 4.5m,4m and 1.5m in S3, S1, S2 respectively. The other layers are seen in cross section mapped as represented on the legend. On the basis of cross-section, (figure 4.2.1). The formations have been classified and rated to different classes. Accordingly, formation with expansive soil thickness of 4.5m and 4m has been rated 4, while formation with thickness of 1.5m has been rated 3.

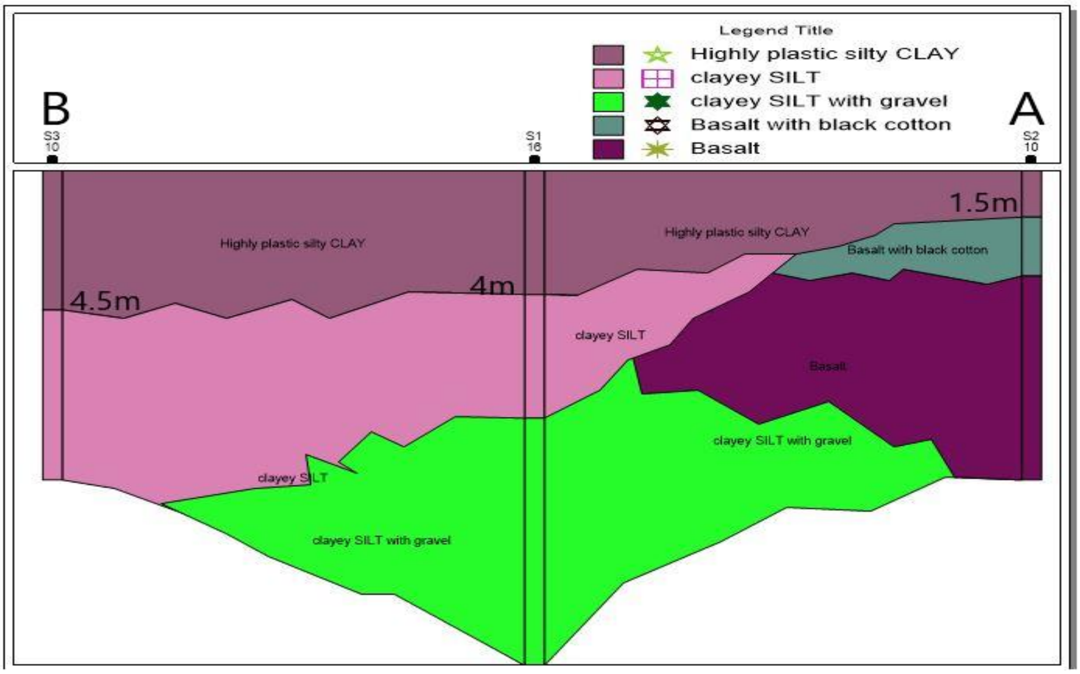



Fig 4.2.1. Geotechnical cross-section A-B

**Section G-H (S1, S2)**

The first layer along this section is dark highly plastic silty CLAY (black cotton) soil with a thickness of 8m and 1.5m in S1, S2 respectively and stiff grayish silty CLAY with the thickness of 7m in S3. The other layers are seen in cross section mapped as represented on the legend. On the basis of cross-section, (figure 4.2.2) the formations has been classified and rated to different classes. Accordingly, formation with expansive soil thickness of 8m and 4m has been rated 4, while formation with thickness of 7m, but stiff silty CLAY has been rated 3.

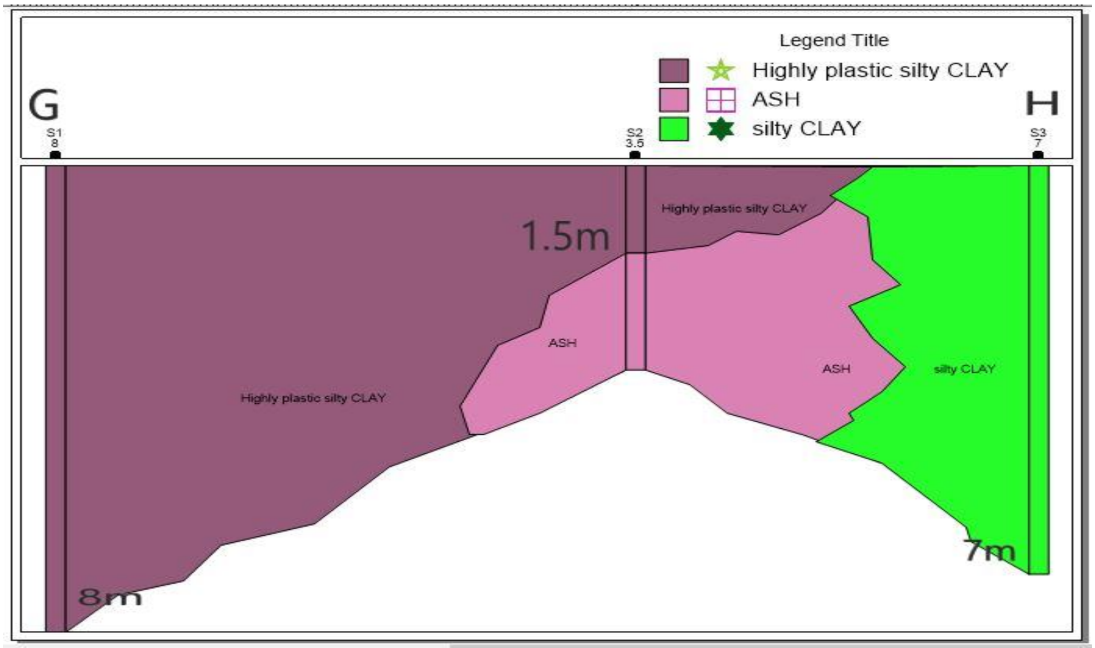



Fig 4.2.2. Geotechnical cross-section G-H

**Section K - L (S1, S2, S3, S4)**

The first layer along this section is dark highly plastic silty CLAY (black cotton) soil with a thickness of 2m, 2.4m, and 2m in S1, S2 and S3 respectively. The other layers are seen in cross section mapped as represented on the legend.

On the basis of cross-section, (figure 4.2.3) the formations has been classified and rated to different classes. Accordingly, formation with expansive soil thickness of 2.4m and 2m has been rated 3.

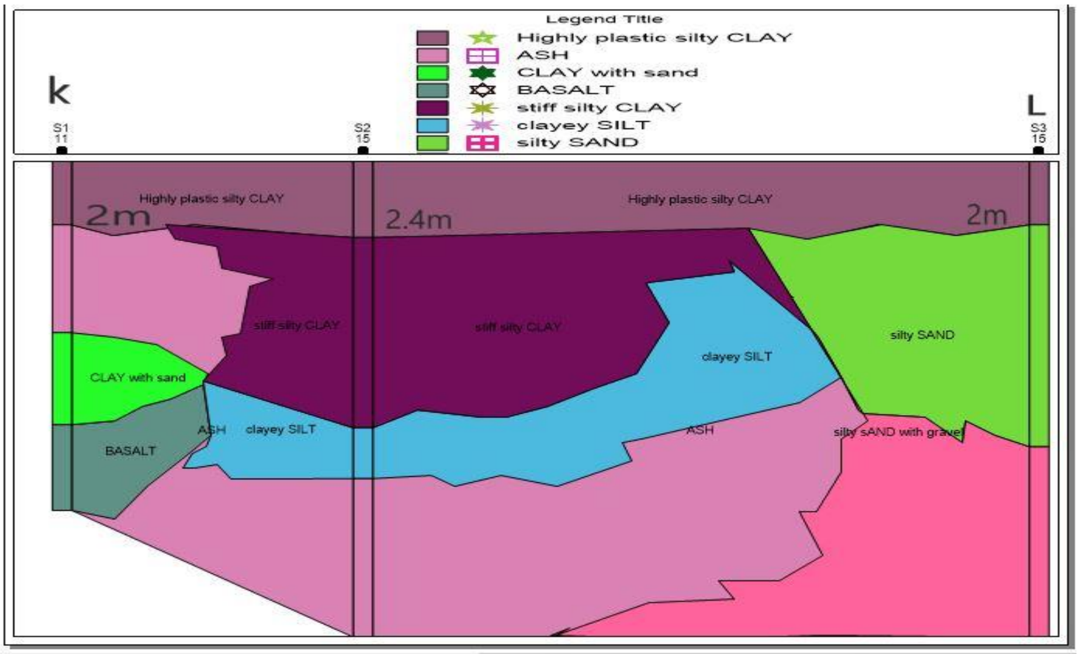



Fig 4.2.3. Geotechnical cross-section K-L

Lithological map has been produced based on cconventional scale used to distinguish the different lithological classes (BRGM,2009) (Fig. 4.1b).

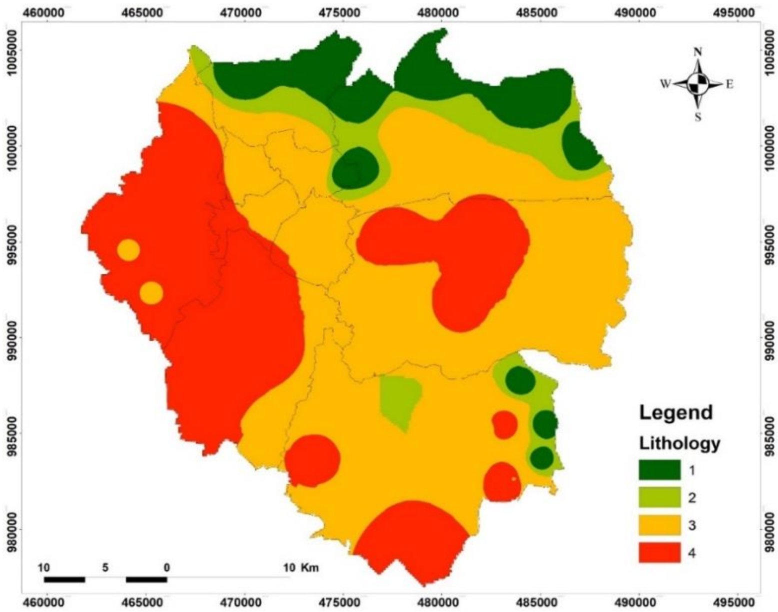



Fig 4.3. IDW interpolated lithological map of study area

**4.2 Mineralogical Criteria**

The shrinking-swelling phenomena are preferentially expressed in the presence of percentage (%) of clay minerals belonging to the smectite group (montmorillonite, beidellite, nontronite, saponite, hectorite, sauconite) and, to a lesser extent, to the group of interstratified, more or less regular alternation of sheets of different natures, by example smectites / illite or illite / smectites.

**4. 2.1 Mineralogical characterization**

Very little information has been published in certain area on the percentage of clay mineralogy or chemistry of Addis Ababa soil. The mineralogical composition of Addis Ababa soil varies from one place to another.

Some clay mineralogy percentage (%) identified by XRD and DTA analysis by different researchers has been used directly. While, the rest of swelling mineral percentage (%) were indirectly interpreted from activity chart of Skempton, (1953) table.4.2. Accordingly, map has been produced.

Table 4.2. Conventional scale for activity

| Activity (Skempton,1953) | Rating |
|---|---|
| <0.33 | 1 |
| 0.33 – 0.46 | 2 |
| 0.46 – 0.9 | 3 |
| >0.9 | 4 |

Susceptibility map based on clay mineralogy has been produced based on above table as follows;

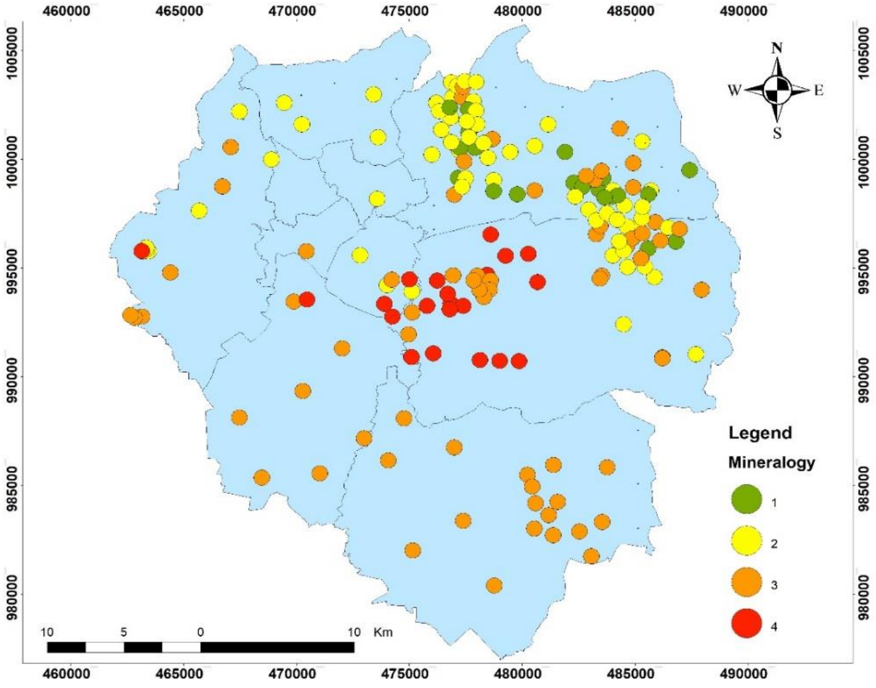



Fig 4.4a. Point distribution of mineralogical data across Addis Ababa

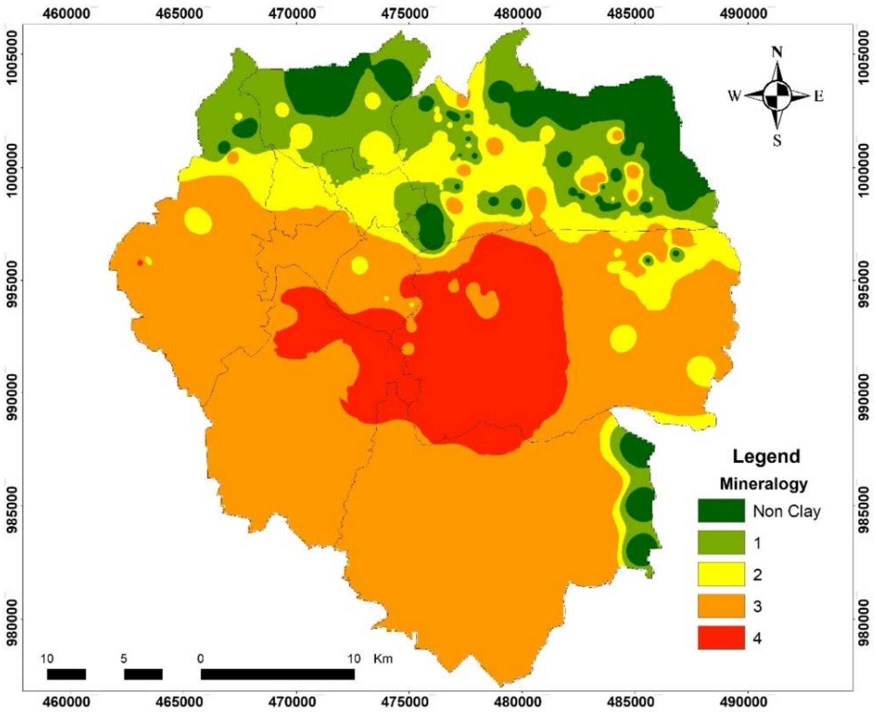


Fig 4.4b. IDW interpolation for all samples using mineralogical at each sample location of Addis Ababa.

**4. 3 Geotechnical criteria**

This criterion makes it possible to integrate geotechnical behavior of material with the susceptibility to shrink-swell phenomena.

There are indirect (index properties) analysis and direct identification methods, which involves the use consolidation apparatus or odometer to determine the swelling potential and / or pressure of expansive clay.

The choice and description of different geotechnical tests used to define this criterion are presented in the following paragraphs, as well as the threshold values used for the determination of the geotechnical grade.

**4. 3.1 Geotechnical characterization**

The main tests whose results have been used here to characterize the geotechnical behavior of the material with the phenomenon of shrink-swell are plasticity index and free swell table (4.3a and 4.3b).

Table 4.3a. Conventional scale used to distinguish the different plasticity index classes

| Classification of potential swell | Plasticity(%)(BRGM), 2009) | Rating |
|---|---|---|
| Low | <12 | 1 |
| Medium | 12-25 | 2 |
| High | 25-40 | 3 |
| Very high | >40 | 4 |

Accordingly, map has been produced based on plasticity index across the study area as follows:

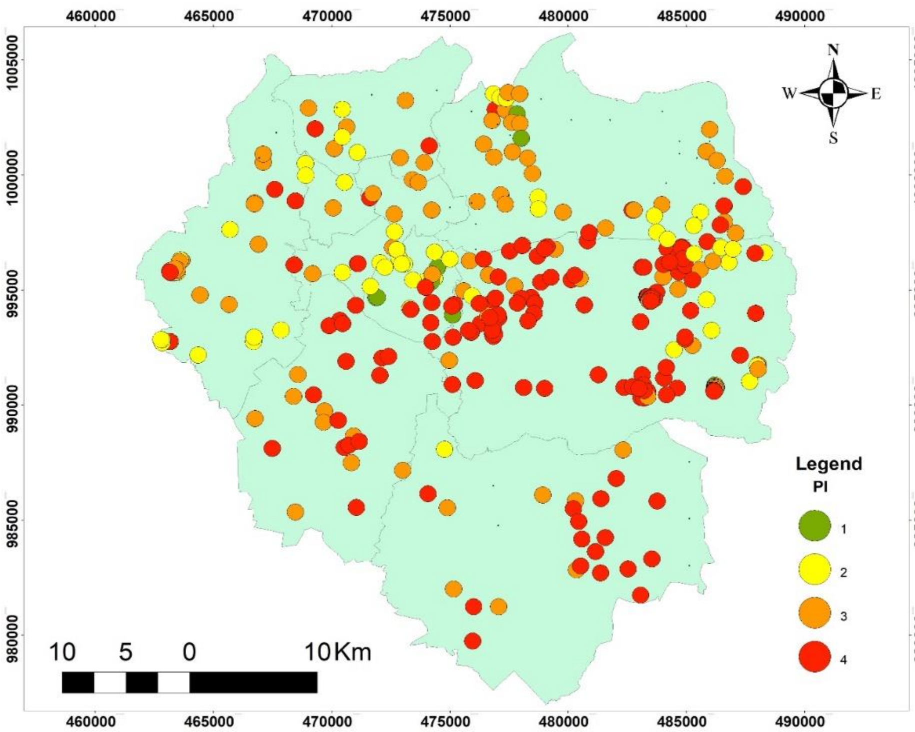



Fig 4.5a. Point distribution of plasticity index data across Addis Ababa

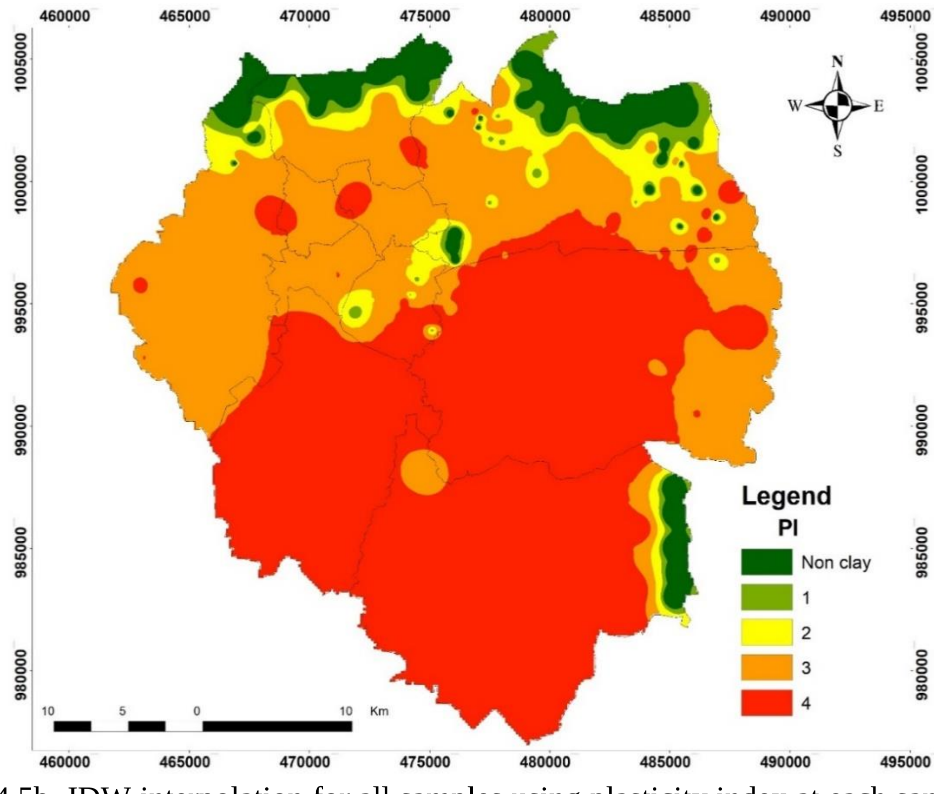



Fig 4.5b. IDW interpolation for all samples using plasticity index at each sample location of Addis Ababa

Table 4.3b. Conventional scale used to distinguish the different free swell classes

| Swell potential | FS value (%)(Holtz and Gibbs,1956) | Rating |
|---|---|---|
| Low | <50 | 1 |
| Medium | 50 – 100 | 2 |
| High | 100 – 200 | 3 |
| Very high | >200 | 4 |

Accordingly, map has been produced based on free swell across the study area as follows:

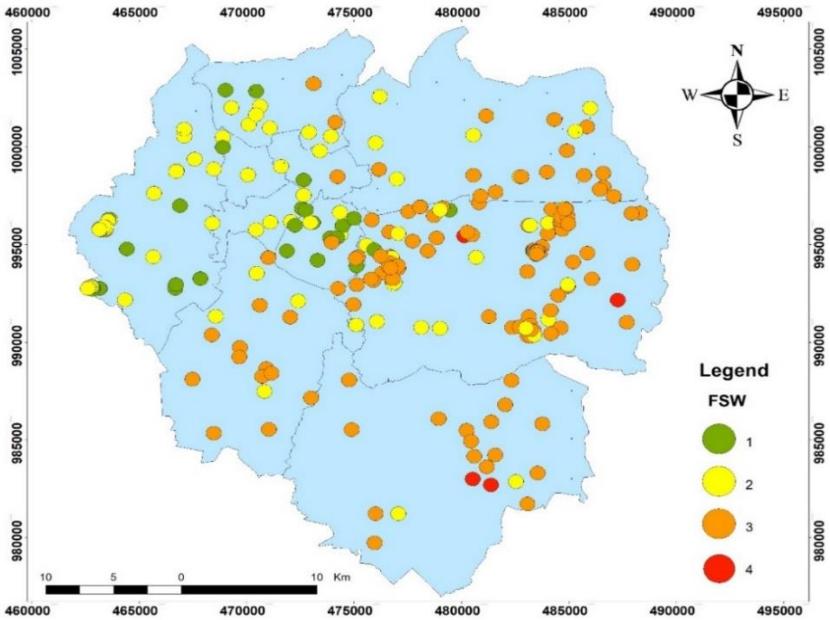



Fig 4.6a. Point distribution of free swell data across Addis Ababa

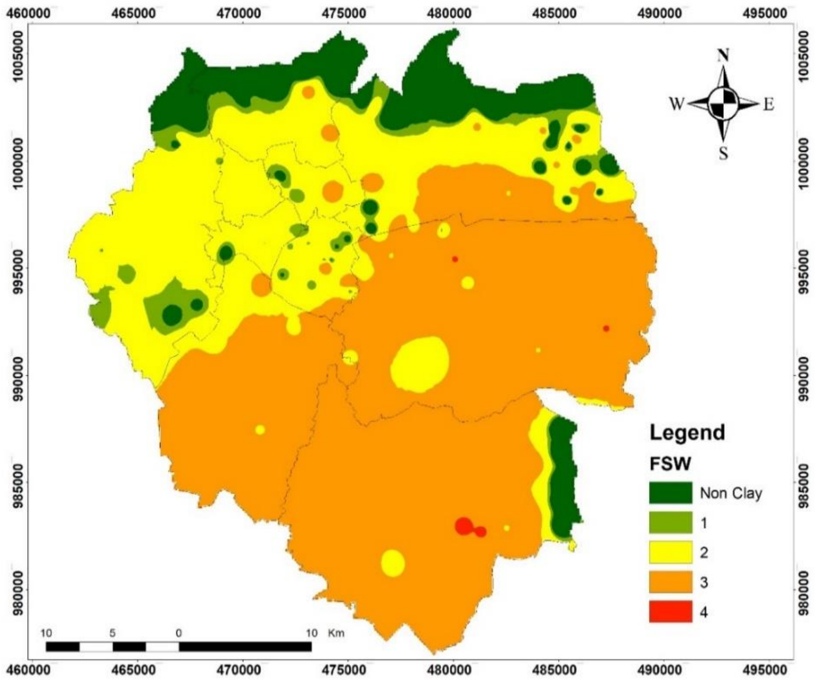



Fig 4.6b. IDW interpolation for all samples using free swell at each sample location of Addis Ababa

### 4.4 Collected data

Data has been collected for this study from various sources. Tests conducted by different companies depend on their project objective, but essential data which is helpful for this study has been collected and classified as per their importance.

In addition, a certain amount of data comes directly from ongoing projects like bulk excavation, test pits, road project in the study area. Accordingly;

- For the plasticity index, 412 data have been utilized
- For the liquid limit, 390 data have been utilized
- For the free swell, 271 data have been utilized
- For the one dimensional swelling pressure, 78 data have been utilized
- For the clay fraction and activity, 94 data have been utilized and
- For mineralogy, 180 data have been utilized
- 108 test pits and bore hole data have been utilized

The collected data have been and presented on map as follows;

Liquid limit data across the city are classified based on (Holtz and Gibbs, 1956) (Fig.18a)

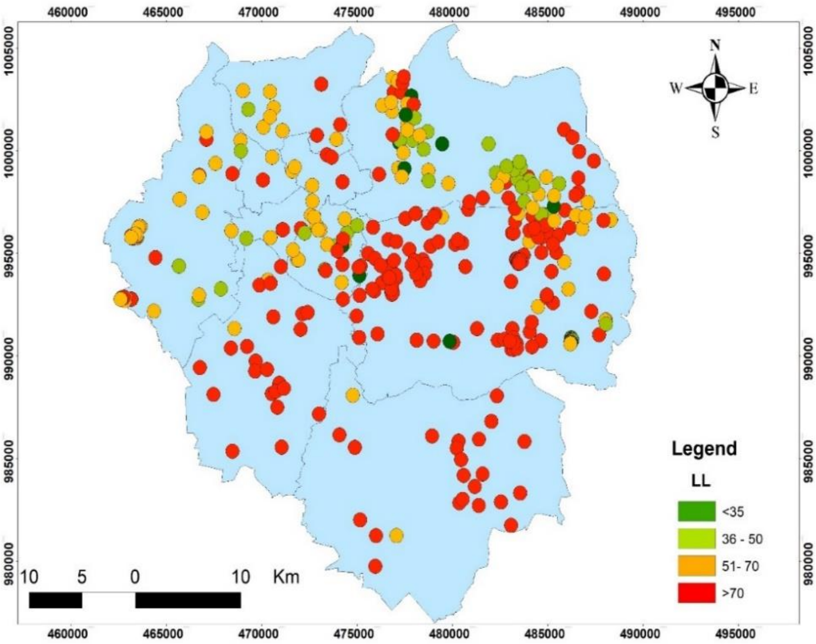



Fig. 4.7.1 Distribution of Liquid limit data (LL) across Addis Ababa.

**Direct identification method**

Direct identification method is accurate technique which involves the use consolidation apparatus or odometer to determine the swelling potential and the swelling pressure of expansive clay. The swelling pressure of soil across the study area is classified in to four categories possessing the following swelling pressure in kpa (table.4.4). Map has been produced depending on swelling pressure (Kpa) they possess.

Table 4.4. Expansive soil classification based on swelling pressure

| Swelling pressure (Kpa) | Susceptibility | Rating |
|---|---|---|
| <50 | Low | 1 |
| 50 – 150 | Medium | 2 |
| 150 -250 | High | 3 |
| >250 | Very high | 4 |

Swelling pressure data across the city are classified and presented on (Fig.4.7.2).

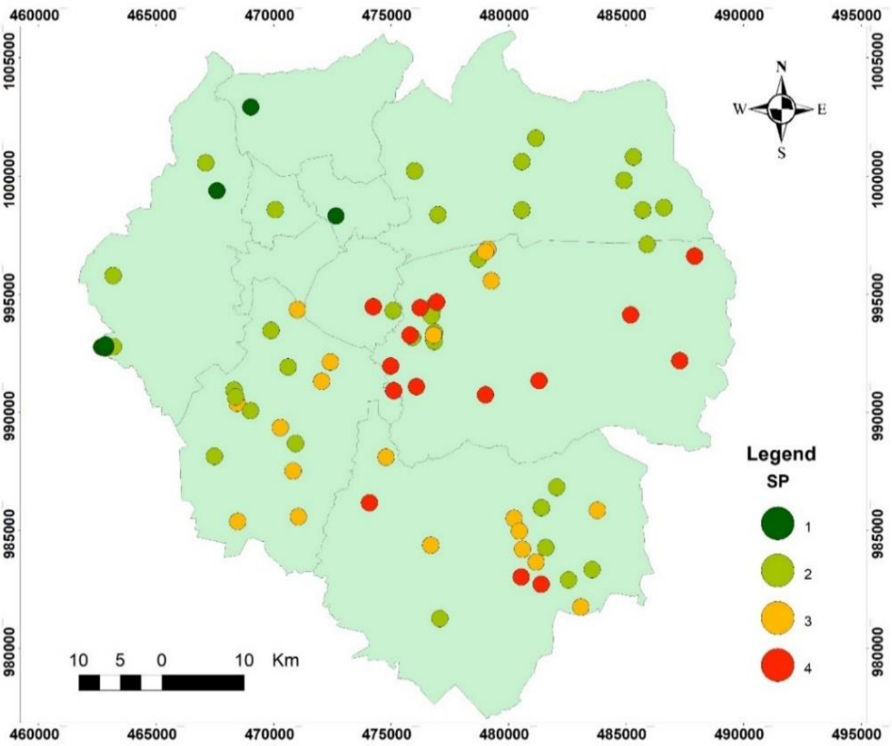



Fig.4.7.2. Distribution of Swelling pressure data (SP) across Addis Ababa

The northern, north western, and north eastern part of the city shows less while southern, south western and south eastern part shows very high to extremely high swelling pressure. Activity data across the city are calculated and classified based on Skempton, (1953). (Fig.4.7.3).

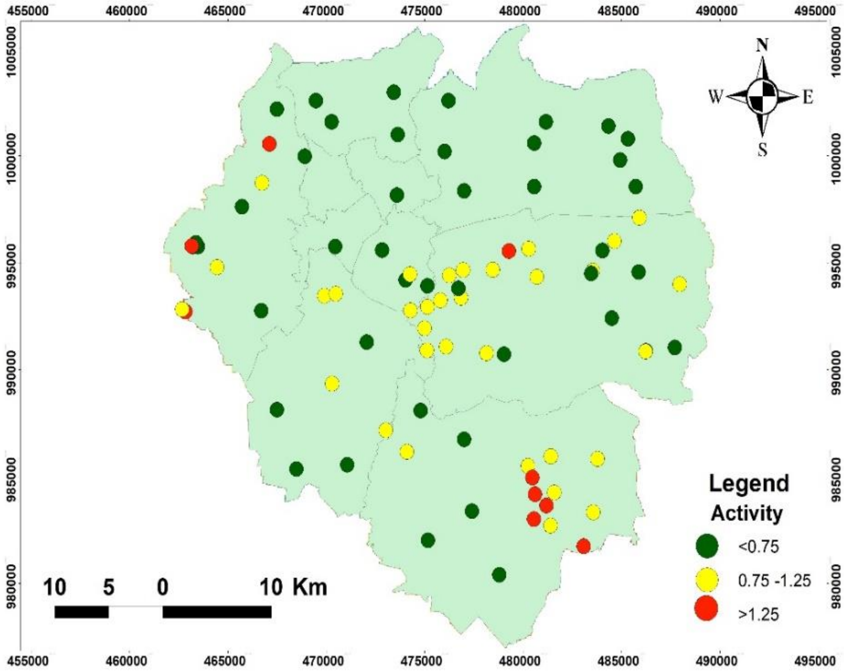


Fig.4.7.3. Distribution of calculated activity across Addis Ababa

**4. 5 Scatter Plot and Best-Fit Curve**

The MS excel spread sheet is found to be the most powerful and manageable tool for scatter plot analysis and determination of correlation between two variables. Correlation measures the linear relationship between two variables. By measuring and relating the variance of each variable, correlation gives an indication of strength of the relationship. The properties of soil which were used for identification and classification was swelling pressure (Kpa), plasticity index, free swell, liquid limit and clay fraction. Accordingly, these collected test results from study area have a direct proportional to each other as illustrated in following charts.

**4. 5. 1 Swelling Pressure Vs Plasticity Index**

The relationship between the swelling pressure and the plasticity index for all of the tested samples. The best fitting trend line for this relationship is SP = 3.2461* PI 0.7132. The strength of this equation in predicting an outcome from the plastic index is around 31.3 % or has $R^2$ = 0.313

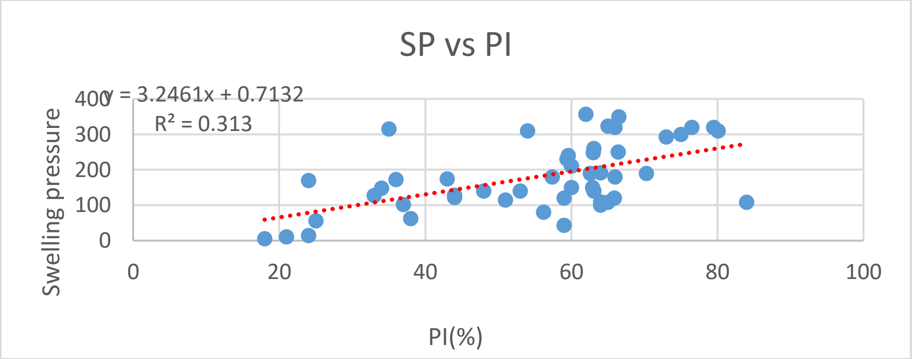


Figure 4.8a. Swelling pressure Vs Plasticity index

The swelling Pressure and the Plasticity index of the study area shows that; points are widely scattered from the trend line. This indicate that their relationship is directly proportional, but are weak due being scattered. This shows that the determination of the Plasticity Index alone cannot satisfactorily indicate the swelling behavior of the soil of the study area.

**4. 5.2 Plasticity index Vs Free swell**

The relationship between the free swell and the plasticity index for all of the tested samples is shown in Figure 4.8b. The best fitting trend line for this relationship is FS = 2.0875* PI18.865. The strength of this equation in predicting an outcome from the free swell is around 28.37 % or has $R^2$ = 0.2837

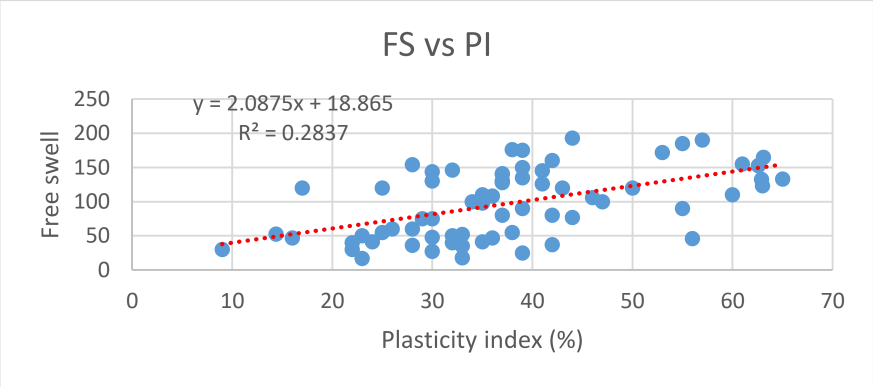



Figure 4.8b. Free swell Vs Plasticity index

The free swell and the Plasticity index of the study area shows that; points are widely scattered points from the trend line. This indicate that the relationship is directly proportional but weak. This shows that the determination of the free swell alone cannot satisfactorily indicate the swelling behavior of the soil of the study area.

**4. 5. 3 Clay fraction Vs Free swell**

The relationship between the clay fraction and the free swell for the tested samples is shown in Figure 4.8c. The best fitting trend line for this relationship is CF = 0.2135* FSW 27.049. The strength of this equation in predicting an outcome from the free swell is around 55.94 % or has $R^2$ = 0.5594

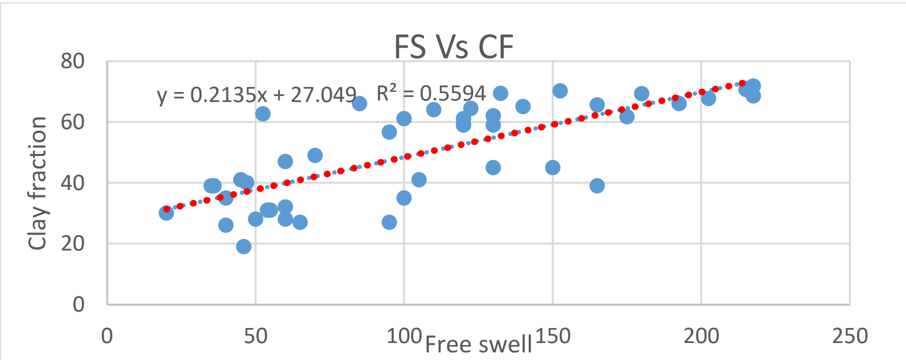



Figure 4.8c. Free swell Vs clay fraction

The clay fraction and the free swell of the study area shows that; points are scattered from the trend line. This indicate that their relationship is directly proportional, but cannot satisfactorily indicate the swelling behavior of the soil since they are widely scattered.

# CHAPTER 5 SHRINK SWELL SUSCEPTIBILITY MAPPING AND RESULT DISCUSION

## 5.1 Shrink swell susceptibility map

The criterions used to establish susceptibility map are the lithological, mineralogical, and geotechnical parameters. Rating for lithology has been given on the basis of thickness of volume changing formation identified from bore hole log and test pits and percentage of clay fraction (<2 micron). While, for geotechnical (plasticity index and free swell), has been rated on the basis of test results of laboratory. Rating for swelling mineral percentage were based on XRD analysis conducted by different researchers, and indirect interpretation of swelling mineral from activity chart. Test pits with known geographic coordinate systems having lithological, mineralogical and geotechnical layers were combined and sum together. This summation was divided by the number of the layers (clay fraction <2 micron, thickness of expansive soil, plasticity index, free swell and percentage of swelling mineral) to get the mean. The formations have been classified in to three different classes based on their calculated mean value (table.5). According to the established map almost 30% of the area of the study area appears as highly susceptible to shrinkage-swelling phenomenon (fig.5).

Table 5. Clay formations susceptibility degree (BRGM,2009)

| Average rating (mean) | Degree of Susceptibility |
|---|---|
| <2 | Low |
| 2-3 | Medium |
| >3 | High |

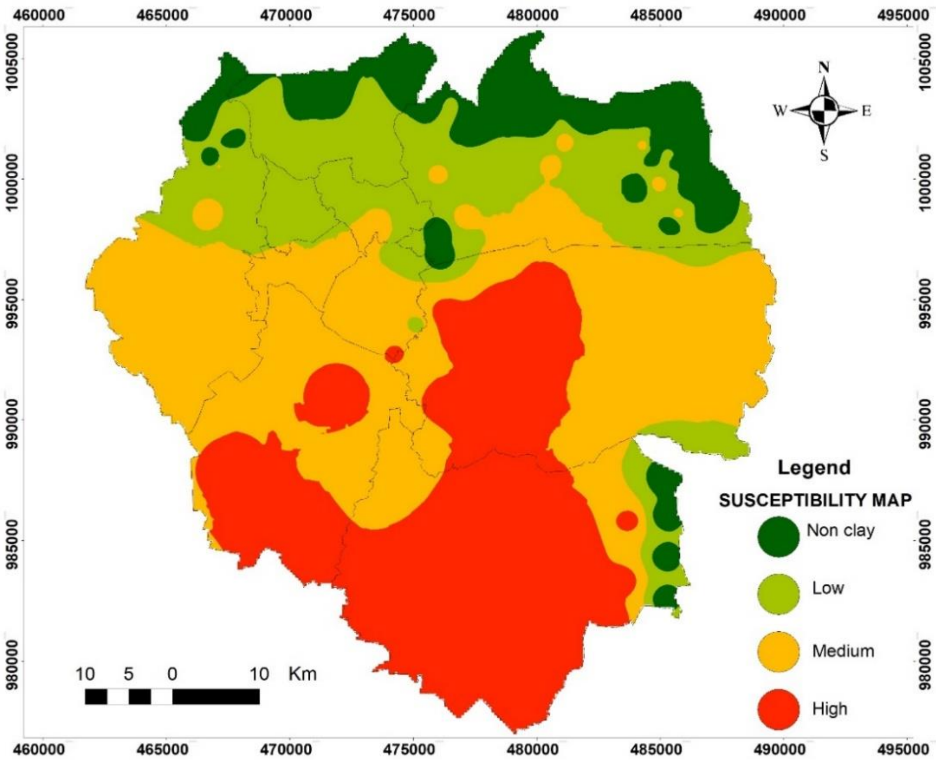



Fig 5. Shrink swell susceptibility map of the study area

## 5.2. Result discussion

Soil is erratic and shows variability spatially. The result of plasticity index, free swell, percentage of swelling mineral, expansive soil thickness and clay fraction show that there is wide variable value of range not only on spatial bases but on depth bases too. Even with in the same layer of soil profile or similarly classified soil types has very variable test results.

The center of the city lies on an undulating topography with some flat land areas, while gentle morphology and flat land areas characterize the southern and southeastern parts of the city.

The topography of the research area is undulating. Southern and south eastern part of the city is characterized by gentle morphology and flat. Thus, low relief topography facilitates the formation of smectite rich soil.

The climate (rainfall and temperature) of the study area show variation which is attributed to the differences in topography. Northern part of the city is characterized by high rainfall and relatively low temperature while, southern part of the city is characterized by higher temperature and low rainfall.

Northern, north western and north eastern part of the city is characterized by low to shrink swell phenomenon while southern, southeastern and south western part of the city is characterized by high to very high and the upper most layer is covered by black cotton soil (lacustrine soil) with dark to grey color and high plasticity and expansive nature which is the case for poorly drained conditions.

**Land use land cover**

Land use land cover of the study area show that major constructions and expansion are being taking place in south, south eastern and south western part of the city, where the upper most soil profile is expansive.

**Plasticity index**

The numbers of secondary data have been collected from different organization. The plasticity index of the study area ranges from 7%-72%.

**Free swell**

The free swell value of the study area ranges from 20% to 420%.

**Clay fraction (<0.002mm)**

The clay fraction value of the study area ranges from 19%-84%.

**Thickness of expansive soil**

The thickness of expansive soil in the study area ranges from 0.5m to 9m. Thick expansive soil formation was found around Bole Medhanialem, Nifas silk Lafto around unity college, and Akaki kality woreda 04 with thickness of 9m, 6m and 8m respectively.

**Activity**

The activity value of the study area ranges from 0.25-1.85.

**Swelling pressure (Kpa)**

The swelling pressure (oedometer) value of the study area ranges from 5Kpa-391Kpa.

**Percentage of swelling clay mineral**

Dominant mineralogical content of northern, north western and north eastern part of the city is kaolinitic, while southern, south eastern and south western part are smectite including montmorillonite.

According to produced shrink swell susceptibility map, about 76 $km^2$ (14%) of the total area have been considered as non-clay or rock formation. About 96 $km^2$ (18%) of the total area have been considered as low to shrink swell phenomena. About 196 $km^2$ (38%) of the total area have been considered as medium to the phenomenon. 159$km^2$ (30%) of the total area have been considered as high to the phenomenon.

### 5.3. Methods of preventing shrink swell damage

In order to minimize the danger of damages to buildings because of swell and shrinkage, the following methods have been used: - namely moisture control, soil stabilization and structural measures (Alemayehu Teferra, 2008 and Chen F.H ,1988, as cited in Hailemariam Girma, 2016).

**A. Moisture Control** if the moisture content is constant throughout the soil, expansive soil will not be a problem. Moisture fluctuation can be controlled by using horizontal barriers, vertical moisture barriers around the foundation soil, subsurface and surface drainage.

**B. Soil Stabilization** is made to minimize the swelling potential of expansive soil by one or more of the following methods, namely: - soil replacement, pre-wetting, compaction control and chemical treatment.

**Soil replacement is** the simplest method preventing damage. The swelling soil is removed and replaced with non-swelling and impermeable soil. This method is recommended for cases where the thickness of expansive soil is small, less than 2.5m. The depth at which the soil to be replaced depends on the depth of the active zone. However, has disadvantage in causing failure during construction due to water ingress unless the fill is impervious which is expansive and the thickness required may also be impractical (Nelson and Miller,1992 as cited in Lee and Ian,2012).

**With Pre-Wetting Method,** the soil is flooded to achieve swelling prior to commencement of construction. However, this method has disadvantage of requiring several years to achieve adequate wetting; loss of strength and failure can occur; ingress limited to a depth less than the active zone; water redistribution can occur - causing heave after construction (Nelson and Miller,1992 as cited in Lee and Ian,2012).

**With Compaction Control Method**, the upper soil is scarified and re-compacted to low soil density. This reduces the swelling property and heave of the expansive soil. The main advantage of using this approach is that the swelling potential can be reduced without the negative effects caused by introducing excessive moisture into the soil. The draw-back with this method is that the low density compaction will result in low bearing capacity of subgrade of foundation soil and may not be effective for soil of high swell potential; requires close and careful quality control (Nelson and Miller,1992 as cited in Lee and Ian,2012).

**With Chemical Treatment Method,** it is the process of mixing additives like lime, cement, and other chemicals to expansive soils, so as to retard their potential expansiveness. Lime will reduce plasticity and hence the swelling potential of the soil, it is often used

successfully in the construction of highways and airports. Meanwhile, the action of cement is to reduce the liquid limit, plastic index and the potential volume change, it is mainly used in highway constructions.
However, has the following disadvantages: Soil chemistry may be detrimental to chemical treatment; health and safety need careful consideration as chemical stabilizers carry potential risks; environmental risks may also occur - e.g. quick lime is particularly reactive; curing inhibited in colder temperatures (Nelson and Miller,1992 as cited in Lee and Ian,2012).
**C. Structural Measures** is the most effective and widely used method. In this method, one of the following measures is employed;
**Design the Building as Rigid Unit:** - A rigid building is one which is free from uneven displacement which might cause structural damage. Rigidity of a building can be achieved by providing adequate reinforcement to foundation, beams, slabs and walls in such a manner that all of these will result in a monolithic form of building. This method is recommended for light and compact buildings. Mat foundations can be used under this category because they can be referred as structural slab-on-ground and stiffened slab to prevent the possibility of differential heave.
**Providing Flexibility to Building: -** A flexible building is one which allows differential movement to occur between its members without itself being damaged. Flexibility can be achieved by providing the building into small rigid compartments with flexible joints. This method is recommended for long buildings.
**Providing Deep Foundations: -** Piles are used as a solution so that the pile should be placed in non-swelling stable zone (i.e. greater than 3.5m depth). The bottom of piles should be enlarged (under-reamed) to increase bearing and anchoring capacities of the piles. Piles should be protected from tension failure by either decreasing pile diameter, or increasing loading on the pile as high as possible, or by reinforcing pile for tensile force due to soil heave, or by providing pile with sleeve (of weak spongy material) in order to isolate pile shaft from soil.

### 5.4 Foundation option in expansive soil

A foundation is a constructed unit that transfer the load from a superstructure to the ground. They are classified as shallow and deep foundation. With regard to vertical loads, most foundations receive a more or less concentrated load from the structure and transfer this load to the soil underneath the foundation, distributing the load as a stress over a certain area (Chen and Richard, 2003).
Ground movement beneath a structure's foundations, can occur due to shrinkage or swell of expansive soils, so appropriate foundation option, to minimize the effects of movement, principally differential is important.
A large number of factors influence foundation types and design methods. These include climatic, financial and legal aspects, as well as technical issues. Importantly, swell-shrink behavior often does not manifest itself for several months and so design alternatives must take account of this. Other issues, such as financial considerations, can place strain on this and so early communication with all relevant stakeholders is essential.

Higher initial costs are often offset many times over by a reduction in post construction maintenance costs when dealing with expansive soils (Nelson and Miller, 1992 as cited by Lee and Ian,2012).

### 5.4.1 Shallow foundation

Shallow foundation is part of the structure which transfer the super structures load to the near surface (Chen and Richard, 2003).

It shall be designed with adequate bearing and structural capacity and with tolerable settlements. The purpose of this type of foundations is to distribute the structural loads over a considerable base area at the foundation bed.

Shallow foundations are applied when the soil beneath the foundation is strong enough to sustain the load of the building, hence generally shallow foundations on expansive soil are further classified as footing foundations and slab foundations (Chen,1988 as cited in Hailemariam Girma, 2016).

**Footing foundation**: Footing foundation is an enlargement at the bottom of columns/bearing walls that distribute the applied structural loads over a sufficiently large soil area. The footing foundation consists of concrete slab/pad under each structural columns and continuous slab under load bearing walls. This type of foundation is often used in small to medium size structures with moderate to good soil conditions.

However, footing foundations can be successfully placed on expansive soil provided that a sufficient dead-load pressure is exerted on the foundation, or the structure is rigid enough so that differential heaving will not cause cracking (Chen,1988 as cited in Hailemariam Girma, 2016). Hence, this type of foundation is not recommended in areas where the anticipated heave in the soil is high.

A footing can also be used where the top layers of expansive soil have small thickness and/or the active zone of the area is at shallow depth so that the footing foundation can be placed on the stable layer (zone) at shallower depth (Daniel Ameneshewa,2007 as cited in Hailemariam Girma, 2016).

Generally, footing foundations can be successfully placed on expansive soil provided one of the following criteria are met; if sufficient dead-load pressure is exerted on the foundation, if the structure is rigid enough so that differential settlement can be reduced, and/or if swelling potential of the foundation soils can be eliminated or reduced (Chen,1988 as cited in Hailemariam Girma, 2016).

Under footing foundation types, the well-known types of footing such as isolated, combined, strap and strip footing can be used within the limits of the above footing applications.

**Slab foundation (slab on ground/ slab on grade and mat or raft foundation):**

**I. A slab-on-ground/slab-on-grade** is a concrete slab placed directly on the ground with little consideration given to its structural requirements. These slabs are constructed either with or without reinforcement.

The unreinforced slabs are generally constructed in residential houses or where a light floor load is expected. The limits of the length of the unreinforced slab are based upon the amount of shrinkage cracking control desired.

Whereas a lightly reinforced slab is normally reinforced with a temperature control as a prime design factor. The choice between the two types depends upon the subsoil conditions as well as the loading conditions.

Slab-on-ground construction on expansive soil will always pose a cracking and heaving problem unless the subgrade soils are treated or replaced.

In construction of building such as warehouse and storage areas, special design is required to maintain the structural integrity of the building.

**II. Mat or raft foundation:** Mat foundations are also known as raft foundations which are heavily reinforced concrete foundations that usually cover the entire plan area of the building to distribute the loads over a large area. Mat/raft foundations are thickened concrete slabs that support a number of columns or walls. Mats are reinforced with both positive and negative steel, adequately reinforced to resist moments in orthogonal directions. They are rigid elements that distribute column and wall loads over a larger area, thus reducing the magnitude of the vertical stress on the foundation soil. They do not only decrease the stress but also produce a more uniform settlement profile and subsequently reduces differential settlement (Mekonnen Zeray, 2006 as cited in Hailemariam Girma, 2016).

Mats may be preferred over spread footings on strata that are erratic or have low bearing capacities. Mats are usually more economical than footings when the total base area required for individual footings exceeds about one-half of the area covered by the structure. Mats can be used to create deep basements, distribute column loads more uniformly and provide basement slabs (water barrier). Mats may be used when the foundation soil has a low bearing capacity or large differential settlements are anticipated. The use of mat foundation may also be advantageous where the foundation is below water table and there is need to eliminate water infiltration into basement of a building. Distortion occurs when the supporting soil swells non-uniformly or differentially (Chen,1988 as cited in Hailemariam Girma,2016). Ribbed mats are frequently used in practice because they are economical than uniform mats.

### 5.4.2 Deep foundation

The deep foundation provides an economical method for transfer of structural loads beyond (or below) unstable (weak, compressible, and expansive) to deeper stable (firm, incompressible, and non-swelling) strata (Chen and Richard, 2003). These foundations are used if the soil near the surface is incapable of adequately supporting the structural load and settlement of shallow foundation is excessive (Craig,2004). Anchoring the structure at a deeper depth where the volumetric change of the soil due to seasonal moisture variation is constant or negligible is the best remedy (Hailemariam,2004).

This can be achieved in expansive soils by using either straight bored piles or under-reamed piles. The method can be economical in areas where considerable heave can be expected and the additional cost can be balanced against the saving in the future maintenance. Straight bored piles or under-reamed piles can be used depending on the soil conditions.

Straight bored piles are used in shallow expansive soils, single under-reamed piles for light structures in deep layers of expansive soils and double under-reamed piles for foundations of heavier structures in deep layers of expansive soils (Alemayehu Teferra,2008; chen,1988 and Daniel Amneshaw as cited in Hailemarim Girma,2016).

**Straight bored pile foundation:** for the straight bored piles, if the combined effect of the weight of the dead load and the skin friction does not balance the uplift force due to swelling, the whole pile may be lifted and cause structural damage to the building (Chen, 1988 as cited in Hailemariam Girma,2016).

**Under reamed pile foundation**: Under-reamed piles are bored cast-in-situ concrete piles having bulb shaped enlargement near base.

These piles are commonly recommended for providing safe and economical foundations in expansive soils and other types of soils having poor bearing capacity. In these types of foundations, the structure is anchored to the ground at a depth where ground movement due to changes in moisture content is negligible. A pile having one bulb is known as single under-reamed pile. It is seen that the load bearing capacity of the pile can be increased by increasing the number of bulbs at the base. In such cases the pile is named as multi-under-reamed pile (Chen,1988).

The increase in the bearing capacity of the pile can also be achieved by increasing the diameter and the length of the pile. Buildings founded on expansive soils often crack due mainly to differential ground movements as a result of alternative swelling and shrinkage of the soil due to changes in its moisture content. With a view to meet this movement effectively, the best remedy is to anchor the structure at a depth where the volumetric change of the soil due to seasonal and other variations is negligible. Under-reamed piles have been economically achieved this anchorage both at shallow and deep layers of expansive soils (Chen,1988; Alemayehu Tefera,2008 as cited in Hailemariam Girma,2016).

### 5.4.3 Pavement and expansive soils

Pavements are particularly vulnerable to expansive soil damage, with estimates suggesting that they are associated with approximately half of the overall costs from expansive soils (Chen 1988). Pavement design is essentially the same as that used for foundations. However, a number of different approaches are required as pavements cannot be isolated from the soils and it is impractical to make pavements stiff enough to avoid differential movements. Therefore, it is often more economic to treat sub-grade soils. Pavement designs are based on either flexible or rigid pavement systems. However, when dealing with expansive soils a number of approaches should be considered (Lee and Ian, 2012);

- Choose an alternative route and avoid expansive soil;
- Remove and replace expansive soil with a non-expansive alternative;
- Design for low strength and allow regular maintenance;
- Physically alter expansive soils through disturbance and re-compaction;
- Stabilize through chemical additives, such as lime treatment;
- Control water content changes - although very difficult over the life of a pavement.

Techniques include pre-wetting, membranes, deep drains, slurry injection treatment.

**5.5 Remedial measures**

According to Afewerk Sisay (2004), 64% of surveyed 96 buildings are affected adversely. 72 % of the affected buildings are due to the consequence of heave or shrinkage of the soil. Improper structural design, surface and sub-surface drainage accounts, watering of plant during landscaping near foundations and/or from giving little or no attention to the expansive nature of expansive soil are the major factors which aggravate the damage.

84 % of the damaged buildings lack drainage system or the drainage system provided is inadequate. 67 % of the buildings wall constructed from hollow concrete block showed crack and 40% of the buildings wall constructed from brick wall also showed crack. 88% of the buildings with masonry foundations are damaged.

According to Alemayehu and Solomon (1986), Case studies of 35 structures all located within the regions of expansive soils, typical damages are observed on those structures and concluded that structures founded on conventional masonary wall foundations resting on an expansive soil are liable to crack. Structures founded on footings or piles that are located within the active zone of the expansive soil are liable to crack.

From the conducted damage assessment, drainage and improper structural design are the most critical initiating factors for the observed damages.

The remedial measures to be taken for a cracked building is simpler once the cause of foundation movement has been determined. Remedial works to be taken differs in each case. The commonly used remedial measures are as follows: (Afewerk sisay,2003; Chen, 1988 and Lee and Ian,2012)

A) For distress caused by up lifting of drilled pier foundation: -

- Loosen soil around the pier to reduce the uplift pressure
- Reconstruct void space beneath the grade beams
- Eliminate the mushroom at the top of the pier
- Cut the top of the pier and adjust the pier by shims
- Remove all the back fill around the building and replace with compacted non-expansive clay to protect surface water entering through the foundation soil
- Improve the drainage condition around the building by providing adequate slope away from the building and paving with concrete

B) For distress caused by up lifting of footing foundation: -

- Decrease the footing size to increase the dead load pressure
- Underpin the pad with piers drilled into the stable zone or bed rock

C) For distress caused by heaving of Interior slab

- Allow free slab movement by providing space between the slab and the grade beam or the foundation wall in the case of basement
- Provide slip joints to all interior slab bearing partitions walls including door frames and stair case walls
- Replace the soil beneath the slab with non-expansive impervious compacted soils

D) Distress caused by heaving of a continuous footing foundation

- Provide voids beneath the continuous footing at calculated interval to increase the dead load pressure. This can be done by removing soil beneath the continuous footing
- Reinforce existing foundation walls with new reinforced grade beams to tie the structure as in box construction
- Post tension the foundation walls to provide structural stability by preventing unequal movement
- Under pine the foundation with piers drilled in to a stable zone

E) Distress caused by the presence of tree near house

The general remedial measures applied to all types' foundation movements are the following:

- Provide positive drainage around the building
- Provide adequate outlet of all down spouts
- Remove and re-compact non expansive backfill
- Provide concrete aprons around the house
- Relocate all lawn sprinkler heads to a distance at least 10 feet from the building
- Remove all shrubs and flowers bed which are planted adjacent to the house
- Provide proper sub drain around the building below the lower floor slab
- Provide a positive out let for sub drains
- Maintain any leaking pipes around the building

# CHAPTER 6 CONCLUSION AND RECCOMENDATION

## 6.1 Conclusion

The geological setting of Addis Ababa is characterized by the different formations, but Bole, Akaki kality and Nifas silk lafto sub-cities are characterized by highly plastic clay/silt formation with flat topography. The establishment of the shrinkage–swelling susceptibility map Addis Ababa was essentially based on the dominant lithology of the formations; the mineralogical composition of the clay fraction, and the geotechnical behavior. This approach is modified from the general methodology developed by the BRGM. Test pits and bore hole with known geographic coordinate having plasticity index, free swell, clay fraction, and percentage of swelling mineral all in one has been selected and rated as per given standards. While, thickness of expansive soil has been rated from the cross section.

Direct XRD analysis and indirect interpretation of index tests allow appointing these fine soils composed mainly of Smectite, Kaolinite, Illite, and interstratified minerals and their degree to shrink and swell.

Three levels of susceptibility (Low, medium, and high) were adopted to characterize clay formation towards the phenomenon, represented by colors (tarragon green, yellow, and red). While, green for non-clay or rock formations.

According to produced shrink swell susceptibility map, about 96 $km^2$ (18%) of the study area is classified as 'low potential to shrink swell phenomenon', 196 $km^2$ (38%) of the study area is classified as 'medium potential to the shrink swell phenomenon', about 159 $km^2$ (30%) of the study area is classified as 'high potential to the shrink swell phenomenon' of shrink swell. Non clay or rock formation covers 76 $km^2$ (14%) of the study area.

The final susceptibility map can be used as a basis for preventive information in the municipality, in order to sensitize the builders, owners and decision-makers on the need to respect constructive rules in the areas subject to shrinkage and swelling. This regulatory tool should emphasize the importance of a geotechnical investigation to the plot for any new construction project. Otherwise, it will be necessary to implement constructive rules to reduce the destructiveness of the phenomenon.

The following conclusions are drawn based on the secondary laboratory data of this research: -

- The percentage of clay fractions ranges from 19%-84%.
- The liquid limit, plastic limit and plasticity index of the study area ranges from 22-123%,7%-72% and 12-93% respectively.
- The soil types in the study area have free swell ranges from 20% to 420%.
- Activity ranges from 0.25-1.85.
- The percentage of clay fractions ranges from 19%-84%.
- Swelling pressure (oedometer) test value ranges from 5Kpa-391Kpa.
- Dominant mineralogical content of northern, north western and north eastern part of the city is kaolinitic, while southern, south eastern and south western part are smectite including montmorillonite.

## 6.2 Recommendation

- The top soil of Bole, Nifas silk lafto and Akaki kaliti sub cities are predominantly covered by highly expansive clay. Light structures with shallow foundations lay on highly expansive soils needs either stabilization mechanism or remove the expansive layer and replace with an appropriate material for the safety of the structure.
- Thick expansive clay formation is found around Bole Medhanialem, Akaki kaliti; woreda 04 and Nifas silk lafto around Unity college with thickness of 9m,8m and 6m respectively. Therefore; needs special engineering approach to overcome the shrink swell problem.
- Shrink swell property of soil could be precisely estimated with the help of XRD analysis therefore; for the coming researchers it is highly recommended.
- High rise building and heavy well founded structures don't suffer in a sensible way the swelling effects, but for light weight buildings it is recommended the utilization of a float concrete slab above the ground, coupled with concrete spread footing or pads.
- The use of drainage network running all around the building perimeter (French drains) with the intent to regulate the ground water excursion and to maintain at a constant water content the soil portion placed under the building itself of recommended.
- It is recommended not to plant trees near buildings since it predisposing factor for shrink swell or the distance between building and tree has to be twice of the height of the tree.
- Shallow foundations can be successfully placed on formation those classified under low susceptibility to shrink swell phenomenon.
- Straight bored piles and reinforced mat can be successfully placed on formation those classified under medium susceptibility to shrink swell phenomenon
- Deep and under reamed foundation are recommended for those formations classified under high shrink swell phenomenon to overcome considerable heave.

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## Appendix-1

## Bore hole log

| Soil thickness(m) | (Soil) Strata description | X | Y | Elev (m) | Company |
|---|---|---|---|---|---|
| **0 -1.5** | Dark gray silty CLAY (Black cotton) | 483000 | 997000 | 2330 | ECDSWC |
| 1.5 – 4.5 | Light gray silty CLAY | | | | |
| 6.4 | Clayey SILT | | | | |
| **0-4** | Medium stiff to stiff, dark grey high plastic silty CLAY | 469036 | 990750 | 2343 | ARKON |
| 4-8 | Stiff, light grey, high plastic clayey SILT | | | | |
| 8-16 | Very stiff, variegated color, low to high plastic clayey SILT with gravel. | | | | |
| 16-28 | Dense to very dense, variegated color, low to non plastic silty SAND/ sandy SILT with gravel. | | | | |
| **0-8** | Dark gray silty CLAY (Black cotton) | 487000 | 995000 | 2400 | ECDSWC |
| 8-15 | Clayey SILT with some gravel | | | | |
| 15 -23 | Sandy SILT | | | | |
| 23 - 25 | RHYOLITE | | | | |
| **0-2** | Medium stiff to stiff, dark , high plastic silty CLAY ( Black cotton soil). | 467932 | 989340 | | ARKON |
| 2 - 25 | Stiff to Very stiff , dark grey , high plastic silty CLAY/ clayey SILT | | | | |
| **0 – 1.2** | Silty CLAY (Black cotton) | 485000 | 992600 | 2370 | ECDSWC |
| 1.2 - 5 | Clayey SILT | | | | |
| **0-7** | Medium stiff to stiff, dark , high plastic silty CLAY ( Black cotton soil). | 468066 | 989302 | | ARKON |
| 7-16 | Stiff to Very stiff , dark grey , high plastic silty CLAY/ clayey SILT | | | | |
| 16-25 | Very stiff, light grey to light brown, high plastic sandy SILT/silty SAND | | | | |
| **0-2** | Medium stiff to stiff, dark grey expansive silty CLAY | 483446 | 994497 | 2324 | ECDSWC |
| 2-9 | Silty SAND with some gravel | | | | |
| 9-15 | Dark brown silty SAND with gravel | | | | |
| **0-3** | Plastic BLACK COTTON | 471888 | 991538 | | ECDSWC |
| **0-3.45** | BLACK COTTON | 473750 | 991429 | 2290 | ECDSWC |
| 3.35-5.70 | Silty GRAVEL | | | | |
| 5.70-10 | Vesicular basalt | | | | |
| **0-3.7** | BLACK COTTON | 469321 | 992025 | 2257 | ECDSWC |
| 3.7-10 | IGNIMBRITE | | | | |
| **0-6.5** | Silty CLAY | 463527 | 996277 | - | ECDSWC |
| 6.5-15 | DECOMPOSED ROCK | | | | |
| **0-2.5** | BLACK COTTON | 473602 | 991508 | 2291 | ECDSWC |
| 2.5-4.9 | Gravely SILT | | | | |

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| 4.9-15 | BASALT | | | | |
| **0-8** | Black cotton | 465836 | 989862 | 2267 | ECDSWC |
| 8-10 | Decomposed weak rock | | | | |
| **0-1.5** | Black cotton (silty CLAY) | 469955 | 994277 | 2320 | ECDSWC |
| 1.5-3.4 | Basalt with black cotton | | | | |
| 3.4-10 | Weathered basalt | | | | |
| **0-3.5** | Soft firm , dark gray to light gray silty CLAY (Black cotton) | 477063 | 996894 | 2339 | ADDIS GEOSYSTE MS |
| 3.5 – 4.6 | Dense, light grey to yellowish grey, silty sandy GRAVEL (Tuff Deposite) | | | | |
| 4.6 – 6.2 | Stiff, light grey to lighty brown, clayey SILT with some sand. | | | | |
| 6.2 – 7 | Stiff, grey, silty CLAY. | | | | |
| 7- 7.5 | Dense, light grey to light brown, silty sandy GRAVEL (Tuff Deposite). | | | | |
| 7.5 – 9.1 | Stiff, light grey, silty CLAY. | | | | |
| 9.1 - 15 | Dense to very dense, light grey to light brown, silty SAND | | | | |
| **0 - 6** | Dark , highly plastic with Firm to stiff, grey, silty CLAY (Black cotton) | 476561 | 994320 | 2282 | ADDIS GEOSYSTE MS |
| 6 – 12.8 | Stiff, reddish brown, sandy silty CLAY | | | | |
| 12.8 - 21 | Grey, fine to medim grained, slightly to moderately and locally highly weathered medium strong, IGINIMBRITE rock | | | | |
| **0 – 4.3** | Dark grey and light grey, highly plastic, silty CLAY/CLAY | | | | |
| 4.3 – 5.2 | Medium dense, yellowish brown, sandy SILT/ silty SAND (Tuff). | | | | |
| 5.2 – 8.1 | sandy GRAVEL with rock cores and rock fragments in between. | 486520 | 997735 | 2425 | |
| 8.1 - 9 | sandy SILT with some clay (Tuff). | | | | |
| 9 -11.25 | welded Tuff (Ignimbrite) | | | | |
| 11.25 - 20 | Stiff to very stiff, light grey, clayey SILT with some sand | | | | |
| **0 -9.5** | Dark grey, light grey and yellowish brown, clayey SILT (ASH/TUFF) | 475060 | 995937 | 2357 | |
| 9.5 - 23.45 | Dense to very dense, dark brown, silty SAND | | | | |
| 23.45 - 25 | Light grey, slightly weathered to fresh and slightly fractured, WELDED TUFF | | | | |
| **0-1.4** | Firm and highly plastic silty CLAY and shows high swelling potential (black cotton) | 473555 | 997984 | 2406 | Addis Ababa Housing dev't coorporation |
| 1.4 – 4.7 | low to medium plastic Silty Gravel and very fine sand/ gravely clay silt (Lateritic soil) | | | | |
| 4.7 - 10 | Basalt | | | | |
| **0-7** | Firm to stiff, reddish brown, clayey SILT | 468492 | 999269 | 2474 | |
| 7 – 15.3 | TUFF (locally decomposed in to silty sandy GRAVEL/ gravely silty SAND | | | | |
| 15.3 - 20 | Tracky BASALT | | | | |
| 20 - 22 | fractured BASALT | | | | |
| **0 -0.65** | Top soil:- Soft, dark grey, silty CLAY | 476836 | 997684 | 2400 | |
| 0.65 – 6.1 | highly fractured, RHYOLITE. | | | | |

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| 6.1 - 14.4 | Very stiff to hard, reddish brown, clayey sandy SILT (residual soil). | | | | |
| 14.4 - 20 | RHYOLITE | | | | |
| **0 -5.75** | clayey silty SAND/sandy clayey SILT (TUFF) | 474984 | 996204 | 2369 | |
| 5.75 – 10 | Soft, yellowish brown, silty CLAY/clayey SILT | | | | |
| 10 - 12 | Medium dense, light grey, sandy GRAVEL | | | | |
| 12 – 19 | IGNIMBRITE | | | | |
| 19 – 21.2 | sandy SILT/silty SAND | | | | |
| 21.2 - 24 | Light grey and reddish brown, clayey SILT | | | | |
| **0 – 2.10** | Black cotton soil: Soft, dark grey, Silty CLAY | 476579 | 997858 | 2425m | ADDIS GEOSYSTE MS PLC. |
| 2.10 – 3.8 | Very stiff to hard, reddish brown, Silty CLAY with some sand. | | | | |
| 3.8 - 12 | Very stiff to hard, yellowish to light gray, Sandy SILT/Silty sand with some clay (derived from decomposed Ignimbrite/Tuff). | | | | |
| **0 – 1** | Black cotton soil: soft, dark to dark gray, CLAY with gravel and grass at the top | 468279 | 992871 | 2299m | ADDIS GEOSYSTE MS PLC. |
| 1 - 2.7 | Very dense, Light gray, Silty SAND with gravel, derived from the complete weathering of the underlying BASALT | | | | |
| 2.7 - 20 | Light gray to dark gray and locally dark brown on weathered surface, fine grained, highly to moderatly weathered and fractured, medium Strong, Trachy BASALT with joints of moderately closely spaced, sub parallel to the core axis. | | | | |
| **0 – 1.7** | Black cotton soil: Soft, dark gray to dark brown, expansive Silty CLAY | 480283 | 995840 | 2262m | ADDIS GEOSYSTE MS PLC. |
| 1.7 – 7.55 | Stiff to very stiff, light gray, silty CLAY. | | | | |
| 7.55 – 8.3 | Light gray, medium grained,slightly to moderatly weathered, medium strong, Lithic TUFF | | | | |
| 8.3 – 9.45 | Very stiff, reddish brown,Silty CLAY | | | | |
| 9.45 – 12.35 | Greenish gray, medium grained, slightly weathered, strong, Lithic TUFF. | | | | |
| 12.35 – 14.85 | Very stiff, reddish brown to yellowish brown, Silty CLAY. | | | | |
| 14.85 – 17.3 | Dense, light gray to dark gray, Sandy SILT(decomposed TUFF) | | | | |
| 17.3 - 20 | Hard, reddish brown, Silty CLAY | | | | |
| **0-5** | RED : Medium stiff to stiff, red, silty CLAY | 469183 | 999357 | 2473 | ECDSWC |
| 5-10 | COMPLETELY DECOMPOSED UNIT : Medium stiff to very ,reddish , completely decomposed gravelly soil. | | | | |
| **0-2** | Medium stiff to stiff, gray with variegated color spots plastic SILTY CLAY with some sand | 472066 | 994752 | 2309 | ECDSWC |

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| 2-9 | Medium stiff to stiff, brownish gray with varigated color spots, SILTY CLAY/clayey silt with some sand | | | | |
| 9-20 | Medium dense to dense, light gray sandy silt (TUFF) | | | | |
| **0-1.2** | SILTY CLAY : reddish brown, slightly moist, moderately stiff | 468633 | 1003165 | 2654 | ECDSWC |
| 1.2-8 | IGNIMBRITE : light gray , highly weathered and closely to widely fractured, moderately strong | | | | |
| **0-5** | Light greyish to yellowish completely decomposed pyroclastic ROCK with trace of rock fragmented | 472102 | 994722 | 2303 | ECDSWC |
| 5-30 | Light greyish to dull grey, fine grained, medium dense, non-plastic un welded TUFF | | | | |
| **0-3** | Stiff, dark brown, fine grained slightly plastic SILTY CLAY | 473881 | 981154 | 2084 | ECDSWC |
| 3-5 | Stiff, brownish, fine grain plastic SILTY CLAY | | | | |
| 5-10 | Stiff, red brown ,fine grain plastic clayey SILT | | | | |
| **0-1.50** | TUFF: welded, moderately to highly weathered, very weak, intensely fractured, pinkish. | 468716 | 1003172 | 2678 | ECDSWC |
| 1.5-2.2 | Very dense brown, sandy coarse GRAVEL, dry. | | | | |
| 2.2-3.15 | TUFF: welded moderately to highly weathered very weak, intensely fractured, pinkish. | | | | |
| 3.15-6.5 | IGNIBRITE: slightly weathered, medium strong to strong, very closely to moderately fractured, light green. | | | | |
| **0-1.5** | BLACK COTTON SOIL | 472792 | 993707 | 2311 | ECDSWC |
| 1.5-4.5 | IGNIMBRITE ROCK :light gray, firm moderately fractured rock. | | | | |
| 4.5-6.3 | COMPLETELY DECOMPOSED ROCK : brownish, very stiff to hard residual silty clay soil. | | | | |
| **0 -0.6** | Soft to medium stiff, black, fine grained, highly plastic CLAY (Black cotton) | 482070 | 983703 | 2221 | ECDSWC |
| 0.6 – 3.45 | Stiff to very stiff, light brown fine grain, slightly plastic CLAY | | | | |
| 3.45 – 6.45 | Stiff to very stiff, light brown fine grain, highly plastic clayey SILT | | | | |
| 6.45 - 7 | Stiff, brown, fine grain, slightly plastic silty CLAY | | | | |
| 7 – 8.6 | Medium stiff, greyish, fine grain, plastic clayey SILT | | | | |
| **0 – 0.50** | Reddish sand clayey SILT mixed with grass root | 464302 | 991502 | 2299 | ECDSWC TP |
| 0.50 – 2.7 | Dark gray, wet, expansive , plastic silty CLAY (Black cotton) | | | | |
| 2.70 – 4 | Reddish brown to dark brown ,wet ,sandy clayey SILT | | | | |
| **0 – 4.5** | Stiff, black, fine grain, slightly plastic , silty CLAY (Black cotton) | 469558 | 987253 | 2238 | ECDSWC |

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| 4.5 – 7 | Very stiff , brownish to dark brown fine grain ,slightly plastic , clayey SILT | | | | |
| 7 - 10 | Very stiff to hard , dull black to dark grayish fine grain , plastic clayey SILT | | | | |
| **0 – 3.10** | Greyish to black , medium stiff , completely decomposed silty GRAVEL. | 471276 | 993579 | 2302 | ECDSWC |
| 3.10 – 8.10 | Highly weathered and decomposed IGNIMBRITE | | | | |
| 8.10 - 12 | Greyish, fine grained, moderately weathered and fractured IGNIMBRITE | | | | |
| **0 – 1.5** | Medium stiff , dark gray , partly organic SILT | 478252 | 997116 | 2385 | ECDSWC |
| 1.5 – 7.2 | Stiff to very stiff , reddish brown , cohesive clayey SILT (residual soil) | | | | |
| 7.2 – 8 | Weak, gray, highly weathered IGNIMBRITE | | | | |
| 8 – 11.5 | Strong, gray, fresh to slightly weathered, extremely close to moderate spacing IGNIMBRITE | | | | |
| 11.5 – 12.8 | Medium dense , greyish clayey sandy SILT | | | | |
| 12.8 - 17 | Stiff to hard , reddish brown , cohesive clayey SILT | | | | |
| **0 – 3.3** | IGNIMBTITE ROCK | 476210 | 997415 | 2391 | ECDSWC |
| 3.3. – 5 | DECOMPOSED UNIT : stiff to firm , grayish to black , completely decomposed rock with silty soil | | | | |
| 5 - 10 | REDSOIL: medium stiff to very stiff , reddish , high plastic , silty CLAY soil | | | | |
| **0 – 1.5** | Black , soft , slightly plastic silty CLAY | 474306 | 984609 | 2175 | ECDSWC |
| 1.5 – 2.10 | Light brown soft , plastic silty CLAY | | | | |
| 2.55 – 3.5 | Light brown soft to hard , plastic silty CLAY | | | | |
| 3.5 – 6 | Medium size, sub rounded GRAVEL with cementing mass | | | | |
| 6-15 | BASALT | | | | |
| **0 – 3** | Dense , brownish to black , fine to coarse grain , granular CLAY with weathered rock fragments | 486343 | 1002287 | 2481 | ECDSWC |
| 3 -5.3 | Medium stiff to hard , greyish to brown , fine grain , plastic clayey SILT with weathered pyroclastic rock fragments | | | | |
| 5.3 - 10 | Hard, brownish , fine grain , plastic clayey SILT with weathered and decomposed rock fragments | | | | |
| **0 -8** | Stiff to very stiff , black to dull black , fine grain highly plastic CLAY (Black cotton) | 476576 | 979251 | 2059 | ECDSWC |
| **0 -8** | Stiff to very stiff , black to dull black , fine grain highly plastic CLAY (Black cotton) | 474263 | 980755 | 2069 | ECDSWC |
| **0 - 8** | Stiff to very stiff , black to dull black , fine grain highly plastic CLAY (Black cotton) | 475602 | 983706 | 2075 | ECDSWC |
| **0 – 2** | Black , medium stiff , high plastic , silty CLAY (Black cotton) | 488583 | 995665 | | ECDSWC |

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| 2 – 10 | Light gray to light brown , stiff to very stiff , high plastic , clayey SILT / silty CLAY | | | | |
| 10 – 14 | Light gray to yellowish brown , stiff to very stiff , high plastic , silty SAND /sandy SILT | | | | |
| 14 - 15 | Light grey highly weathered and fractured TUFF | | | | |
| **0-8.15** | Dark and Gray, Stiff, Highly Plastic, Expansive CLAY (Black Cotton Soil) | 477072 | 993963 | 2345 | CWCE |
| 8.15 – 14.4 | IGNIMBRITE | | | | |
| 14.4 - 15 | Light brown very stiff to hard , clayey SILT | | | | |
| **0-9** | Reddish brown, stiff to hard, medium to highly plastic, Silty clay soil with few gravel nodules | 475390 | 997300 | - | CWCE |
| 9-10 | Grey, stiff to hard, medium to non-plastic, Silty with sand soil | | | | |
| 10-22 | Brownish grey, moderately weathered, vesicular basalt | | | | |
| **0-1** | Soft. Light brown, CLAY (Top soil) | 475221 | 997706 | - | CWCE |
| 1-10 | Firm to stiff. Reddish Brown. Silty CLAY | | | | |
| **0-1** | Dark grey, loose, highly expansive and plastic, Silty Clay (black cotton soil) | 481735 | 995301 | | CWCE |
| 1-5 | Yellowish grey, highly plastic, stiff, Silty clay (decomposed tuff) soil. This soil has covered | | | | |
| 5-7 | Grey, non-plastic, hard, welded tuff (ignimbrite) rock | | | | |
| | Soft, dark CLAY | 487851 | 995937 | - | ADDIS GEOSYSTEMS PLC |
| | Stiff, Light grey Silty CLAY | | | | |
| | Stiff, light brown to yellowish grey, clayey SILT (derived from weathering of Welded Tuff / Ignimbrite rock | | | | |
| **0-2** | Soft, dark, CLAY (BLACK COTTON) | 485822 | 996492 | | ADDIS GEOSYSTEMS PLC |
| 2-7 | Stiff, grey, Silty CLAY | | | | |
| 7-13 | Dense to very dense, light grey to yellowish grey, sandy SILT with some gravel | | | | |
| 13-15 | Light grey, fine to medium grained, slightly to moderately weathered IGINIMBRITE ROCK with joints of closely to medium spaced and sub-ortho to the core axis | | | | |
| **0-2** | Soft, dark, CLAY (BLACK COTTON) | 485843 | 996492 | - | ADDIS GEOSYSTEMS PLC |
| 2-6 | Stiff, grey, Silty CLAY | | | | |
| 6-11 | Dense to very dense, light grey to yellowish grey, sandy SILT with some gravel | | | | |
| 11-14 | Light grey, fine to medium grained, slightly to moderately weathered IGINIMBRITE ROCK with joints of closely to medium spaced and sub-ortho to the core axi | | | | |
| **0-1** | Soft, dark, CLAY (Black cotton) soil | 487707 | 996860 | - | ADDIS GEOSYSTEMS PLC |
| 1-5 | Firm to stiff, grayish to light brown, sandy Silty CLAY (ASH deposit) | | | | |

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| 5-7.5 | Light gray, Fine grained, slightly weathered, weak welded TUFF | | | | |
| 7.5-8.5 | Stiff, light gray, silty CLAY | | | | |
| 8.5-10 | Light gray, fine grained, slightly weathered weak, welded TUFF | | | | |
| **0-1.4** | Black cotton soil: Soft, dark brown Silty CLAY with grass roots | 487750 | 996584 | - | ADDIS GEOSYSTE MS PLC |
| 1.4-2.2 | Firm, Yellow to light grey Clayey SILT derived from the decomposition of Ignimbrite rock. | | | | |
| 2.2-3.8 | Light grey, fine to medium grained, highly weathered and fractured weak IGNIMBRITE rock | | | | |
| **0-0.80** | Medium stiff DARK GRAY highly plastic and expansive silty CLAY (Black cotton) | 488587 | 996056 | - | |
| 0.80-7.30 | Stiff light grey high plastic clayey SILT | | | | |
| 7.30-10 | Hard light brown sandy SILT ( residual soil of weathered rhyolite) | | | | |
| **0-1.0** | Medium stiff dark grey high plastic and expansive silty CLAY (Black cotton) | 488562 | 996013 | - | |
| 1-10.0 | Stiff dark grey high plastic Clayey SILT | | | | |
| 10-11.50 | Hard light grey Clayey SILT (weathered product s of Rhyolite) | | | | |
| **0-8** | Silty CLAY | 478337 | 984727 | 2177 | Gondwana Engineering |
| **0-6** | Silty CLAY | 478783 | 984164 | 2162 | Gondwana Engineering |
| 0-1.5 | Highly expansive soil (Black cotton) | 479716 | 982090 | 2149 TP | EJ Engineering |
| 1.5-3.5 | Red ash | | | | |
| **0-1** | Highly expansive soil (Black cotton) | 479706 | 987324 | 2165 TP | EJ Engineering |
| 1-10 | Decomposed basalt | | | | |
| **0-1.5** | Highly expansive soil Black cotton) | 480999 | 985481 | 2216 | Building Design Sco. |
| 1.5-10 | Silty clay | | | | |
| **0-3** | Highly expansive soil (Black cotton) | 474437 | 984327 | 2169 | Building Design Sco. |
| 3-10 | Silty clay | | | | |
| **0-1** | Silty CLAY | 474360 | 982127 | 2185 | Building Design Sco. |
| 1-3 | Silty sand | | | | |
| 3-10 | Silty sandy gravel | | | | |
| 0-3 | Highly expansive soil (Black cotton) | 474006 | 986180 | 2184 | EJ Engineering |
| **0-9** | Silty CLAY | 478537 | 985127 | 2183 | Gondwana Engineering |
| 0-7 | Silty clay | 481519 | 984415 | 2209 | Building Design Sco. |
| **0-1.8** | Highly expansive soil (Black cotton) | 474876 | 983078 | 2160 TP | EJ Engineering |
| 1.8-3.8 | Decomposed basalt | | | | |
| 0-4 | Highly expansive (Black cotton) | 474372 | 981834 | 2152 | Building Design Sco. |
| 4-7 | Sandy silt | | | | |
| 0-8 | Silty clay | 479178 | 984270 | 2166 | Gondwana Engineering |
| 0-8 | Silty clay | 480046 | 984970 | 2200 | Building Design Sco. |

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| **0-1.5** | Predominantly dark soft to firm Silty CLAY (high plastic) | 480971 | 985307 | 2210 | Addis Ababa Housing dev't coorporation |
| 1.5-15 | Predominantly light gray to dark gray firm to stiff Sandy/Clayey SILT with local carbonate/rock fragments | | | | |
| **0-2.5** | Predominantly dark soft to firm Silty CLAY (high plastic) | 481025 | 985384 | 2212 | Addis Ababa Housing dev't coorporation |
| 2.5- 15 | Predominantly light gray to dark gray firm to stiff Sandy/Clayey SILT with local carbonate/rock fragments | | | | |
| **0-1** | Predominantly dark soft to firm Silty CLAY ( highly plastic) | 480353 | 985710 | 2204 | Addis Ababa Housing dev't coorporation |
| 1-7.5 | Predominantly light gray to dark gray firm to stiff Sandy/Clayey SILT with local carbonate/rock fragments | | | | |
| 7.5-10 | Gray to brown stiff to very stiff, Sandy Clayey SILT (highly weathered to decomposed scoraceous BASALT | | | | |
| **0-1.5** | Predominantly dark soft to firm Silty CLAY (highly plastic) | 480404 | 985786 | 2203 | Addis Ababa Housing dev't coorporation |
| 1.5-8 | Predominantly light gray to dark gray firm to stiff Sandy/Clayey SILT with local carbonate/rock fragments | | | | |
| 8-10 | Gray to brown stiff to very stiff, Sandy Clayey SILT (highly weathered to decomposed scoraceous BASALT | | | | |
| **0-1.5** | Predominantly dark soft to firm Silty CLAY (highly plastic) | 480443 | 985726 | 2206 | Addis Ababa Housing dev't coorporation |
| 1.5-10 | Predominantly light gray to dark gray firm to stiff Sandy/Clayey SILT with local carbonate/rock fragments | | | | |
| **0-1** | Predominantly dark soft to firm Silty CLAY (highly plastic) | 480469 | 985819 | 2203 | Addis Ababa Housing dev't coorporation |
| 1-7.5 | Predominantly light gray to dark gray firm to stiff Sandy/Clayey SILT with local carbonate/rock fragments | | | | |
| 7.5-10.5 | Gray to brown stiff to very stiff, Sandy Clayey SILT (highly weathered to decomposed scoraceous BASALT | | | | |
| **0-0.5** | Predominantly dark soft to firm Silty CLAY (highly plastic) | 480311 | 985732 | 2203 | Addis Ababa Housing dev't coorporation |
| 0.5-7 | Predominantly light gray to dark gray firm to stiff Sandy/Clayey SILT with local carbonate/rock fragments | | | | |
| 7-10 | Gray to brown stiff to very stiff, Sandy Clayey SILT (highly weathered to decomposed scoraceous BASALT | | | | |
| **0-1.5** | Predominantly dark soft to firm Silty CLAY (highly plastic) | 480164 | 985744 | 2196 | Addis Ababa Housing dev't coorporation |
| 1.5-7 | Predominantly light gray to dark gray firm to stiff Sandy/Clayey SILT with local carbonate/rock fragments | | | | |
| 7-10 | Gray to brown stiff to very stiff, Sandy Clayey SILT (highly weathered to decomposed scoraceous BASALT | | | | |
| **0-1.10** | Dark gray expansive clay soil (Black cotton) | 481359 | 984320 | - | Civil Works Cosulting |

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| 1.10-8.5 | light grey expansive clay soil, highly plastic soil like dark grey expansive clay soil. | | | | Engineers PLC |
| 8.5-15 | Fresh to decomposed vesicular basalt | | | | |
| **0-2.20** | Dark gray expansive clay soil (Black cotton) | 481398 | 984251 | - | Civil Works Cosulting Engineers PLC |
| 2.20-14 | light grey expansive clay soil, highly plastic soil like dark grey expansive clay soil. | | | | |
| 14-15 | Fresh to decomposed vesicular basalt | | | | |
| **0-2** | Dark gray expansive clay soil (Black cotton) | 481423 | 984357 | - | Civil Works Cosulting Engineers PLC |
| 2-15 | light grey expansive clay soil, highly plastic soil like dark grey expansive clay soil. | | | | |
| **0-2** | Dark gray expansive clay soil (Black cotton) | 481448 | 984280 | - | Civil Works Cosulting Engineers PLC |
| 2-14 | light grey expansive clay soil, highly plastic soil like dark grey expansive clay soil. | | | | |
| 14-15 | Fresh to decomposed vesicular basalt | | | | |
| **0-.1.20** | Soft, dark grey, CLAY (Black cotton) soil with grass roots | 476452 | 994014 | 2338m | ADDIS GEOSYSTEMS PLC |
| 1.20-9 | Firm to Stiff, light grey, Silty CLAY | | | | |
| 9-12 | Stiff, reddish brown Silty CLAY /Clayey SILT with some Sand | | | | |
| **0-2.4** | Soft, dark, CLAY mixed with tree roots (Black Cotton Soil) | 477200 | 993768 | 2272m | ADDIS GEOSYSTEMS PLC |
| 2.4-8.4 | Firm to Stiff, grey, Silty CLAY | | | | |
| 8.4-10 | Very Stiff, light brown, Clayey SILT with Some Sand | | | | |
| 10-15 | Dense to very dense, light brown to light grey, Silty SAND (Decomposed Ash/ Tuff deposit) | | | | |
| **0-0.4** | Top Soil:- Soft, reddish brown, silty CLAY with gravel | 476281 | 994637 | 2339m | ADDIS GEOSYSTEMS PLC |
| 0.4-3.5 | Soft to firm, dark grey to light grey, silty CLAY | | | | |
| 3.5-5 | Light grey, fine to medium grained, highly to moderately weathered and fracutured, weak, welded TUFF. | | | | |
| 5-6 | Stiff, light grey to yellowish grey, sandy SILT with some clay. | | | | |
| 6-6.75 | Light grey, fine to medium grained, moderately weathered and highly fractured, weak, welded TUFF | | | | |
| 6.75-8.4 | Dense, light grey to yellowish grey, silty sandy GRAVEL (Tuff Deposite) | | | | |
| 8.4-10.3 | Stiff, light grey, silty CLAY. | | | | |
| **0-2** | Soft, dark, CLAY (BLACK COTTON) with grass roots at the top | 476526 | 994299 | 2282m | ADDIS GEOSYSTEMS PLC |
| 2-6.25 | Firm to stiff, grey, silty CLAY | | | | |
| 6.25-13.5 | Stiff, reddish brown, sandy silty CLAY | | | | |
| 13.5-20.5 | Grey, fine to medim grained, slightly weathered strong ,IGINIMBRITE rock with joints of sub parallel to the core axi | | | | |

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| **0-2** | Soft, dark gray to black CLAY ( Black Cotton Soil). | 475183 | 991826 | 2293m | ADDIS GEOSYSTEMS PLC |
| 2-5.4 | Soft, light brown clayey SILT (Ash Deposite | | | | |
| 5.4-8.3 | Stiff, reddish silty CLAY with some sand | | | | |
| 8.3-11 | Grayish, slightly to moderately weathred and fractured medium strong vesicular BASALT. | | | | |
| **0-1.5** | Top soil:- soft, dark gray, silty CLAY with gravel | 476615 | 993317 | 2329m | ADDIS GEOSYSTEMS PLC |
| 1.5-11 | Stiff to very stiff, gray, silty CLAY | | | | |
| 11-13.5 | Medium dense, light gray, clayey sandy SILT (decomposed TUFF deposit) | | | | |
| 13.5-17 | Very stiff to hard, light brown, clayey SILT/silty CLAY (derived from the complete weathering of the underlying vesicular BASALT | | | | |
| **0-0.6** | Black cotton :-Soft, dark grey, CLAY(Expansive Soil) | 474312 | 986243 | 2162m | ADDIS GEOSYSTEMS PLC |
| 0.6-9 | Medium dense to dense, light grey to light brown Sandy SILT/Silty SAND with some Clay (Ash deposit) | | | | |
| **0-1.2** | Soft, dark gray, CLAY (Black Cotton Soil). | 473483 | 985942 | 2171m | ADDIS GEOSYSTEMS PLC |
| 1.2-8 | Firm to stiff, greyish to light grey, silty CLAY | | | | |
| 8-10 | Medium dense to dense, reddish brown, clayey sandy SILT /calyey silty SAND | | | | |
| **0-3.5** | Black cotton soil: Firm to stiff, Dark to dark gray, Silty CLAY (expansive soil) | 479986 | 980768 | 2148m | ADDIS GEOSYSTEMS PLC |
| 3.5-8.4 | Medium dense to dense, reddish brown to yellowish gray, Silty Sandy GRAVEL derived from complete weathering of the underlying | | | | |
| 8.4-15 | Dark gray, fine grained, slightly weathered and fracture, Aphanitic BASALT, strong | | | | |
| **0-0.45** | Soft, reddish brown, Silty CLAY with grass at the top | 476471 | 994653 | 2343m | ADDIS GEOSYSTEMS PLC |
| 0.45-5.6 | Firm to stiff, light grey, Silty CLAY | | | | |
| 5.6-6.25 | Grey, fine to course grained, slightly weathered, welded TUFF | | | | |
| 6.25-9.3 | Stiff to very stiff, grey, Silty CLAY | | | | |
| 9.3-20 | Dense to very dense, light grey, Silty SAND (Ash deposit) | | | | |
| **0-2** | Back fill, Soft, light gray, Silty CLAY (black cotton soil) with grass at the top. | 474273 | 992744 | 2324m | ADDIS GEOSYSTEMS PLC |
| 2-5 | Firm to stiff, light brown to reddish brown, Silty CLAY derived from completely weathering of underlying basalt | | | | |
| 5-6 | Light gray, fine grained, highly weathered and fractured Aphanitic BASALT recovered as gravel and cobble sized rock fragments, weak | | | | |
| **0-1** | Soft, dark gray silty CLAY ( black cotton) | 475896 | 994260 | 2340m | |

| | | | | | |
|---|---|---|---|---|---|
| 1-7 | Light gray, medium grained, slightly to highly weathered and fractured, TUFF, weak. | | | | ADDIS GEOSYSTEMS PLC |
| 7-10 | Stiff to very stiff, light yellowish gray to brownish gray, Clayey SILT | | | | |
| **0-0.3** | Firm to stiff, dark grey Silty CLAY (black cotton soil) | 478140 | 986178 | 2191m | ADDIS GEOSYSTEMS PLC |
| 0.3-10 | Firm to very stiff, light yellowish grey Silty CLAY probably derived from completely weathered tuff | | | | |
| 0-2 | Soft to firm, black, wet Silty CLAY (black cotton soil) | 478159 | 986209 | 2193m | ADDIS GEOSYSTEMS PLC |
| 2-10 | Firm to very stiff, buff grey to light yellowish grey, moist and plastic Silty CLAY/Clayey SILT derived from completely weathered Basalt/Trachyte | | | | |
| **0-1.5** | Firm to stiff, dark grey, moist, Silty CLAY (black cotton soil) | 478256 | 986301 | 2198m | ADDIS GEOSYSTEMS PLC |
| 1.5-15 | Firm to very stiff, light yellowish grey Silty CLAY probably derived from completely weathered tuff | | | | |
| **0-1.5** | Firm to stiff, black Silty CLAY (black cotton soil) | 478141 | 986263 | 2195m | ADDIS GEOSYSTEMS PLC |
| 1.5-15 | Firm to very stiff, light yellowish grey Silty CLAY probably derived from completely weathered tuff | | | | |
| **0-4** | Black cotton | 483548 | 983311 | 2265 | |
| **0-4** | Black cotton | 482543 | 982869 | 2250 | |
| **0-4** | Black cotton | 480535 | 982999 | 2204 | |
| **0-4** | Black cotton | 480234 | 985486 | 2207 | |
| **0-4** | Black cotton | 480452 | 984938 | 2200 | |
| **0-4** | Black cotton | 480590 | 984164 | 2194 | |
| **0-4** | Black cotton | 481574 | 984241 | 2210 | |
| **0-4** | Black cotton | 481172 | 983632 | 2205 | |
| 0-4 | Black cotton | 481379 | 982695 | 2206 | |
| 0-4 | Black cotton | 483070 | 981729 | 2246 | |

## Appendix 2

| X | Y | Plasticity index ® | Free swell ® | Clay fraction ® | Swelling mineral ® | Thickness | Mean |
|---|---|---|---|---|---|---|---|
| 473005 | 987156 | 3 | 3 | 2 | 3 | 3 | 2.8 |
| 475122 | 993909 | 1 | 1 | 2 | 2 | 2 | 1.6 |
| 474777 | 988078 | 2 | 3 | 2 | 3 | 3 | 2.6 |
| 470447 | 995755 | 2 | 2 | 2 | 3 | 2 | 2.2 |
| 474018 | 994193 | 3 | 1 | 2 | 2 | 2 | 2 |
| 472829 | 995580 | 2 | 1 | 3 | 2 | 2 | 2 |
| 472037 | 991287 | 4 | 3 | 3 | 3 | 4 | 3.4 |
| 467480 | 988117 | 4 | 3 | 3 | 3 | 3 | 3.2 |
| 468471 | 985344 | 3 | 3 | 3 | 3 | 3 | 3 |
| 471046 | 985542 | 4 | 3 | 3 | 3 | 3 | 3.2 |
| 478773 | 980391 | 4 | 3 | 3 | 3 | 4 | 3.4 |
| 477386 | 983363 | 4 | 3 | 3 | 3 | 4 | 3.4 |
| 476990 | 986731 | 4 | 3 | 3 | 3 | 3 | 3.2 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 467480 | 1002184 | 2 | 2 | 2 | 2 | 2 | 2 |
| 473622 | 1000995 | 2 | 1 | 2 | 2 | 2 | 1.8 |
| 470254 | 1001590 | 3 | 1 | 2 | 2 | 2 | 2 |
| 469461 | 1002580 | 3 | 1 | 2 | 2 | 2 | 2 |
| 473424 | 1002976 | 2 | 1 | 2 | 2 | 2 | 1.8 |
| 476990 | 998354 | 3 | 2 | 2 | 3 | 2 | 2.4 |
| 480556 | 998552 | 3 | 3 | 2 | 3 | 2 | 2.6 |
| 485707 | 998552 | 3 | 3 | 2 | 2 | 2 | 2.4 |
| 475999 | 1000203 | 3 | 2 | 2 | 2 | 2 | 2.2 |
| 480556 | 1000599 | 3 | 2 | 2 | 2 | 2 | 2.2 |
| 484915 | 999807 | 3 | 3 | 2 | 3 | 3 | 2.8 |
| 481150 | 1001590 | 3 | 3 | 2 | 2 | 2 | 2.4 |
| 485311 | 1000797 | 2 | 2 | 2 | 2 | 2 | 2 |
| 476197 | 1002580 | 3 | 2 | 2 | 2 | 2 | 2 |
| 484320 | 1001391 | 3 | 3 | 2 | 3 | 2 | 2.6 |
| 483771 | 985819 | 4 | 3 | 3 | 4 | 3 | 3.4 |
| 481391 | 985930 | 4 | 3 | 3 | 4 | 2 | 3.2 |
| 483548 | 983311 | 4 | 3 | 3 | 4 | 4 | 3.6 |
| 482543 | 982869 | 4 | 2 | 2 | 4 | 3 | 3 |
| 480535 | 982999 | 4 | 4 | 3 | 4 | 3 | 3.6 |
| 480452 | 984938 | 4 | 3 | 3 | 4 | 3 | 3.4 |
| 480590 | 984164 | 4 | 4 | 3 | 4 | 3 | 3.6 |
| 481574 | 984241 | 4 | 3 | 3 | 4 | 3 | 3.4 |
| 481172 | 983632 | 4 | 4 | 3 | 4 | 3 | 3.6 |
| 481379 | 982695 | 4 | 4 | 3 | 4 | 2 | 3.4 |
| 483070 | 981729 | 4 | 3 | 3 | 4 | 3 | 3.4 |
| 473583 | 998162 | 2 | 2 | 3 | 2 | 2 | 2.2 |
| 468899 | 999975 | 2 | 1 | 2 | 2 | 2 | 1.8 |
| 465700 | 997621 | 2 | 2 | 2 | 2 | 2 | 2 |
| 469476 | 100182 | 3 | 1 | 1 | 4 | 2 | 2.2 |
| 463176 | 992753 | 2 | 1 | 2 | 3 | 2 | 2.2 |
| 467100 | 1000550 | 3 | 2 | 1 | 3 | 2 | 2.2 |
| 463207 | 995751 | 3 | 2 | 2 | 3 | 2 | 2.4 |
| 463465 | 995757 | 2 | 2 | 3 | 2 | 2 | 2.2 |
| 463383 | 995856 | 2 | 1 | 3 | 2 | 2 | 2 |
| 463359 | 995926 | 3 | 2 | 2 | 2 | 2 | 2.2 |
| 463158 | 995774 | 4 | 2 | 1 | 4 | 2 | 2.6 |
| 464433 | 994782 | 3 | 1 | 2 | 3 | 2 | 2.2 |
| 462833 | 992707 | 2 | 1 | 1 | 4 | 2 | 2 |
| 466727 | 998734 | 3 | 2 | 1 | 3 | 2 | 2.2 |
| 484020 | 995563 | 3 | 3 | 2 | 2 | 2 | 2.4 |
| 485861 | 994564 | 3 | 3 | 3 | 2 | 2 | 2.6 |
| 484493 | 992400 | 2 | 3 | 3 | 2 | 3 | 2.6 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 487946 | 993990 | 4 | 3 | 2 | 3 | 2 | 2.8 |
| 484627 | 996001 | 4 | 3 | 2 | 3 | 2 | 2.8 |
| 483525 | 994634 | 4 | 3 | 2 | 3 | 3 | 3 |
| 483446 | 994497 | 4 | 2 | 3 | 3 | 2 | 2.8 |
| 474976 | 991934 | 3 | 3 | 2 | 3 | 2 | 2.6 |
| 470468 | 993538 | 4 | 2 | 2 | 4 | 3 | 3 |
| 475132 | 992940 | 4 | 3 | 3 | 3 | 2 | 3 |
| 475104 | 990894 | 4 | 2 | 3 | 4 | 2 | 3 |
| 476072 | 991063 | 4 | 2 | 3 | 4 | 3 | 3.2 |
| 478128 | 990761 | 4 | 2 | 3 | 4 | 3 | 3.2 |
| 479011 | 990717 | 4 | 2 | 3 | 4 | 3 | 3.2 |
| 480277 | 995645 | 4 | 3 | 3 | 4 | 3 | 3.4 |
| 478444 | 994669 | 4 | 3 | 3 | 4 | 4 | 3.6 |
| 476701 | 993796 | 4 | 3 | 3 | 4 | 4 | 3.6 |
| 474262 | 992760 | 4 | 3 | 3 | 4 | 2 | 3.2 |
| 476240 | 994409 | 4 | 3 | 3 | 4 | 4 | 3.6 |
| 480686 | 994341 | 4 | 2 | 3 | 4 | 3 | 3.2 |
| 488543 | 995700 | 4 | 3 | 3 | 3 | 2 | 3 |

## Appendix -3

| Localitie | X | Y | Elevat (m) | Depth (m) | Soil type | Water cont (w%) | LL % | **Rating (R)** | PL% | PI% | **Rating (R)** | FSW % | **Rating (R)** | Activity % | **Rating (R)** | % clay fraction | **Rating (R)** | SP (Kpa) | Dominant mineral | Rating (R) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ayat | 488543 | 995700 | - | 2- 3.5 | Silty CLAY | - | 113 | **4** | 48 | 65 | **4** | 150 | **3** | 0.82 | **2** | 79 | **3** | | Illite | 3 |
| Kolfe | 468470 | 998870 | 2455 | - | Red CLAY | 32 | 86 | 4 | 34 | 52 | 4 | 85 | 2 | - | | - | | - | | |
| Lideta | 472055 | 996188 | 2360 | - | Paleosol | 34 | 71 | 4 | 50 | 21 | 2 | 51 | 2 | - | | - | | - | | |
| Kirkos | 472863 | 996385 | 2357 | - | Ash | 37.6 | 53 | 3 | 33 | 20 | 2 | - | | - | | - | | - | | |
| Kirkos | 472750 | 996752 | 2364 | - | Red clay | 33 | 63 | 3 | 35 | 28 | 3 | - | | - | | - | | - | | |
| Bole | 476798 | 993085 | 2329 | - | Exp. clay | 37 | 102 | 4 | 36 | 66 | 4 | 108 | 3 | - | | - | | 180 | | |
| Bole | 476835 | 992987 | 2327 | - | Exp. clay | 45 | 98 | 4 | 34 | 64 | 4 | 100 | 3 | - | | - | | 100 | | |
| Bole | 476889 | 993078 | 2316 | - | silty clay | 39 | 103 | 4 | 35 | 68 | 4 | 98 | 2 | - | | - | | - | | |
| Kirkos | 473887 | 995350 | 2357 | - | Tuff/ash | 19 | 48 | 2 | 28 | 20 | 2 | 36 | 1 | - | | - | | - | | |
| Kirkos | 471871 | 994671 | 2304 | - | Tuff/ash | 47 | 54 | 3 | 42 | 12 | 1 | 37 | 1 | - | | - | | - | | |
| Kirkos | 472580 | 996839 | 2374 | - | paleosol | 35 | 65 | 3 | 36 | 29 | 3 | 47 | 1 | - | | - | | - | | |
| Kirkos | 472750 | 996752 | 2364 | - | paleosol | 32 | 58 | 3 | 35 | 23 | 2 | 41 | 1 | - | | - | | - | | |
| Kirkos | 472252 | 995989 | 2364 | - | paleosol | 32 | 48 | 2 | 30 | 18 | 2 | 48 | 1 | - | | - | | - | | |
| Kirkos | 474359 | 995495 | 2355 | - | paleosol | 34 | 60 | 3 | 38 | 22 | 2 | 55 | 2 | - | | - | | - | | |
| Bole | 476705 | 993728 | 2335 | - | E. silty clay | 30 | 80 | 4 | 47 | 33 | 3 | 100 | 3 | - | | - | | - | | |
| Lideta | 471094 | 996141 | 2355 | - | paleosol | 15 | 59 | 3 | 39 | 20 | 2 | 25 | 1 | - | | - | | - | | |
| Kirkos | 473311 | 994202 | 2320 | - | Tuff/ash | 26 | 48 | 2 | 24 | 24 | 2 | 41 | 1 | - | | - | | - | | |
| Arada | 474231 | 998472 | 2448 | - | E. silty clay | 38 | 105 | 4 | 65 | 40 | 3 | 133 | 3 | - | | - | | - | | |
| Kirkos | 474471 | 995977 | 2339 | - | Tuff/ash | 34 | 45 | 2 | 33 | 12 | 1 | 35 | 1 | - | | - | | - | | |
| Kirkos | 474351 | 996652 | 2372 | - | paleosol | 39 | 51 | 3 | 33 | 18 | 2 | 52 | 2 | - | | - | | - | | |
| Arada | 473410 | 999789 | 2500 | - | silty clay | 38 | 93 | 4 | 55 | 38 | 3 | 90 | 2 | - | | - | | - | | |
| Arada | 473668 | 999674 | 2391 | - | silty clay | 40.5 | 80 | 4 | 50 | 30 | 3 | - | | - | | - | | - | | |
| Bole | 476696 | 994402 | 2342 | - | E. silty clay | 41 | 79 | 4 | 28 | 51 | 4 | 154 | 3 | - | | - | | 115 | | |
| Bole | 476754 | 994337 | 2343 | - | E. silty clay | 36 | 83 | 4 | 35 | 48 | 4 | 100 | 3 | - | | - | | 140 | | |
| Arada | 472657 | 997534 | 2397 | - | silty clay | 44 | 61 | 3 | 44 | 17 | 2 | 77 | 2 | - | | - | | - | | |
| yeka | 485998 | 001974 | 2484 | - | E. silty clay | 44 | 90 | 4 | 53 | 37 | 3 | 80 | 2 | | | - | | - | | |
| yeka | 477525 | 996690 | 2377 | - | E. silty clay | 39 | 104 | 4 | 63 | 41 | 4 | 145 | 3 | - | | - | | - | | |
| yeka | 481589 | 997691 | 2420 | - | E. silty clay | 35 | 93 | 4 | 61 | 32 | 3 | 146 | 3 | - | | - | | - | | |
| Nifaslk | 473005 | 987156 | 2172 | - | E. silty clay | 30 | 100 | 4 | 61 | 39 | 3 | 150 | 3 | 0.8 | 2 | 45 | 2 | - | Illite | 3 |
| yeka | 480822 | 997130 | 2577 | - | E. silty clay | 52 | 98 | 4 | 37 | 61 | 4 | 155 | 3 | - | | - | | - | | |
| yeka | 478090 | 996939 | 2390 | - | ash | 32 | 62 | 3 | 37 | 25 | 2 | 55 | 2 | - | | - | | - | | |

| | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Akaki/ka | 475158 | 982005 | 2128 | - | silty clay | - | 90 | 4 | 53 | 37 | 3 | - | | 0.76 | 2 | 51 | 2 | - | illite | 3 |
| Nifaslk | 475122 | 993909 | 2333 | - | tuff | 19.9 | 33 | 1 | 22 | 11 | 1 | 36 | 1 | 0.28 | 1 | 39 | 2 | - | Kaoli | 2 |
| Bole | 477743 | 995172 | 2330 | - | E. silty clay | 44 | 88 | 4 | 58 | 30 | 3 | 144 | 3 | - | | - | | - | | |
| Bole | 478851 | 995332 | 2354 | - | E. silty clay | 42 | 120 | 4 | 65 | 55 | 4 | 185 | 3 | - | | - | | - | | |
| yeka | 475837 | 996262 | 2360 | - | E. silty clay | 36 | 92 | 4 | 53 | 39 | 3 | 175 | 3 | - | | - | | - | | |
| yeka | 478062 | 996928 | 2381 | - | E. silty clay | 45 | 96 | 4 | 53 | 43 | 4 | 120 | 3 | - | | - | | - | | |
| Ayat | 486612 | 997962 | 2424 | - | E. silty clay | 37 | 90 | 4 | 53 | 37 | 3 | 141 | 3 | - | | - | | - | | |
| Stadium | 473089 | 996133 | 2355 | - | paleosol | 36 | 54 | 3 | 38 | 16 | 2 | 47 | 1 | - | | - | | - | | |
| Bole | 475587 | 994971 | 2310 | - | paleosol | 35 | 75 | 4 | 49 | 26 | 3 | 60 | 2 | - | | - | | - | | |
| Geol.sur | 479452 | 996761 | 2382 | | Tuff/ash | 45 | 70 | 3 | 40 | 32 | 3 | 40 | 1 | - | | - | | - | | |
| Bole | 476644 | 993743 | 2337 | - | E. silty clay | 40 | 100 | 4 | 43 | 57 | 4 | 190 | 3 | - | | - | | - | | |
| Ayat | 486604 | 998656 | 2427 | - | E. silty clay | 42 | 99 | 4 | 46 | 53 | 4 | 172 | 3 | - | | - | | 140 | | |
| yeka | 482374 | 990763 | 2248 | - | E. silty clay | 32 | 86 | 4 | 23 | 63 | 4 | 123 | 3 | - | | - | | - | | |
| Ayat | 486442 | 997826 | 2333 | - | E. silty clay | 51 | 87 | 4 | 45 | 42 | 4 | 160 | 3 | - | | - | | - | | |
| Dembel | 474222 | 995345 | 2354 | - | tuff | 35 | 32 | 1 | 23 | 9 | 1 | 30 | 1 | - | | - | | - | | |
| Bole.me | 476706 | 994071 | 2343 | - | E. silty clay | 39 | 101 | 4 | 57 | 44 | 4 | 193 | 3 | - | | - | | 128 | | |
| Gullele | 473921 | 1000541 | 2535 | - | silty clay | 32 | 70 | 3 | 40 | 39 | 3 | 90 | 2 | - | | - | | - | | |
| Gullele | 474122 | 1001267 | 2546 | - | silty clay | 37 | 73 | 4 | 25 | 48 | 4 | 120 | 3 | - | | - | | - | | |
| Gullele | 470100 | 1001140 | 2599 | - | silty clay | 32 | 67 | 3 | 39 | 28 | 3 | 80 | 2 | - | | - | | - | | |
| Gullele | 472903 | 1000742 | 2434 | - | silty clay | 45.76 | 73 | 4 | 41 | 32 | 3 | 60 | 2 | - | | - | | - | | |
| Gul(kus | 473119 | 1003231 | 2710 | - | silty clay | 30 | 76 | 4 | 50 | 26 | 3 | 125 | 3 | - | | - | | - | | |
| Kaz(tot) | 475004 | 996342 | 2364 | - | tuff | 39 | 45 | 2 | 29 | 16 | 2 | 31 | 1 | - | | - | | - | | |
| Bole | 476296 | 993543 | 2351 | - | E. silty clay | 47 | 78 | 4 | 36 | 42 | 4 | 122 | 3 | - | | - | | - | | |
| Telemed | 475938 | 994742 | 2342 | - | Tuff/ash | 33 | 71 | 4 | 49 | 20 | 2 | 45 | 1 | - | | - | | - | | |
| yeka | 482330 | 988045 | 2420 | - | E. silty clay | 31 | 78 | | 30 | 40 | 3 | 136 | 3 | - | | - | | - | | |
| Yeka | 480886 | 997491 | 2391 | - | E. silty clay | 38 | 110 | 4 | 60 | 50 | 4 | 150 | 3 | - | | - | | - | | |
| yeka | 483977 | 998713 | 2501 | - | E. silty clay | 39 | 102 | 4 | 66 | 36 | 3 | 200 | 4 | - | | | | - | | |
| Yeka | 485849 | 1001021 | 2421 | - | silty clay | - | 72 | 4 | 36 | 36 | 3 | 155 | 3 | - | | - | | - | | |
| Kali/ring | 474777 | 988078 | 2108 | - | E. silty clay | 29.8 | 70 | 3 | 46 | 24 | 2 | 136 | 3 | 0.56 | 1 | 43 | 2 | 170 | illite | 3 |
| Bole | 480136 | 995436 | 2360 | - | E. silty clay | 39 | 100 | 4 | 66 | 44 | 4 | 240 | 4 | - | | | | - | | |
| bolemed | 477059 | 993791 | 2360 | - | E. silty clay | 42 | 96 | 4 | 51 | 45 | 4 | 200 | 4 | - | | - | | - | | |
| Bolmedh | 476610 | 993880 | 2343 | - | E. silty clay | 39 | 102 | 4 | 62 | 40 | 4 | 140 | 3 | - | | - | | - | | |
| Kalty/kil | 480357 | 982833 | 2199 | - | E. silty clay | 40 | 101 | 4 | 63 | 38 | 3 | - | | - | | - | | - | | |
| Akaki/ka | 475961 | 979739 | 2068 | - | E. silty clay | 41 | 91 | 4 | 49 | 42 | 4 | 128 | 3 | - | | - | | - | | |
| Meshual | 473436 | 995433 | 2353 | - | tuff | 34 | 57 | 3 | 32 | 25 | 2 | - | | - | | - | | - | | |
| Kirkos | 471930 | 994675 | 2305 | - | tuff | 35 | 52 | 3 | 41 | 11 | 1 | - | | - | | - | | - | | |
| Yeka | 487096 | 997467 | 2405 | - | E. silty clay | 36 | 56 | 3 | 40 | 26 | 3 | 110 | 3 | - | | - | | - | | |

| | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Bole | 469691 | 989741 | 2225 | - | E. silty clay | 35 | 90 | 4 | 50 | 40 | 4 | 140 | 3 | - | | - | | - | | |
| Lideta | 470447 | 995755 | 2346 | - | silty clay | 39 | 53 | 3 | 29 | 24 | 2 | 92 | 2 | 0.63 | 1 | 38 | 2 | - | illite | 3 |
| Bole | 482714 | 998476 | 2374 | - | E. silty clay | 41 | 98 | 4 | 53 | 45 | 4 | 80 | 2 | - | | - | | - | | |
| welosefe | 475186 | 994374 | 2341 | - | E. silty clay | 40 | 84 | 4 | 34 | 50 | 4 | 120 | 3 | - | | - | | - | | |
| Gerji | 482797 | 998475 | 2382 | - | E. silty clay | 35 | 89 | 4 | 50 | 39 | 3 | 135 | 3 | - | | - | | - | | |
| Jacros | 480503 | 995498 | 2271 | - | E. silty clay | 45 | 73 | 4 | 38 | 35 | 3 | 110 | 3 | - | | - | | - | | |
| Jemo | 468384 | 990375 | 2263 | - | E. silty clay | 40 | 98 | 4 | 60 | 38 | 3 | 176 | 3 | - | | - | | - | | |
| Kality | 474890 | 985530 | 2282 | - | E. silty clay | 32 | 97 | 4 | 60 | 37 | 3 | 140 | 3 | - | | - | | - | | |
| Kebena | 476157 | 998845 | 2471 | - | E. silty clay | 43 | 93 | 4 | 63 | 30 | 3 | 130 | 3 | - | | - | | - | | |
| Kolfe | 468569 | 991325 | 2466 | - | silty clay | 46 | 65 | 3 | 36 | 29 | 3 | 75 | 2 | - | | - | | - | | |
| Lebu | 469661 | 989250 | 2225 | - | E. silty clay | 35 | 89 | 4 | 52 | 37 | 3 | 130 | 3 | - | | - | | - | | |
| Mekanis | 470528 | 988152 | 2231 | - | E. silty clay | 40 | 90 | 4 | 23 | 67 | 4 | - | | - | | - | | - | | |
| Kirkos | 474193 | 993571 | 2320 | - | E. silty clay | 50 | 70 | 3 | 24 | 46 | 4 | - | | - | | - | | - | | |
| Bole | 477045 | 993927 | 2336 | - | E. silty clay | 32 | 86 | 4 | 45 | 41 | 4 | 126 | 3 | - | | - | | - | | |
| Bole | 476640 | 995652 | 2375 | - | E. silty clay | 38 | 89 | 4 | 52 | 37 | 3 | 128 | 3 | - | | - | | - | | |
| 22mazor | 476428 | 996341 | 2375 | - | silty clay | - | - | | - | 45 | 4 | - | | - | | - | | - | | |
| Beklobet | 473349 | 994146 | 2320 | - | E. silty clay | 37 | 82 | 4 | 35 | 47 | 4 | - | | - | | - | | - | | |
| Nifaslk | 470928 | 988652 | 2232 | - | E. silty clay | 37 | 89 | 4 | 52 | 37 | 3 | 130 | 3 | - | | - | | 102 | | |
| Pastor.A | 466741 | 998792 | 2411 | - | silty clay | 33 | 71 | 4 | 41 | 30 | 3 | 75 | 2 | - | | - | | - | | |
| Nifaslk | 470728 | 988252 | 2225 | - | E. silty clay | 39 | 92 | 4 | 51 | 41 | 4 | 165 | 3 | - | | - | | - | | |
| Gullele | 471085 | 1000968 | 2425 | - | silty clay | 32 | 63 | 3 | 41 | 22 | 2 | 53 | 2 | - | | - | | - | | |
| Flaming | 474257 | 995675 | 2328 | - | E. silty clay | 46 | 80 | 4 | 41 | 39 | 3 | - | | - | | - | | - | | |
| Bole | 475899 | 993149 | 2231 | - | E. silty clay | 44 | 98 | 4 | 54 | 44 | 4 | 150 | 3 | - | | - | | 122 | | |
| Arada | 471741 | 999192 | 2411 | - | E. silty clay | 33 | 111 | 4 | 65 | 46 | 4 | - | | - | | - | | - | | |
| Legehar | 472968 | 996126 | 2362 | - | paleosol | 38 | 61 | 3 | 37 | 24 | 2 | 60 | 2 | - | | - | | - | | |
| Near AU | 471644 | 995149 | 2326 | - | tuff | 42 | 51 | 3 | 35 | 16 | 2 | - | | - | | - | | - | | |
| Arada | 471741 | 999192 | 2411 | - | E. silty clay | 30 | 99 | 4 | 57 | 42 | 4 | - | | - | | - | | - | | |
| yeka | 486306 | 1000634 | 2456 | - | E. silty clay | 41 | 90 | 4 | 61 | 29 | 3 | - | | - | | - | | - | | |
| yeka | 486650 | 999945 | 2436 | - | E. silty clay | 40 | 102 | 4 | 72 | 30 | 3 | - | | - | | - | | - | | |
| kolfe | 467104 | 1000909 | 2497 | - | silty clay | 41 | 69 | 3 | 38 | 31 | 3 | 88 | 2 | - | | - | | - | | |
| kolfe | 467586 | 999375 | 2453 | - | silty clay | 34 | 48 | 2 | 29 | 19 | 2 | - | | - | | - | | - | | |
| kolfe | 466897 | 996986 | 2357 | - | silty clay | 36 | 81 | 4 | 57 | 24 | 2 | - | | - | | - | | - | | |
| kolfe | 468412 | 996091 | 2323 | - | silty clay | 36 | 79 | 4 | 49 | 30 | 3 | - | | - | | - | | - | | |
| kolfe | 465659 | 994370 | 2386 | - | silty clay | 40 | 73 | 4 | 54 | 19 | 2 | - | | - | | - | | - | | |
| kolfe | 464351 | 992168 | 2316 | - | silty clay | 35 | 55 | 3 | 31 | 24 | 2 | 90 | 2 | - | | - | | - | | |
| Nifaslk | 469237 | 990447 | 2214 | - | E. silty clay | 49 | 81 | 4 | 25 | 56 | 4 | - | | - | | - | | - | | |
| Nifaslk | 470614 | 991893 | 2194 | - | E. silty clay | 39 | 94 | 4 | 34 | 60 | 4 | 110 | 3 | - | | - | | 150 | | |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Nifaslk | 471165 | 988412 | 2205 | - | E. silty clay | 40 | 102 | 4 | 56 | 46 | 4 | 106 | 3 | - | | - | | - | | |
| Nifaslk | 466760 | 989415 | 2232 | - | E. silty clay | 36 | 81 | 4 | 46 | 35 | 3 | - | | - | | - | | - | - | |
| Nifaslk | 470339 | 993682 | 2290 | - | E. silty clay | 35 | 59 | 3 | 10 | 49 | 4 | - | | - | | - | | - | - | |
| Nifaslk | 472128 | 992038 | 2253 | - | E. silty clay | 32 | 118 | 4 | 66 | 52 | 4 | - | | - | | - | | - | - | |
| Bole | 483071 | 993613 | 2282 | - | E. silty clay | 32 | 99 | 4 | 40 | 59 | 4 | 140 | 3 | - | | - | | - | - | |
| Bole | 485274 | 992581 | 2270 | - | E. silty clay | 40 | 80 | 4 | 43 | 37 | 3 | - | | - | | - | | - | - | |
| Bole | 482727 | 990792 | 2209 | - | E. silty clay | 50 | 100 | 4 | 53 | 47 | 4 | 200 | 4 | - | | - | | - | - | |
| Akaki/ka | 478935 | 986092 | 2176 | - | E. silty clay | 38 | 95 | 4 | 56 | 39 | 3 | 120 | 3 | - | | - | | - | - | |
| Akaki/ka | 480318 | 985836 | 2185 | - | E. silty clay | 38 | 90 | 4 | 56 | 34 | 3 | - | | - | | - | | - | - | |
| Akaki/ka | 482039 | 986805 | 2200 | - | E. silty clay | 38.5 | 110 | 4 | 51 | 59 | 4 | 162 | 3 | - | | - | | 120 | - | |
| Addi ket | 468893 | 000496 | 2507 | - | silty clay | 43 | 80 | 4 | 48 | 32 | 3 | - | | - | | - | | - | - | |
| AddiKet | 470063 | 998569 | 2441 | - | silty clay | 32 | 79 | 4 | 46 | 33 | 3 | 60 | 2 | - | | - | | 127 | - | |
| AddiKet | 470545 | 999670 | 2475 | - | silty clay | 36 | 65 | 3 | 43 | 22 | 2 | - | | - | | - | | - | - | |
| - | 474018 | 994193 | - | 1.5 | Silty clay | - | 70 | 3 | 43 | 27 | 3 | 43 | 1 | 0.5 | 1 | 53 | 2 | - | Kaol | 2 |
| - | 472829 | 995580 | - | 1.5 | Silty clay | - | 68 | 3 | 46 | 22 | 2 | 48 | 1 | 0.36 | 1 | 61 | 3 | - | Kaol | 2 |
| - | 472037 | 991287 | - | 2 | Clayey silt | - | 85 | 4 | 41 | 44 | 4 | 157 | 3 | 0.65 | 1 | 67 | 3 | 170 | Illite | 3 |
| - | 467480 | 988117 | - | 2 | Clayey silt | - | 80 | 4 | 39 | 41 | 4 | 160 | 3 | 0.59 | 1 | 69 | 3 | 140 | Illite | 3 |
| - | 468471 | 985344 | - | 2 | Clayey silt | - | 83 | 4 | 44 | 39 | 3 | 148 | 3 | 0.61 | 1 | 63 | 3 | 180 | Illite | 3 |
| - | 471046 | 985542 | - | 2 | Silty clay | - | 81 | 4 | 38 | 43 | 4 | 165 | 3 | 0.63 | 1 | 68 | 3 | 160 | Illte | 3 |
| - | 478773 | 980391 | - | 2 | Silty clay | - | 93 | 4 | 47 | 46 | 4 | 140 | 3 | 0.66 | 1 | 69 | 3 | - | Illite | 3 |
| - | 477386 | 983363 | - | 2 | Silty clay | - | 90 | 4 | 50 | 40 | 4 | 150 | 3 | 0.57 | 1 | 70 | 3 | - | Illte | 3 |
| - | 476990 | 986731 | - | 1.5 | Silty clay | - | 88 | 4 | 46 | 42 | 4 | 145 | 3 | 0.62 | 1 | 67 | 3 | - | Illite | 3 |
| - | 467480 | 1002184 | - | 1.5 | Silty clay | - | 63 | 3 | 39 | 24 | 2 | 75 | 2 | 0.45 | 1 | 53 | 2 | - | Kaol | 2 |
| - | 473622 | 1000995 | - | 1.5 | Clayey silt | - | 65 | 3 | 43 | 22 | 2 | 45 | 1 | 0.47 | 1 | 46 | 2 | - | Kaol | 2 |
| - | 470254 | 1001590 | - | 2 | Silty clay | - | 63 | 3 | 37 | 26 | 3 | 40 | 1 | 0.50 | 1 | 51 | 2 | - | Kaol | 2 |
| - | 469461 | 1002580 | - | 2 | Clayey silt | - | 64 | 3 | 37 | 27 | 3 | 38 | 1 | 0.5 | 1 | 53 | 2 | - | Kaol | 2 |
| - | 473424 | 1002976 | - | 2 | Silty clay | - | 63 | 3 | 43 | 20 | 2 | 43 | 1 | 0.36 | 1 | 55 | 2 | - | Kaol | 2 |
| - | 476990 | 998354 | - | 1 | Clayey silt | - | 77 | 4 | 46 | 31 | 3 | 90 | 2 | 0.67 | 1 | 46 | 2 | 90 | Illte | 3 |
| - | 480556 | 998552 | - | 1 | Silty clay | - | 80 | 4 | 50 | 30 | 3 | 105 | 3 | 0.57 | 1 | 52 | 2 | 102 | Illite | 3 |
| - | 485707 | 998552 | - | 1 | Silty clay | - | 82 | 4 | 54 | 28 | 3 | 113 | 3 | 0.49 | 1 | 57 | 2 | 85 | Kaol | 2 |
| - | 475999 | 1000203 | - | 1 | Clayey silt | - | 78 | 4 | 52 | 26 | 3 | 80 | 2 | 0.61 | 1 | 42 | 2 | 70 | Kaol | 2 |
| - | 480556 | 1000599 | - | 1 | Clayey silt | - | 66 | 3 | 37 | 29 | 3 | 95 | 2 | 0.59 | 1 | 49 | 2 | 86 | Kaol | 2 |
| - | 484915 | 999807 | - | 1 | Silty clay | - | 69 | 3 | 36 | 33 | 3 | 110 | 3 | 0.61 | 1 | 54 | 2 | 57 | Illite | 3 |
| - | 481150 | 1001590 | - | 1 | Silty clay | - | 65 | 3 | 35 | 30 | 3 | 107 | 3 | 0.6 | 1 | 50 | 2 | 69 | Kaol | 2 |
| - | 485311 | 1000797 | - | 1 | Clayey silt | - | 63 | 3 | 39 | 24 | 2 | 88 | 2 | 0.54 | 1 | 44 | 2 | 70 | Kaol | 2 |
| - | 476197 | 1002580 | - | 1 | Silty clay | - | 67 | 3 | 39 | 28 | 3 | 90 | 2 | 0.54 | 1 | 51 | 2 | - | Kaol | 2 |
| - | 484320 | 1001391 | - | 1 | Silty clay | - | 71 | 4 | 38 | 33 | 3 | 125 | 3 | 0.58 | 1 | 56 | 2 | - | Illite | 3 |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 468309 | 990922 | - | 1.2 | Silty CLA | 39 | 80 | 4 | 34 | 47 | 4 | 120 | 3 | 0.94 | 2 | 50 | 2 | 140 | Illite | 3 |
| | 468438 | 990368 | - | 2.5 | Silty CLA | 45 | 91 | 4 | 52 | 40 | 3 | 102 | 3 | 0.66 | 1 | 60 | 3 | 220 | Illite | 3 |
| | 469017 | 990046 | - | 1.25 | Silty CLA | 52 | 101 | 4 | 38 | 63 | 4 | 110 | 3 | 1.23 | 2 | 51 | 2 | 115 | Mont | 4 |
| | 468373 | 990623 | - | 3 | Silty CLA | 38 | 95 | 4 | 37 | 58 | 4 | 130 | 3 | 0.95 | 2 | 61 | 3 | 130 | illite | 3 |
| Koye | 483771 | 985819 | 2251 | 3 | Dark grey | 44.45 | 104.5 | 4 | 41.8 | 62.6 | 4 | 152 | 3 | 1.01 | 2 | 70.2 | 3 | 190 | Mont | 4 |
| Koye | 481391 | 985930 | 2222 | 3 | Grey clay | 44.93 | 100 | 4 | 38.0 | 62.9 | 4 | 132 | 3 | 1.05 | 2 | 69.4 | 3 | 150 | Mont | 4 |
| Koye TP | 483548 | 983311 | 2265 | 3 | Redis CLAY | 45.02 | 100.9 | 4 | 37.8 | 63.1 | 4 | 165 | 3 | 1.13 | 2 | 65.6 | 3 | 140 | Mont | 4 |
| Koye TP | 482543 | 982869 | 2250 | 3 | Yel grey CLAY | 46.14 | 90.4 | 4 | 34.6 | 56.2 | 4 | 95 | 2 | 1.21 | 2 | 56.6 | 2 | 80 | Mont | 4 |
| Koye TP | 480535 | 982999 | 2204 | 3 | grey clay | 38.90 | 100.1 | 4 | 37.1 | 63.1 | 4 | 217 | 4 | 1.32 | 3 | 68.5 | 3 | 260 | Mont | 4 |
| Koye TP | 480234 | 985486 | 2205 | 1.5<br>3 | grey clay | 45.17<br>42.63 | 97.3<br>94.7 | 4 | 37.0<br>35.4 | 60.3<br>59.4 | 4 | 175<br>195 | 3 | 1.14<br>1.12 | 2 | 61.7<br>61.9 | 3 | 150<br>230 | Mont | 4 |
| Koye TP | 480452 | 984938 | 2200 | 1.5<br>3 | grey clay | 42.17<br>43.65 | 108.0<br>92.4 | 4 | 40.8<br>35.0 | 67.2<br>57.4 | 4 | 192<br>147 | 3 | 1.27<br>1.20 | 3 | 66.0<br>65.8 | 3 | 250<br>180 | Mont | 4 |
| Koye TP | 480590 | 984164 | 2194.5 | 1.5<br>3 | grey clay | 38.32<br>39.31 | 100.1<br>98.4 | 4 | 37.2<br>38.8 | 62.9<br>59.6 | 4 | 202<br>187 | 4 | 1.28<br>1.26 | 3 | 67.7<br>66.9 | 3 | 250<br>240 | Mont | 4 |
| Koye TP | 481574 | 984241 | 2210.5 | 1.5<br>3 | Black clay | 44.31<br>45.33 | 99.8<br>105.3 | 4 | 38.6<br>39.4 | 61.2<br>65.9 | 4 | 122<br>145 | 3 | 1.11<br>1.20 | 2 | 64.4<br>67.0 | 3 | 140<br>120 | Mont | 4 |
| Koye T[ | 481172 | 983632 | 2205.5 | 1.5<br>3 | Black clay<br>Whitish grey clay | 43.53<br>43.16 | 111.8<br>108.1 | 4 | 42.7<br>41.7 | 69.1<br>66.4 | 4 | 215<br>200 | 4 | 1.29<br>1.31 | 3 | 70.6<br>69.3 | 3 | 200<br>250 | Mont | 4 |
| Koye TP | 481379 | 982695 | 2206.5 | 1.5<br>3 | grey clay | 37.17<br>37.83 | 110.9<br>105.2 | 4 | 42.5<br>38.7 | 68.4<br>66.5 | 4 | 217<br>210 | 4 | 1.21<br>1.02 | 2 | 71.8<br>72.5 | 3 | 400<br>350 | Mont | 4 |
| Koye TP | 483070 | 981729 | 2246.5 | 1.5<br>3 | Black clay<br>Dark grey clay | 42.71<br>45.32 | 109.8<br>113.3 | 4 | 41.8<br>43.1 | 68.0<br>70.3 | 4 | 180<br>135 | 3 | 1.29<br>1.29 | 3 | 69.3<br>68.0 | 3 | 250<br>190 | Mont | 4 |
| - | 476936 | 994652 | - | 1.3<br>2.8 | Black clay<br>Gray clay | 38.40<br>39.60 | 101<br>105 | 4 | 43<br>39 | 58.0<br>66.0 | 4 | - | - | 0.81 | 2 | 76.0<br>81.0 | 3 | 420<br>320 | Illite | 3 |
| - | 476839 | 993360 | - | 1.3<br>2.8 | Black clay<br>Gray clay | 37.50<br>42.00 | 110<br>121 | 4 | 34<br>37 | 76.0<br>84.0 | 4 | - | - | 1.16 | 2 | 65.0<br>72.0 | 3 | 300<br>108 | Mont | 4 |
| - | 485893 | 997096 | - | 1.3 | Black clay | 37.60 | 96 | 4 | 42 | 54.0 | 4 | - | - | 0.82 | 2 | 60.0 | 3 | 267 | Illite | 3 |
| | | | | 2.8 | Gray clay | 44.30 | 111 | | 47 | 64.0 | | | | | | 78.0 | | 109 | | |
| - | 470282 | 989330 | - | 1.3 | Black clay | 33.20 | 96 | 4 | 36 | 60 | 4 | - | - | 0.96 | 2 | 62 | 3 | 210 | Illite | 3 |
| - | 474075 | 986145 | - | 1.3 | Black clay | 42.00 | 105 | 4 | 40 | 65.0 | 4 | - | - | 0.83 | 2 | 72 | 3 | 200 | Illite | 3 |
| | | | | 2.8 | Gray clay | 40.00 | 110 | | 45 | 65.0 | | | | | | 78 | | 323 | | |
| - | 479270 | 995542 | - | 1.3 | Black clay | 40.00 | 96 | 4 | 42 | 54.0 | 4 | - | - | 1.26 | 3 | 67 | 3 | 199 | Mont | 4 |

| | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 2.8 | Gray clay | 42.10 | 101 | | 38 | 63.0 | | | | | | 50 | | 248 | | |
| - | 469889 | 993446 | - | 1.3 | Black clay | 38.00 | 106 | 4 | 41 | 65.0 | 4 | - | - | 1 | 2 | 65 | 3 | 108 | Mont | 4 |
| | | | | 2.8 | Gray clay | | | | | | | | | | | | | | | |
| - | 474235 | 994452 | - | 1.3 | Black clay | 35.00 | 98 | 4 | 26 | 72.0 | 4 | - | - | 1.04 | 2 | 66 | 3 | 285 | Mont | 4 |
| | | | | 2.8 | Gray clay | 37.00 | 101 | | 28 | 73.0 | | | | | | 70 | | 293 | | |
| | 473583 | 998162 | 2419 | 2 | Dark brown | | 50.82 | 2 | 36.4 | 14.3 | 2 | 52.5 | 2 | 0.24 | 1 | 62.62 | 3 | | Halloy | 2 |
| - | 468899 | 999975 | 2206 | 2 | Red High | - | 46 | 2 | 27 | 19 | 2 | 47 | 1 | 0.47 | 1 | 40 | 2 | - | Kaoli | 2 |
| - | 465700 | 997621 | 2460 | 3 | Red High | - | 50 | 2 | 33 | 18 | 2 | 54 | 2 | 0.58 | 1 | 31 | 2 | - | Kaoli | 2 |
| - | 469476 | 100182 | 2415 | 4 | Red High | - | 64 | 3 | 32 | 32 | 3 | 40 | 1 | 1.23 | 1 | 26 | 1 | - | Mont | 4 |
| - | 463176 | 992753 | 2356 | 2 | Red High | - | 55 | 3 | 30 | 25 | 2 | 40 | 1 | 0.71 | 1 | 35 | 2 | - | Illite | 3 |
| - | 467100 | 1000550 | 2517 | 4 | Red High | - | 73 | 4 | 35 | 38 | 3 | 90 | 2 | 1.72 | 3 | 22 | 1 | 62 | Mont | 3 |
| - | 463207 | 995751 | 2413 | 2.5 | High Plastic | - | 71 | 4 | 34 | 37 | 3 | 60 | 2 | 0.61 | 1 | 60 | 2 | - | Illte | 3 |
| - | 463465 | 995757 | 2235 | 4.1 | Low Plastic | - | 49 | 2 | 25 | 24 | 2 | 60 | 2 | 0.38 | 1 | 63 | 3 | - | Kaol | 2 |
| - | 463383 | 995856 | 2335 | 3.5 | High Plastic | - | 46 | 2 | 26 | 20 | 2 | 40 | 1 | 0.29 | 1 | 67 | 3 | - | Kaoli | 2 |
| - | 463359 | 995926 | 2213 | 2 | High Plastic | - | 60 | 3 | 24 | 36 | 3 | 60 | 2 | 0.73 | 1 | 49 | 2 | - | Kaol | 2 |
| - | 463158 | 995774 | 2356 | 3 | Claye SILT | - | 66 | 3 | 16 | 50 | 4 | 95 | 2 | 1.85 | 3 | 27 | 1 | - | Mont | 4 |
| - | 463152 | 992759 | 2410 | 2 | Claye SILT | - | 84 | 4 | 30 | 54 | 4 | 50 | 1 | | | - | | - | - | |
| - | 464433 | 994782 | 2442 | 2 | Silty CLAY | - | 82 | 4 | 50 | 30 | 3 | 45 | 1 | 0.73 | 1 | 41 | 2 | - | Illite | 3 |
| - | 469018 | 1002911 | 2623 | 2 | Caye CLAY | - | 62 | 3 | 34 | 28 | 3 | 40 | 1 | - | | - | | - | - | |
| - | 466686 | 992756 | 2316 | 2 | clay SILT | - | 49 | 2 | 27 | 22 | 2 | 30 | 1 | 0.51 | | 43 | 2 | - | - | |
| - | 469198 | 995712 | 2354 | 6 | Claye SILT | - | 49 | 2 | 22 | 27 | 3 | 25 | 1 | - | | - | | - | - | |
| - | 462674 | 992746 | 2510 | 2.5 | Silt CLAY | - | 54 | 3 | 36 | 18 | 2 | 41 | 1 | - | | - | | 5 | - | |
| - | 462833 | 992707 | 2332 | 4 | silty CLAY | - | 51 | 2 | 27 | 24 | 2 | 46 | 1 | 1.26 | 3 | 19 | 1 | 14 | Mont | 4 |
| - | 462833 | 992840 | 2415 | 2 | Plas SILT | - | 60 | 3 | 39 | 21 | 2 | 40 | 1 | - | | - | | 11 | - | |
| - | 467586 | 999375 | 2453 | 6 | silty CLAY | - | 68 | 3 | 11 | 59 | 4 | 90 | 2 | - | | - | | 43 | - | |
| - | 462665 | 992818 | 2452 | 2 | Plas SILT | - | 96 | 4 | 67 | 29 | 3 | 60 | 2 | 0.9 | 2 | 32 | 2 | - | Illite | 3 |
| - | 466727 | 998734 | 2433 | 3 | silty CLAY | - | 55 | 3 | 25 | 30 | 3 | 65 | 2 | 1.11 | 2 | 27 | 1 | - | Mont | 3 |
| CMC | 487694 | 991024 | 2297 | 3 | Light grey | 43 | 73 | 4 | 48 | 25 | 2 | 120 | 3 | 0.4 | | 61 | 3 | - | Kaoli | 2 |
| Ayat | 486076 | 993243 | 2301 | 3 | Dark grey | 41 | 55 | 3 | 38 | 17 | 2 | 120 | 3 | - | | - | | - | | |
| Ayat 5 | 484020 | 995563 | 2367 | 3 | Light gray | 38 | 68 | 3 | 41 | 27 | 3 | 130 | 3 | 0.45 | 1 | 59 | 2 | - | Kaoli | 2 |
| Aa yat | 485861 | 994564 | 2307 | 3 | Light dark | 40 | 62 | 3 | 43 | 19 | 3 | 130 | 3 | 0.3 | 1 | 62 | 3 | - | Kaoli | 2 |
| Summit | 484493 | 992400 | 2306 | 3 | Tuff | 44 | 52 | 3 | 36 | 16 | 2 | 110 | 3 | 0.25 | 1 | 64 | 3 | - | Kaoli | 2 |
| Ayat | 488306 | 996620 | 2216 | 3 | Light grey | 45 | 59 | 3 | 38 | 21 | 2 | 110 | 3 | - | | - | | - | - | |
| Arabsa | 487946 | 993990 | 2306 | 3 | silty clay | 39 | 95 | 4 | 47 | 48 | 4 | 120 | 3 | 0.81 | 2 | 59 | 2 | - | Illite | 3 |
| - | 483741 | 994902 | - | - | clay SILT | - | 97 | 4 | 49 | 48 | 4 | 110 | 3 | - | | - | | - | - | |
| - | 483127 | 995979 | - | - | silty CLAY | - | 102 | 4 | 56 | 46 | 4 | 130 | 3 | - | | - | | - | - | |
| - | 483207 | 995979 | - | - | silty clay | - | 105 | 4 | 56 | 49 | 4 | 100 | 2 | - | | - | | - | - | |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| - | 484039 | 996104 | - | - | Gra CLAY | - | 100 | 4 | 57 | 43 | 4 | 100 | 2 | - | | - | | - | - | |
| - | 484198 | 996799 | - | - | Silt CLAY | - | 98 | 4 | 48 | 50 | 4 | 130 | 3 | - | | - | | - | - | |
| - | 484627 | 996001 | - | - | Silty CLAY | - | 107 | 4 | 53 | 54 | 4 | 130 | 3 | 1.2 | 2 | 45 | 2 | - | Mont | 3 |
| - | 484600 | 996144 | - | - | silty CLAY | - | 111 | 4 | 66 | 45 | 4 | 110 | 3 | - | | - | | - | - | |
| - | 484692 | 995772 | - | - | silty CLAY | - | 99 | 4 | 53 | 46 | 4 | 120 | 3 | - | | - | | - | - | |
| - | 484652 | 996244 | - | - | silty CLAY | - | 90 | 4 | 43 | 47 | 4 | 110 | 3 | - | | - | | - | - | |
| - | 484638 | 996416 | - | - | silty CLAY | - | 93 | 4 | 38 | 55 | 4 | 105 | 3 | - | | - | | - | - | |
| - | 484948 | 996423 | - | - | silty CLAY | - | 101 | 4 | 45 | 56 | 4 | 120 | 3 | - | | - | | - | - | |
| - | 484971 | 996064 | - | - | silty CLAY | - | 103 | 4 | 57 | 46 | 4 | 160 | 3 | - | | - | | - | - | |
| - | 484807 | 996875 | - | - | silty CLAY | - | 97 | 4 | 52 | 45 | 4 | 100 | 2 | - | | - | | - | - | |
| - | 484874 | 996824 | - | - | silty CLAY | - | 103 | 4 | 57 | 46 | 4 | 180 | 3 | - | | - | | - | - | |
| - | 484810 | 996823 | - | - | silty CLAY | - | 103 | 4 | 57 | 46 | 4 | 130 | 3 | - | | - | | - | - | |
| - | 484957 | 992866 | - | - | silty CLAY | - | 102 | 4 | 55 | 47 | 4 | 120 | 3 | - | | - | | - | - | |
| - | 484952 | 992952 | - | - | silty CLAY | - | 87 | 4 | 40 | 47 | 4 | 100 | 2 | - | | - | | - | - | |
| - | 483660 | 994602 | - | - | silty CLAY | - | 97 | 4 | 52 | 45 | 4 | 140 | 3 | - | | - | | - | - | |
| - | 483335 | 994718 | - | - | silty CLAY | - | 109 | 4 | 60 | 49 | 4 | 110 | 3 | - | | - | | - | - | |
| - | 483353 | 994721 | - | - | silty CLAY | - | 100 | 4 | 59 | 41 | 4 | 110 | 3 | - | | - | | - | - | |
| - | 483332 | 994670 | - | - | silty CLAY | - | 93 | 4 | 45 | 48 | 4 | 130 | 3 | - | | - | | - | - | |
| - | 483349 | 994680 | - | - | silty CLAY | - | 106 | 4 | 58 | 48 | 4 | 140 | 3 | - | | - | | - | - | |
| - | 483390 | 994671 | - | - | silty CLAY | - | 104 | 4 | 52 | 52 | 4 | 150 | 3 | - | | - | | - | - | |
| - | 483407 | 994681 | - | - | silty CLAY | - | 113 | 4 | 67 | 46 | 4 | 140 | 3 | - | | - | | - | - | |
| - | 483415 | 994715 | - | - | Claye SILT | - | 108 | 4 | 63 | 45 | 4 | 100 | 2 | - | | - | | - | - | |
| - | 483391 | 994712 | - | - | silty CLAY | - | 97 | 4 | 47 | 50 | 4 | 115 | 3 | - | | - | | - | - | |
| - | 483482 | 994661 | - | - | silty CLAY | - | 99 | 4 | 65 | 34 | 3 | 120 | 3 | - | | - | | - | - | |
| - | 483537 | 994666 | - | - | silty CLAY | - | 103 | 4 | 54 | 49 | 4 | 130 | 3 | - | | - | | - | - | |
| - | 483547 | 994689 | - | - | silty CLAY | - | 98 | 4 | 48 | 50 | 4 | 130 | 3 | - | | - | | - | - | |
| - | 483444 | 994622 | - | - | silty CLAY | - | 92 | 4 | 45 | 47 | 4 | 140 | 3 | - | | - | | - | - | |
| - | 483467 | 994632 | - | - | silty CLAY | - | 102 | 4 | 53 | 49 | 4 | 105 | 3 | - | | - | | - | - | |
| - | 483502 | 994624 | - | - | silty CLAY | - | 100 | 4 | 52 | 48 | 4 | 140 | 3 | - | | - | | - | - | |
| - | 483525 | 994634 | - | - | silty CLAY | - | 104 | 4 | 59 | 45 | 4 | 120 | 3 | 0.76 | 2 | 59 | 2 | - | Illite | 3 |
| - | 483470 | 994502 | - | - | silty CLAY | - | 97 | 4 | 54 | 43 | 4 | 110 | 3 | - | | - | | - | - | |
| - | 483446 | 994497 | - | - | clayey SIL | - | 97 | 4 | 57 | 40 | 4 | 100 | 2 | 0.65 | 1 | 61 | 3 | - | Illite | 3 |
| - | 483497 | 994502 | - | - | claye SILT | - | 106 | 4 | 61 | 45 | 4 | 170 | 3 | - | | - | | - | - | |
| - | 483510 | 994516 | - | - | claye SILT | - | 101 | 4 | 57 | 44 | 4 | 170 | 3 | - | | - | | - | - | |
| - | 483142 | 991319 | - | - | silty CLAY | - | 95 | 4 | 51 | 44 | 4 | 160 | 3 | - | | - | | - | - | |
| - | 483198 | 990875 | - | - | claye SILT | - | 101 | 4 | 57 | 44 | 4 | 140 | 3 | - | | - | | - | - | |
| - | 483087 | 990316 | - | - | Claye SILT | - | 101 | 4 | 53 | 48 | 4 | 150 | 3 | - | | - | | - | - | |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| - | 483210 | 990301 | - | - | claye SILT | - | 105 | 4 | 60 | 45 | 4 | 160 | 3 | - | | - | | - | - | |
| - | 483365 | 990599 | - | - | Claye SILT | - | 106 | 4 | 61 | 45 | 4 | 120 | 3 | - | | - | | - | - | |
| - | 483382 | 990359 | - | - | silty CLAY | - | 87 | 4 | 51 | 36 | 3 | 100 | 2 | - | | - | | - | - | |
| - | 484619 | 990734 | - | - | Claye SILT | - | 98 | 4 | 47 | 51 | 4 | 140 | 3 | - | | - | | - | - | |
| - | 483229 | 990626 | - | - | Claye SILT | - | 94 | 4 | 50 | 44 | 4 | 140 | 3 | - | | - | | - | - | |
| - | 483009 | 990713 | - | - | silty CLAY | - | 102 | 4 | 61 | 41 | 4 | 95 | 2 | - | | - | | - | - | |
| - | 484050 | 991167 | - | - | claye SILT | - | 95 | 4 | 52 | 43 | 4 | 90 | 2 | - | | - | | - | - | |
| - | 484169 | 990441 | - | - | claye SILT | - | 101 | 4 | 56 | 45 | 4 | 120 | 3 | - | | - | | - | - | |
| - | 484158 | 991625 | - | - | silty CLAY | - | 101 | 4 | 57 | 44 | 4 | 150 | 3 | - | | - | | - | - | |
| - | 486223 | 990874 | - | - | grav CLA | - | 47 | 2 | 30 | 17 | 2 | - | | 0.62 | 1 | 27 | 1 | - | Illite | 3 |
| - | 486218 | 990838 | - | - | grav SAN | - | 42 | 2 | 20 | 22 | 2 | - | | 1.04 | 2 | 21 | 1 | - | Mont | 3 |
| - | 486215 | 990814 | - | - | claye SILT | - | 51 | 2 | 17 | 34 | 3 | - | | - | | - | | - | - | |
| - | 486209 | 990780 | - | - | San CLAY | - | 42 | 2 | 17 | 25 | 2 | - | | - | | - | | - | - | |
| - | 486272 | 990780 | - | - | silty SAND | - | 40 | 2 | 8 | 32 | 3 | - | | - | | - | | - | - | |
| - | 486268 | 990757 | - | - | san SILT | - | 37 | 2 | 9 | 29 | 3 | - | | - | | - | | - | - | |
| - | 486204 | 990748 | - | - | claye GRA | - | 28 | 1 | 11 | 17 | 2 | - | | - | | - | | - | - | |
| - | 486207 | 990724 | - | - | clay GRA | - | 26 | 1 | 11 | 15 | 2 | - | | - | | - | | - | - | |
| - | 486251 | 990715 | - | - | silty GRA | - | 43 | 2 | 12 | 31 | 3 | - | | - | | - | | - | - | |
| - | 486263 | 990735 | - | - | silty GRA | - | 47 | 2 | 17 | 30 | 3 | - | | - | | - | | - | - | |
| - | 486191 | 990659 | - | - | claye GRA | - | 28 | 1 | 11 | 17 | 2 | - | | - | | - | | - | - | |
| - | 486231 | 990678 | - | - | silty GRA | - | 49 | 2 | 12 | 37 | 3 | - | | - | | - | | - | - | |
| - | 486227 | 990643 | - | - | Claye GRA | - | 22 | 1 | 7 | 15 | 2 | - | | - | | - | | - | - | |
| - | 486182 | 990640 | - | - | silt SAND | - | 69 | 3 | 17 | 52 | 4 | - | | - | | - | | - | - | |
| - | 486178 | 990608 | - | - | silty SAND | - | 56 | 3 | 13 | 43 | 4 | - | | - | | - | | - | - | |
| - | 486181 | 990585 | - | - | sandy SILT | - | 61 | 3 | 16 | 45 | 4 | - | | - | | - | | - | - | |
| - | 488042 | 991754 | - | - | silty SAND | - | 58 | 3 | 20 | 38 | 3 | - | | - | | - | | - | - | |
| - | 488020 | 991702 | - | - | claye SILT | - | 52 | 3 | 19 | 33 | 3 | - | | - | | - | | - | - | |
| - | 488002 | 991702 | - | - | silty SAND | - | 54 | 3 | 31 | 23 | 2 | - | | - | | - | | - | - | |
| - | 488043 | 991557 | - | - | silty GRA | - | 48 | 2 | 13 | 35 | 3 | - | | - | | - | | - | - | |
| Goffa | 472405 | 992109 | - | - | - | - | 91 | 4 | 48 | 43 | 4 | 91 | 2 | - | | - | | 174 | - | |
| Megena | 479013 | 996783 | - | - | - | - | 103 | 4 | 38 | 64 | 4 | 100 | 2 | - | | - | | 191 | - | |
| Jem-gar | 470829 | 987485 | - | - | - | 46 | 74 | 4 | 38 | 36 | 3 | 90 | 2 | - | | - | | 172 | - | |
| B. Bulbu | 474976 | 991934 | - | - | - | 43 | 73 | 4 | 38 | 35 | 3 | 165 | 3 | 0.89 | 2 | 39 | 2 | 315 | Illite | 3 |
| B. Air Po | 481286 | 991318 | - | - | - | 42 | 102 | 4 | 40 | 62 | 4 | 195 | 3 | - | | - | | 357 | - | |
| Akaki Tir | 477069 | 981229 | - | - | - | 30 | 68 | 3 | 34 | 34 | 3 | 78 | 2 | - | | 50 | 2 | 148 | Illite | 3 |
| Ayer Ten | 466720 | 992952 | - | 2.70 | - | - | 53.1 | 3 | 31.3 | 21.7 | 2 | 40 | 1 | - | | - | | - | - | |
| Mekanis | 470468 | 993538 | - | 2.70 | - | - | 110 | 4 | 45.4 | 64.2 | 4 | 100 | 2 | 1.16 | 2 | 55 | 2 | - | Mont | 4 |
| Kirkos | 473967 | 995116 | - | 3.0 | - | - | 97 | 4 | - | 64.0 | 4 | 200 | 3 | - | | - | | - | - | |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Lideta | 471109 | 996148 | - | 3.0 | - | - | 79.1 | 4 | 38.4 | 40.6 | 4 | 90 | 2 | - | | - | | - | - | |
| Kality | 476002 | 981235 | - | 2.8 | - | - | 88.9 | 4 | 44.7 | 44.1 | 4 | 120 | 3 | - | | - | | - | - | |
| Bole | 475132 | 992940 | - | 3.0 | - | - | 98.0 | 4 | 49.0 | 48.9 | 4 | 140 | 3 | 0.75 | 2 | 65 | 3 | - | Illite | 3 |
| Bole area | 475104 | 990894 | - | 1.9 | Black clay | 31.8 | 110 | 4 | 40 | 75.0 | 4 | 89 | 2 | 1.05 | 2 | 71 | 3 | 300 | 81-25 %mon | 4 |
| Bole area | 476072 | 991063 | | 2 | Black clay | 34 | 117 | 4 | 37.5 | 79.5 | 4 | 100 | 2 | 1.17 | 2 | 67.6 | 3 | 320 | 60-75%m | 4 |
| Bole area | 478128 | 990761 | - | 3.5 | Black clay | 29.5 | 98 | 4 | 32.1 | 65.9 | 4 | 75 | 2 | 1.02 | 2 | 65.8 | 3 | - | 80-85 %mon | 4 |
| Bole area | 479011 | 990717 | | 0.6 | Gray clay | 39 | 96 | 4 | 42 | 54.0 | 4 | 55 | 2 | 0.72 | 1 | 75.4 | 3 | 310 | 60-70%m | 4 |
| Bole area | 479865 | 990710 | - | 0.5 | Gray clay | 17.7 | 26.5 | 1 | - | - | | - | | - | | 74 | 3 | - | 80-90 | 4 |
| Bole area | 480277 | 995645 | - | 2.2 | Gray clay | 38 | 110 | 4 | 42.6 | 67.4 | 4 | 113 | 3 | 0.82 | 2 | 81.2 | 3 | - | 70-75 | 4 |
| Bole area | 478444 | 994669 | - | 0.5 | Gray clay | 32 | 105 | 4 | 36.6 | 68.4 | 4 | 126 | 3 | 0.97 | 2 | 70 | 3 | - | 80-90 | 4 |
| Bole area | 476701 | 993796 | - | 2.2 | Silty clay | 33 | 98 | 4 | 36.4 | 61.6 | 4 | 105 | 3 | 0.72 | 1 | 84.4 | 3 | - | 80-85 | 4 |
| Bole area | 475793 | 993244 | - | 3.0 | Silty clay | 39 | 120 | 4 | 43.5 | 76.5 | 4 | 130 | 3 | 1.08 | 2 | 70.4 | | 320 | 70-80 | 4 |
| Bole area | 474262 | 992760 | - | 2.8 | Gray clay | 31.1 | 110 | 4 | 33.1 | 76.9 | 4 | 115 | 3 | 0.9 | 2 | 84.7 | 3 | | 80-85 | 4 |
| Bole area | 476240 | 994409 | - | 1.25 | Silty clay | 43.7 | 125 | 4 | 44.9 | 80.1 | 4 | 125 | 3 | 1.21 | 2 | 65.8 | 3 | 310 | 80-85 | 4 |
| Bole area | 480686 | 994341 | - | 1.4 | Silty clay | 31.3 | 103 | 4 | 34 | 69 | 4 | 85 | 2 | 1.04 | 2 | 66 | 3 | - | 80-90 | 4 |
| - | 485076 | 996840 | - | 0.3 | - | - | 36.8 | 2 | 16.4 | 20.4 | 2 | 10.0 | 1 | - | | - | | - | Kaoli | 2 |
| - | 484645 | 996893 | - | 0.3 | - | - | 37.7 | 2 | 23.0 | 14.7 | 2 | 60.0 | 2 | - | | - | | - | Kaoli | 2 |
| - | 485305 | 997275 | - | 0.3 | - | - | 33.7 | 2 | 15.4 | 18.3 | 2 | 20.0 | 1 | - | | - | | - | Kaoli | 2 |
| - | 484924 | 998700 | - | 0.3 | - | - | 52.8 | 3 | 29.4 | 23.4 | 2 | 60.0 | 2 | - | | - | | - | Smec | 2 |
| - | 483286 | 996537 | - | 0.3 | - | - | 84.8 | 4 | 37.4 | 47.4 | 4 | 140 | 3 | - | | - | | - | Smec | 2 |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| - | 483463 | 996925 | - | 0.3 | - | - | 62.6 | 3 | 26.3 | 36.3 | 3 | 60.0 | 2 | - | | - | | - | Smec | 2 |
| - | 483395 | 998602 | - | 0.3 | - | - | 48.0 | 2 | 31.0 | 17.0 | 2 | 40.0 | 1 | - | | - | | - | Halloy | 1 |
| - | 484532 | 997869 | - | 0.3 | - | - | 59.2 | 3 | 25.9 | 33.3 | 3 | 90.0 | 2 | - | | - | | - | Mixt | 2 |
| - | 483949 | 998262 | - | 0.3 | - | - | 53.9 | 3 | 27.2 | 26.7 | 3 | 50.0 | 1 | - | | - | | - | Halloy | 1 |
| - | 484038 | 998554 | - | 0.3 | - | - | 50.0 | 2 | 18.3 | 31.7 | 3 | 30.0 | 1 | - | | - | | - | Mixt | 2 |
| - | 483586 | 999138 | - | 0.3 | - | - | 49.7 | 2 | 39.4 | 10.3 | 1 | 20.0 | 1 | - | | - | | - | Halloy | 1 |
| - | 482283 | 998909 | - | 0.3 | - | - | 46.6 | 2 | 28.4 | 18.2 | 2 | 25.0 | 1 | - | | - | | - | Halloy | 1 |
| - | 483226 | 999048 | - | 0.3 | - | - | 41.7 | 2 | 15.7 | 26.0 | 3 | 10.0 | 1 | - | | - | | - | Smect | 3 |
| - | 482671 | 998722 | - | 0.3 | - | - | 58.1 | 3 | 30.2 | 27.9 | 3 | 40.0 | 1 | - | | - | | - | Halloy | 1 |
| - | 481903 | 1000321 | - | 0.3 | - | - | 46.3 | 2 | 20.0 | 26.3 | 3 | 70.0 | 2 | - | | - | | - | Halloy | 1 |
| - | 483516 | 999450 | - | 0.3 | - | - | 41.2 | 2 | 18.8 | 22.4 | 2 | 40.0 | 1 | - | | - | | - | Smect | 3 |
| - | 482838 | 999224 | - | 0.3 | - | - | 43.8 | 2 | 20.3 | 23.5 | 2 | 40.0 | 1 | - | | - | | - | Smect | 3 |
| - | 477913 | 1000511 | - | 0.3 | - | - | 47.6 | 2 | 23.7 | 23.9 | 2 | 40.0 | 1 | - | | - | | - | Halloy | 1 |
| - | 477630 | 1001229 | - | 0.3 | - | - | 57.0 | 3 | 34.5 | 22.5 | 2 | 40.0 | 1 | - | | - | | - | Halloy | 1 |
| - | 477215 | 1000384 | - | 0.3 | - | - | 32.0 | 1 | 14.0 | 18.0 | 2 | 35.0 | 1 | - | | - | | - | Mixt | 2 |
| - | 477253 | 1000507 | - | 0.3 | - | - | 49.4 | 2 | 24.7 | 24.7 | 2 | 30.0 | 1 | - | | - | | - | Halloy | 1 |
| - | 477428 | 999893 | - | 0.3 | - | - | 52.8 | 3 | 27.6 | 25.2 | 2 | 60.0 | 2 | - | | - | | - | Smect | 3 |
| - | 478693 | 1000913 | - | 0.3 | - | - | 50.0 | 2 | 30.3 | 19.7 | 2 | 30.0 | 1 | - | | - | | - | Smect | 3 |
| - | 479467 | 1000324 | - | 0.3 | - | - | 34.5 | 1 | 30.3 | 4.2 | 1 | 10.0 | 1 | - | | - | | - | Mixtu | 2 |
| - | 484233 | 998328 | - | 0.3 | - | - | 47.6 | 2 | 16.2 | 31.4 | 3 | 40.0 | 1 | - | | - | | - | Halloy | 1 |

| | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| - | 484492 | 995783 | - | 0.3 | - | - | 96.0 | 4 | 43.4 | 52.6 | 4 | 70.0 | 2 | - | | - | | - | Mixt | 2 |
| - | 485264 | 995426 | - | 0.3 | - | - | 91.2 | 4 | 35.6 | 55.6 | 4 | 80.0 | 2 | - | | - | | - | Mixt | 2 |
| - | 485442 | 995042 | - | 0.3 | - | - | 85.0 | 4 | 34.1 | 50.9 | 4 | 90.0 | 2 | - | | - | | - | Mixt | 2 |
| - | 482947 | 997677 | - | 0.3 | - | - | 73.0 | 4 | 34.0 | 39.0 | 3 | 105 | 3 | - | | - | | - | Mixt | 2 |
| - | 482358 | 998273 | - | 0.3 | - | - | 68.9 | 3 | 30.1 | 38.8 | 3 | 90.0 | 2 | - | | - | | - | Mixt | 2 |
| - | 485581 | 995878 | - | 0.3 | - | - | 82.6 | 4 | 53.7 | 28.9 | 3 | 20.0 | 1 | - | | - | | - | Halloy | 1 |
| - | 484878 | 996355 | - | 0.3 | - | - | 88.0 | 4 | 38.7 | 49.3 | 4 | 40.0 | 1 | - | | - | | - | Smect | 3 |
| - | 486810 | 996199 | - | 0.3 | - | - | 64.2 | 3 | 49.2 | 15.0 | 2 | 10.0 | 1 | - | | - | | - | Halloy | 1 |
| - | 484297 | 996208 | - | 0.3 | - | - | 89.0 | 4 | 47.0 | 42.0 | 4 | 75.0 | 2 | - | | - | | - | Mixt | 2 |
| - | 486126 | 996248 | - | 0.3 | - | - | 77.0 | 4 | 40.5 | 36.5 | 3 | 105 | 3 | - | | - | | - | Smect | 3 |
| - | 487418 | 999494 | - | 0.3 | - | - | 84.8 | 4 | 26.3 | 58.5 | 4 | 100 | 2 | - | | - | | - | Halloy | 1 |
| - | 476839 | 1001916 | - | 0.3 | - | - | 60.4 | 3 | 28.5 | 31.9 | 3 | 35.0 | 1 | - | | - | | - | Mixt | 2 |
| - | 476920 | 1002834 | - | 0.3 | - | - | 76.4 | 4 | 35.3 | 41.1 | 4 | 120 | 3 | - | | - | | - | Mixt | 2 |
| - | 476859 | 1003529 | - | 0.3 | - | - | 64.5 | 3 | 52.2 | 12.3 | 1 | 80.0 | 2 | - | | - | | - | Mixt | 2 |
| - | 476333 | 1002199 | - | 0.3 | - | - | 70.0 | 3 | 36.8 | 33.2 | 3 | 40.0 | 1 | - | | - | | - | Mixt | 2 |
| - | 476428 | 1001349 | - | 0.3 | - | - | 58.1 | 3 | 27.0 | 31.1 | 3 | 80.0 | 2 | - | | - | | - | Mixt | 2 |
| - | 476867 | 1000776 | - | 0.3 | - | - | 70.4 | 3 | 41.3 | 29.1 | 3 | 20.0 | 1 | - | | - | | - | Mixt | 2 |
| - | 477643 | 1000998 | - | 0.3 | - | - | 61.8 | 3 | 35.0 | 26.8 | 3 | 30.0 | 1 | - | | - | | - | Mixt | 2 |
| - | 478291 | 1000735 | - | 0.3 | - | - | 60.7 | 3 | 21.8 | 38.9 | 3 | 85.0 | 2 | - | | - | | - | Mixt | 2 |
| - | 478493 | 1000060 | - | 0.3 | - | - | 46.5 | 2 | 18.3 | 28.2 | 3 | 20.0 | 1 | - | | - | | - | Mixt | 2 |
| - | 478736 | 999032 | - | 0.3 | - | - | 50.1 | 2 | 25.7 | 24.4 | 2 | 85.0 | 2 | - | | - | | - | Mixt | 2 |
| - | 478743 | 998526 | - | 0.3 | - | - | 48.2 | 2 | 26.8 | 21.4 | 2 | 20.0 | 1 | - | | - | | - | Halloy | 1 |
| - | 477163 | 999130 | - | 0.3 | - | - | 51.4 | 3 | 25.1 | 26.3 | 3 | 50.0 | 1 | - | | - | | - | Halloy | 1 |
| - | 479789 | 998384 | - | 0.3 | - | - | 54.4 | 3 | 24.5 | 29.9 | 3 | 35.0 | 1 | - | | - | | - | Halloy | 1 |
| - | 477493 | 999119 | - | 0.3 | - | - | 33.4 | 1 | 28.9 | 4.5 | 1 | 40.0 | 1 | - | | - | | - | Mixtu | 2 |
| - | 477344 | 998727 | - | 0.3 | - | - | 59.4 | 3 | 29.2 | 30.2 | 3 | 20.0 | 1 | - | | - | | - | Mixt | 2 |
| - | 483649 | 998227 | - | 0.3 | - | - | 49.2 | 2 | 32.4 | 16.8 | 2 | 40.0 | 1 | - | | - | | - | Halloy | 1 |
| - | 483275 | 997,173 | - | 0.3 | - | - | 76.6 | 4 | 30.5 | 46.1 | 4 | 110 | 2 | - | | - | | - | Mixt | 2 |
| - | 483755 | 997504 | - | 0.3 | - | - | 49.5 | 2 | 25.0 | 24.5 | 2 | 30.0 | 1 | - | | - | | - | Mixt | 2 |
| - | 485598 | 998374 | - | 0.3 | - | - | 43.8 | 2 | 26.8 | 17.0 | 2 | 40.0 | 1 | - | | - | | - | Halloy | 1 |
| - | 485327 | 997795 | - | 0.3 | - | - | 59.5 | 3 | 37.6 | 21.9 | 2 | 20.0 | 1 | - | | - | | - | Mixt | 2 |
| - | 484211 | 997205 | - | 0.3 | - | - | 52.8 | 3 | 39.8 | 13.0 | 2 | 30.0 | 1 | - | | - | | - | Mixt | 2 |
| - | 486468 | 996840 | - | 0.3 | - | - | 50.5 | 2 | 35.1 | 15.4 | 2 | 10.0 | 1 | - | | - | | - | Mixt | 2 |
| - | 484665 | 995030 | - | 0.3 | - | - | 70.2 | 3 | 39.2 | 31.0 | 3 | 70.0 | 2 | - | | - | | - | Mixt | 2 |
| - | 485334 | 996583 | - | 0.3 | - | - | 58.8 | 3 | 38.7 | 20.1 | 2 | 105 | 3 | - | | - | | - | Smec | 3 |
| - | 486970 | 996780 | - | 0.3 | - | - | 62.2 | 3 | 49.7 | 12.5 | 1 | 10.0 | 1 | - | | - | | - | Smect | 3 |
| - | 476793 | 1002361 | - | 0.3 | - | - | 64.6 | 3 | 28.4 | 36.2 | 3 | 30.0 | 1 | - | | - | | - | Halloy | 1 |
| - | 477344 | 1002832 | - | 0.3 | - | - | 82.0 | 4 | 49 | 33.0 | 3 | 65.0 | 2 | - | | - | | - | Smect | 3 |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| - | 477845 | 1002651 | - | 0.3 | - | - | 26.0 | 1 | 14.5 | 11.5 | 1 | 20.0 | 1 | - | | - | | - | Mixt | 2 |
| - | 477619 | 1002286 | - | 0.3 | - | - | 62.6 | 3 | 34.5 | 28.1 | 3 | 20.0 | 1 | - | | - | | - | Halloy | 1 |
| - | 477966 | 1002234 | - | 0.3 | - | - | 74.8 | 4 | 42.4 | 32.4 | 3 | 40.0 | 1 | - | | - | | - | Mixt | 2 |
| - | 478020 | 1001590 | - | 0.3 | - | - | 45.4 | 2 | 34 | 11.4 | 1 | 20.0 | 1 | - | | - | | - | Mixt | 2 |
| - | 477553 | 1001731 | - | 0.3 | - | - | 33.6 | 1 | 30.6 | 3.0 | 1 | 30.0 | 1 | - | | - | | - | Mixt | 2 |
| - | 477134 | 1003372 | - | 0.3 | - | - | 61.7 | 3 | 44.3 | 17.4 | 2 | 45.0 | 1 | - | | - | | - | Mixt | 2 |
| - | 477384 | 1003318 | - | 0.3 | - | - | 79.6 | 4 | 60.5 | 19.1 | 2 | 60.0 | 2 | - | | - | | - | Smec | 3 |
| - | 477457 | 1003584 | - | 0.3 | - | - | 74.8 | 4 | 37.5 | 37.3 | 3 | 20.0 | 1 | - | | - | | - | Mixt | 2 |
| - | 477958 | 1003533 | - | 0.3 | - | - | 56.5 | 3 | 22.7 | 33.8 | 3 | 45.0 | 1 | - | | - | | - | Mixt | 2 |
| - | 478012 | 994630 | - | 0.3 | - | - | 95.4 | 4 | 40.9 | 54.5 | 4 | 150. | 3 | - | | - | | - | Smect | 3 |
| - | 478604 | 994429 | - | 0.3 | - | - | 105 | 4 | 46.8 | 59.0 | 4 | 180 | 3 | - | | - | | - | Smect | 3 |
| - | 478556 | 993981 | - | 0.3 | - | - | 92.4 | 4 | 37 | 55.4 | 4 | 185 | 3 | - | | - | | - | Smect | 3 |
| - | 478309 | 993651 | - | 0.3 | - | - | 92.0 | 4 | 45.4 | 46.6 | 4 | 100 | 2 | - | | - | | - | Smect | 3 |
| - | 478100 | 994002 | - | 0.3 | - | - | 96.0 | 4 | 45.4 | 50.6 | 4 | 150 | 3 | - | | - | | - | Smect | 3 |
| - | 477856 | 994418 | - | 0.3 | - | - | 90.2 | 4 | 42.3 | 47.9 | 4 | 170 | 3 | - | | - | | - | Smect | 3 |
| - | 485264 | 995426 | - | 0.3 | - | - | 90.0 | 4 | 38 | 52.0 | 4 | 74.0 | 2 | - | | - | | - | Smect | 3 |
| AMCE | 478615 | 996523 | - | 1.2 | Black | 38.6 | 102 | 4 | 24 | 78 | 4 | 130 | 3 | 1.6 | 3 | 50 | 3 | 125 | Mont | 4 |
| | | | | 2 | Gray | 32.6 | 123 | | 30 | 93 | | 120 | | 1.3 | | 70 | | 125 | | |
| Bole | 475008 | 994469 | - | 1 | Black | 32.4 | 110 | 4 | 35 | 75 | 4 | 150 | 3 | 1.3 | 3 | 60 | 3 | 188 | Mont | 4 |
| road | | | | 2 | Gray | 34.8 | 108 | | 22 | 76 | | 140 | | 1.4 | | 65 | | 220 | | |
| Civil | 477394 | 993248 | - | 1.2 | Black | 36.7 | 94 | 4 | 22 | 72 | 4 | 130 | 3 | 1.6 | 3 | 45 | 2 | 157 | Mont | 4 |
| Old airp | 473903 | 993340 | - | 1 | Black | 39.3 | 98 | 4 | 30 | 68 | 4 | 140 | 3 | 1.4 | 3 | 50 | 2 | 235 | Mont | 4 |
| Ya red | 476798 | 993085 | - | 1 | Black | 40.0 | 114 | 4 | 25 | 89 | 4 | 125 | 3 | 1.5 | 3 | 60 | 3 | 94 | Mont | 4 |
| chur | | | | 2 | Gray | 32.9 | 107 | | 25 | 82 | | 170 | | 1.8 | | 47 | | 188 | | |