



**ADDIS ABABA UNIVERSITY**  
**INSTITUTE OF TECHNOLOGY**  
**DEPARTEMENT OF CIVIL AND ENVIRONMENTAL ENGINEERING**

**FAILURE ASSESSMENT OF BURIED WATER MAIN CONSTRUCTED**

**IN**

**EXPANSIVE SOIL AREA OF ADDIS ABABA**

**BY**

**MUBAREK NASSIR**

A project submitted to the School of Graduate studies of Addis Ababa University in Partial fulfillment for the requirement of the Degree of Master of Engineering in Civil Engineering under Geotechnical Engineering

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## **ACKNOWLEDGEMENT**

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## **ABSTRACT**

This project gives information for the failure distribution of water supply main which is buried in susceptible areas of expansive soil of Addis Ababa and comparing with the area of non-expansive soil. It is known that the water supply line has several reasons to fail. External load exerted on the pipe, due to age, soil pressure, construction work along the line and internal pressure are among others. However, the concern of this project is the failure due to pressure. According to Addis Ababa Water and Sewerage Authority (AAWSA) failure data, if there is a failure and has no reason, then the failure data has been recorded as failure due to pressure.

Therefore, in this study an attempt was made to assess the failure data and the failure comparison to understand the cause for failure of water main in area of Expansive soils of Addis Ababa.

# Chapter one

## Introduction

### 1.1 Background

Expansive soils contain clay minerals that undergo significant volume changes with changes in moisture. Swelling is caused by the attraction of water molecules to plates of expanding clay minerals such as montmorillonite. The swelling behavior of the soil creates vertical and horizontal stresses that can potentially fail objects constructed on it. Layers of water molecules and hydrated cations are added between plates as the clay expands or swells (Keller, 1996). Generally, expansive clays have a high plasticity index, reflecting a tendency to take up much water while in the plastic state (Brown, 1979). The plasticity index is the numerical difference between the liquid and plastic limits. Respectively, the plastic and liquid limits are the moisture contents at which the soil changes from a semi-solid to a plastic and from a plastic to a liquid.

Montmorillonite is associated with most expansive soils. With the addition of water, this clay mineral may expand 15 to 20 times its dry volume (Brown, 1979). However, 25 to 50 percent expansion is more common in soils that contain various minerals and organic matter (Keller, 1996). Unfortunately, a volume increase of only 3 percent is potentially dangerous and requires special design considerations (Brown, 1979). A confined clay deposit containing montmorillonite can exert pressures of several tons per square meter (Brown, 1979).

Much of the previous work on expansive clays has focused on building foundations and roads. For example, Assessment on damages of BUILDINGS in expansive soils area of Addis Ababa (Afewerk Sisay, 2004) and the University of Texas at Arlington (UTA, 1978) studied the Effects of Expansive soils and Remedial measures on Residential, Monolithic slab foundations in the Eagle Ford and Taylor Formations of north-central Texas. The study involved ten damaged houses, overlying expansive soils derived from shale and marl bedrock. Allen and Flanigan (1986) sampled 228 foundation failures over several soil associations in Dallas County, Texas. Most of the damage was associated with soils having a high shrink-swell potential. In a study conducted by the City of Carrollton, Texas, 26 to 36 percent of the ten-year old homes surveyed had suffered damage to sheet rock and brick veneers that were attributed to expansive soils (Allen and Flanigan, 1986).

Pipes and other structures that are buried in montmorillonitic soils also are subject to damage caused by large hydration pressures (Day, 1994). With numerical modeling, Sorochan and Kim (1994) showed that wetting an expansive soil creates vertical and horizontal stresses that can ultimately crack objects enclosed in the soil. Moreover, the pressure component associated with swelling increases with an increasing vertical load. The load prevents loosening of the soil, leading to a stress increase in the backfill around the structure. This is especially true of water and sewage lines, where even minor damage can create leaks. Once a leak occurs, the water saturates the material next to the leak, compounding the problem by causing continued expansion or movement.

The buried water main bursts can lead to the loss of water. Once a leak occurs, the water can saturate the material next to the leak, and this leads the additional stress due to the increase of heaving effect and damage to surrounding infrastructures. The water losses due to pipe breaks may vary in different areas of Addis Ababa town. The maintenance cost of pipe and the cost due to loss of water can also be considerable amount.

### **1.2 Statement of the problem**

With the stress created by heave and shrinkage of the expansive soil, the pipe line tends to breaks/burst and occurrences of damages. The breaks of pipe tends to leak and since this occur; the water is going to be contaminated, damages can be caused to the surround structures, the profits of the company is also going to be less due to the loss of water.

### **1.3 Objective**

The main aim of this project is to assess water supply lines which are buried in expansive soil of Addis Ababa. The investigation results will provide information about the cause of failure and will be basis for new design and constructions of water supply lines on expansive soils.

#### **1.4 Specific objective**

To show the failure distribution of buried water supply line in an Expansive soil area of Addis Ababa

#### **1.5 Organization of the project**

The paper consists of five chapters. The first chapter is the introduction part and it discusses briefly about expansive soil and the objective of the project. The second chapter is literature review of expansive soil mineralogy, its distribution, soil moisture relationship of expansive soil, factors affecting swelling and shrinkage of expansive soils and buried pipe in an expansive soil. The third chapter comprises scope of the project, data collection and analyzing, expansive soil properties of Addis Ababa. The fourth chapter is about results and discussion. The fifth chapter is about conclusion part of the project.

## **Chapter two**

### **Literature review**

#### **2.1 General on expansive soil**

The engineering properties of expansive soil are greatly influenced by moisture. Soil and soft rock that tend to swell or shrink due to changes in moisture content are known as expansive soils. An expansive soil is recognized as a clayey soil which exhibits swell and shrinkage behavior with change in moisture content. The moisture may come from rain, flooding, leaking water from water supply lines or sewer lines, or from a reduction in surface evapo-transpiration when an area is covered by building. When a soil is referred to as expansive or when reference is made to swell potential, it should be recognized that there also exists a potential for shrinking or settlement to occur due to changes in moisture content. Thus, the term expansive soil and swell potential will generally be used in universal sense to refer to soils that both shrink and swell.

In the capital, Addis Ababa, it has been noticed that expansive soils cover large parts of the city where recent constructions are carried out. During the past decades, rapid expansion of the city and the growth of population due to migration from different parts of the country led to the construction of various structures, particularly low-cost buildings in the suburbs. The existence of expansive soils in the city has caused structural damages on light buildings, asphalt pavement, and buried utility lines (Eleyas Assefa and Samuel Tadesse, Journal of EEA, Vol. 30, 2013).

## **2.2 Expansive Soil Mineralogy**

The parent materials of expansive soils may be classified into two groups. The first group comprises the basic igneous rocks such as basalt, dolerite sills, dykes, gabbros and etc. where 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 sedimentary rocks that contain montmorillonite, and break down physically to form expansive soils.

In most cases, when we talk about the expansive soil, the clays are the most influential soil, which are very different from gravels, sands and silts. Clay particles have an effective diameter of two micron (0.002mm) or less in most soil classification system.

It is a known fact that the three most important groups of clay minerals are montmorillonite, illite, and kaolinite, which are crystalline hydrous aluminosilicates. Of these groups, it is the clay mineral montmorillonite that presents most of the foundation problems. Essentially, montmorillonite (also called the smectite group) is a three-layered mineral having a single octahedral alumina sheet sandwiched between two silica sheets. The units are stacked one above the other like leaves of a book. The bonds are comparatively weak, and water can enter between the sheets causing them to expand readily when water is removed from the boundary, the sheets contract. Thus soil containing substantial amounts of montmorillonite will exhibit high shrinkage and swelling characteristics.

Due to their chemical compositions and crystalline structures, these minerals have a different susceptibility to swelling. Among the three minerals, montmorillonite is the clay mineral that causes most soil to swell. Swelling occurs when water infiltrates between and within the clay particles, causing them to separate.

### 2.2.1 Montmorillonite

The basic structural unit of these mineral consists of an aluminum sheet sandwiched between two silica sheets. In the stacking of the silica-alumina- silica unit, oxygen layers of each unit are adjacent to oxygen's of the neighboring units with a consequence that there is a weak bond and an excellent cleavage between them (Dr.K.R Arora)

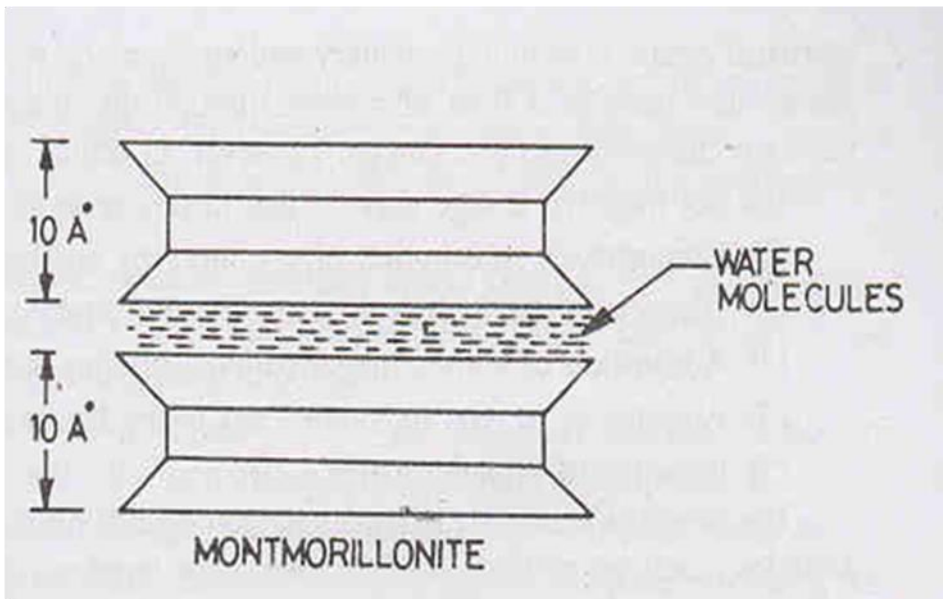


Fig. 2.1 structural unit of montmorillonite

### 2.2.2 Illite

The structural unit of the illite is the same as that for the montmorillonite except that some of the silicones are always replaced by aluminums and the resultant charge deficiency is balanced by potassium ions (Dr.K.R Arora).

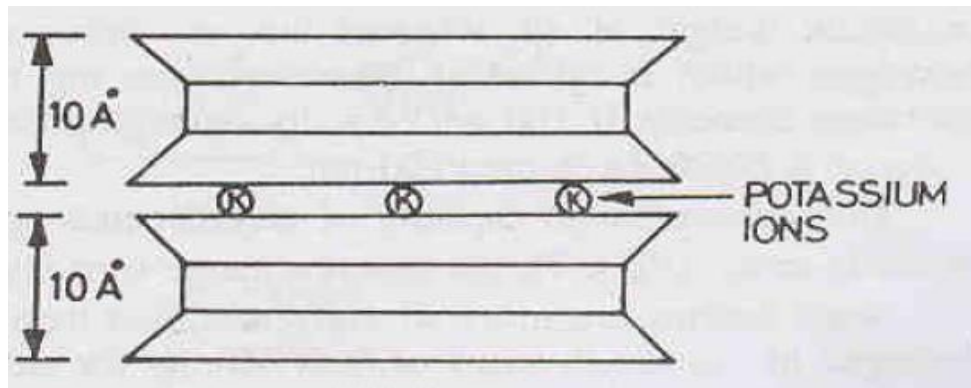


Fig. 2.2 structural unit of illite

### 2.2.3 Kaolinite

The structural unit of kaolinite consists of aluminum sheet (Gibbsite) and silica (S) sheets which the tips of the silica point towards to the base of the aluminum sheet and successive structural units are stacked by the hydrogen bond (Dr.K.R Arora).

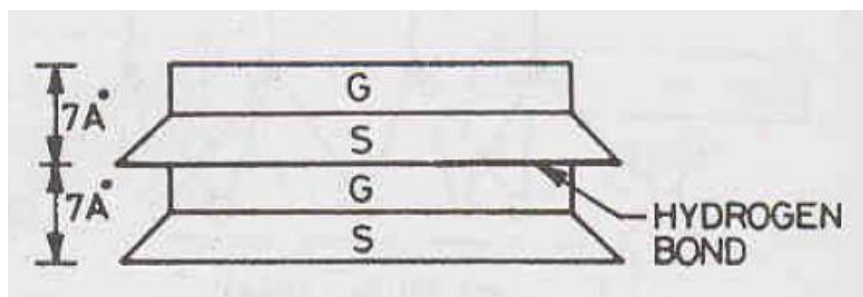


Fig. 2.3 structural unit of Kaolinite

## **2.3 Physical properties of Expansive soils**

Expansive soils can be classified on the basis of certain inherent characteristics of the soil. It is first necessary to understand certain basic parameters used in the classification.

### **2.3.1 Swelling Potential**

Swelling potential is defined as the percentage of swell of a laterally confined sample in an odometer test which is soaked under a surcharge load of 7 kPa (1 lb/in<sup>2</sup>) after being compact to maximum dry density at optimum moisture content according to the AASHTO compaction test.

### **2.3.2 Swelling Pressure**

The swelling pressure is defined as the pressure required for preventing volume expansion in soil in contact with water. It should be noted here that the swelling pressure measured in a laboratory odometer is different from that in the field. The actual field swelling pressure is always less than the one measured in the laboratory.

### **2.3.3 Free Swell**

Free swell  $S_f$  is defined as,

$$S_f = \left( \frac{V_f - V_i}{V_i} \right) * 100$$

Where:  $V_i$ =initial dry volume of poured soil

$V_f$ = final volume of poured soil

According to Holtz and Gibbs (1956),  $10 \text{ cm}^3$  ( $V_i$ ) of dry soil passing through a No. 40 sieve is poured into a  $100 \text{ cm}^3$  graduated cylinder filled with water. The volume of settled soils measured after 24 hours which gives the value of  $V_f$ . Bentonite-clay is supposed to have a free swell value ranging from 1200 to 2000 percent. The free swell value increases with plasticity index. Holtz and Gibbs suggested that soils having a free-swell value as low as 100 percent can cause considerable damage to lightly loaded structures and soils heaving a free swell value below 50 percent seldom exhibit appreciable volume change even under light loadings.

The swelling tendencies of expansive soils are quantified by the swell potential and swelling pressure parameters.

These expansive soil parameters can be directly estimated in the laboratory from special odometer tests and the differential free swell test.

Apart from these direct tests, soil mechanics practice for determining the engineering characteristics of expansive soils is usually based on the Atterberg Limits, sometimes in conjunction with grain size analysis.

However, swell potentials based on index properties are in far excess of the odometer swell potentials. The soil properties, external pressure, and wetting–drying process affect the swell potential and swell pressure of expansive soils.

## **2.4 Factors influencing swelling and shrinking of soil**

The swelling in expansive soil is influenced by a number of factors such as physical soil properties (plasticity or density). The factors influencing the shrink- swell potential of a soil can be categorized as soil characteristics and environmental factors.

### **2.4.1 Soil properties that influence shrink-swell potential**

**Clay mineralogy;** Clay minerals which typically cause soil volume changes are montmorillonite, vermiculite, and some mixed layer minerals. Illites and kaolinite are influentially expansive, but can cause volume changes when particle sizes are extremely fine (Grim (1968); Mitchell (1973, 1976); Snethen et al. (1977))

**Soil water chemistry;** Swelling is repressed by increasing cat ion concentration and increased cat ion valence. For example  $Mg^{2+}$  cations in the soil water would result in less swelling than  $Na^{+}$  cat ions (Mitchell (1976))

**Soil suction;** Soil suction is an independent effective stress variable, represented by negative pore pressure in unsaturated soils. Soil suction is released to saturation, gravity, pore size and shape, surface tension, and electrical and chemical characteristics of the soil particles and water (Snethen (1980); Fredlund and Morgensten (1977); Johnson (1973); Olsen and Langfelder (1965); Aitchison et al.)

**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 shrinking. Plasticity is an indicator for swelling potential.

**Soil structure and fabric;** Flocculated clay tends to be more expansive than dispersed clays. Cemented particles reduce swell. Fabric and structure are altered by compaction at higher water content or remolding. Kneading compaction has been shown to create dispersed structures with lower swelling potential than soils statically compacted at lower water contents. (Johnson and Snethen (1978); Seed et al. (1962a))

**Dry density;** higher densities usually indicate closer particle spacing's, which may mean greater repulsive forces between particles and large swelling potential. (Chen 1973; Komomik and David 1969; Upal 1965)

#### **2.4.2 Environmental conditions that influence shrink swell potential**

A desiccated expansive soil will have a higher affinity for water, or higher suction, than the same soil at higher suction, than the same soil at higher water content, lower suction conversely, at wet soil profile will lose water more readily on exposure to drying influences and shrink more than a relatively dry initial profile. The initial soil suction must be considered in conjunction with the expected range of final suction conditions. Moisture in the active zone near the upper part of the profile primarily define heave. It is in those layers that the widest variation in moisture and volume change will occur. (Johnson 1969)

Amount and variation of precipitation and evapotranspiration greatly influence the moisture availability and depth of seasonal moisture fluctuations. Greatest seasonal heave occurs in semi-arid climates that have pronounced short wet periods. Shallow water tables provide a source of moisture and fluctuating water tables contribute to moisture. (Holand and Lawrence 1980)

#### **2.4.3 Drainage and manmade water source**

Surface drainage features, such as ponding around a poorly graded house foundation provide source of water at the surface leaky plumbing can give the soil access to water at greater depth (Kraznyski 1980)

#### **2.4.4 Stress conditions**

An over consolidated soil is more expansive than the same soil at the same void ratio, but normally consolidated. Swell pressure 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 tends to reduce swell on laboratory samples, but after certain number of wetting drying cycles, swell is unaffected (Mitchell 1976; Kassiff and Baker 1971)

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 reduce swell

The problems associated with expansive soils are not widely appreciated by Architects, Engineers, Contractors and others who have not worked in expansive soils area.

The alternative shrinks and swells process causes, movement on soil. This movement is usually in an uneven pattern and of such a magnitude as to cause extensive damage to the structures, pavements, and underground conduits resting on it.

## **2.5 Pipe lines buried in general**

Pipes can be classified as flexible or rigid, depending on how they perform when installed. Flexible pipes take advantage of their ability to move or deflect, under load with structural damage. Common types of flexible pipes are manufactured from polyethylene, polyvinyl chloride, steel and aluminum. Rigid pipes are classified as pipes that cannot deflect more than 2% without significant structural distress such as cracking.

The soil-pipe interaction between both rigid and flexible pipe is different. Which means, when a load is applied to a rigid pipes then the load is transferred through the pipe wall to the surrounding materials. But on the other hand, when a flexible pipe is subjected to a load, the load is transferred to and carried by the surrounding materials.

### **2.5.1 Pipe line installation method**

Installation of the pipe lines below the ground surface has been found to be very attractive since it provides a convenient mode of critical loads for engineering design of buried pipes requires consideration of the internal pressure of transported fluid and/or external loads from the soil surrounding. For example, the design of high pressure lines under operating

conditions is mostly governed by the internal constant pressure (e.g. oil and gas pipe lines) as the external soil loads are comparatively small under typical operating conditions. In comparison, for pipe lines with relatively low internal pressure (e.g. water and sewer pipe lines); the soil overburden loads can be significant operating conditions.

Most pipe lines are buried at shallow depths below the ground for the ease of installation and access during maintenance or repair.

### **2.5.2 Effect of volume changes of expansive soil on buried pipes**

Expansive soils expand and contract severely as a function of moisture content. Soil expansion can cause an increase in soil pressure just as frost can cause an increase in soil pressure. This rise in pressure is directly due to expansion and is a function of confinement. Tremendously high pressures can result if such soils are confined between non-yielding surfaces. However, data are lacking concerning such forces which may be induced on buried conduits. This lack of data can probably be attributed to design practices that do not allow such soils to be placed directly around the pipe. Also, in the case of gravity sewers, designs usually require such material to be removed for certain depths below the pipe if moisture content is variable at such depths. The primary reason for this requirement is to ensure that the grade is maintained. The design engineer should be cognizant that expansive soils do pose certain potential problems. He or she should seek advice from a competent soils (geotechnical) engineer and then take appropriate steps in the installation design to mitigate adverse effects of expanding soil.

Large amounts of water may enter the soil during the rainy seasons and result in excessive soil heave. Conversely, a significant reduction in the water content during the dry seasons may result in the settlement of soils, as shown in Fig.2.4. The soil deformations were found to be induced on the underground pipes to such magnitudes as to cause them to fail, especially in the case of small diameter pipes. The level of soil stresses on the pipelines depends mainly on the nature of the soil, its natural degree of saturation, and the extent of variation in soil moisture. Morris (1967) and Clark (1971) reported that volume changes in clay were a considerable contributing factor to the high number of water main breaks. Newport (1981) observed that the high breakage rates occurred following very hot and dry summers. In general, a circular break of a pipeline is evidence of bending tensile stress conditions. Bending stresses on underground lines are mainly induced by earth movements.

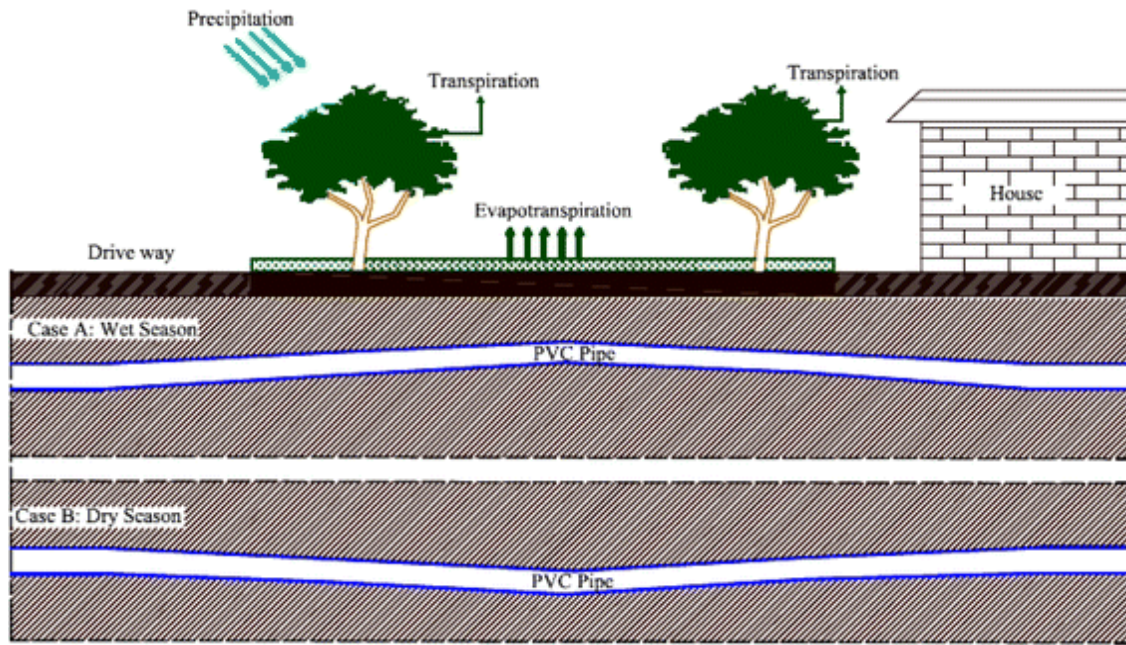


Fig.2.4 Schematic diagram of the effect of dry and wet soil conditions on a buried pipeline (after Rajeev et al., 2012)

## **Chapter three**

### **Materials and methodology**

#### **3.1 Scope of the project**

The study area, Addis Ababa is the capital city of Ethiopia that is located at 80 7" Northern latitude and 380 45" Eastern longitudes. The city is situated at downstream of the Entoto Mountain that as a result is having significant elevation differences among different localities. According to the 2007 census the Addis Ababa city has a total population 27384248 with a growth rate of 2.1% per annum.

#### **3.2 Administrative structure of Addis Ababa**

The administrative structure of Addis Ababa has three levels. These are the central city administration, sub-cities and Kebeles. The city is divided in to ten sub-cities and 99 kebeles. The administrative structure of the sub-cities of Addis Ababa is shown in fig.3.1

Addis Ababa Water and Sewerage Authority (AAWSA) is the governmental office that facilitates water supply distribution systems for Addis Ababa city, through different types and sizes of pipes. By taking in to consideration of the city's vastly expansion it also branched in six different areas which are Gulale branch, Mekanisa branch, Addis ketema branch, Gurd shola branch and Akakikalit branch. Those branches have duties of maintaining and/ or laying pipes diameter of 100mm and below. According to the AAWSA standards the heavy water supply lines are considered as the diameter of above 100mm

which is governed by the head office crew called **Heavy water supply line maintenance and lay.**

Water supply line damages are occurred by different reasons. Among these reasons, damages are caused by, Construction, age, corrosion, poor workmanship and internal pressure. But as several soil investigation researches indicated that in most regions of Addis Ababa, there is an expansive soil and this leads damages on several structures

### **3.3 Engineering properties of expansive soils of Addis Ababa**

According to Ethiopian Ministry of water and Energy, 2004, the dominant soil type of Addis Ababa is Pellic Vertisol which covers 277.25 sq.Km of Addis Ababa and found in the south and North part of the city. The second most dominant type of soil is Eutric Nitisol and covers 111.5 sq.Km of the city which is found in central and North West part of the region.

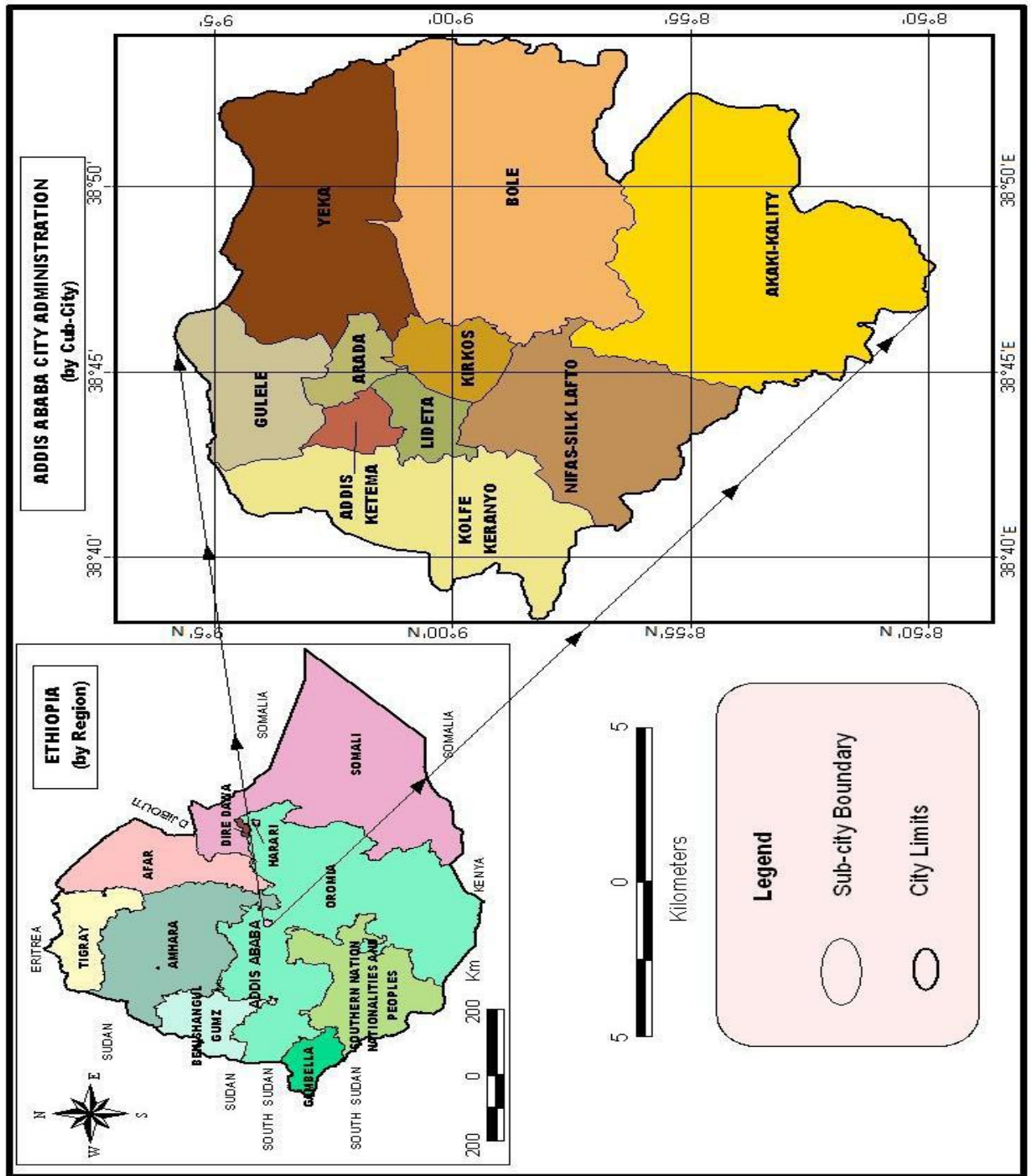


Fig 3.1 shows Location map of Addis Ababa

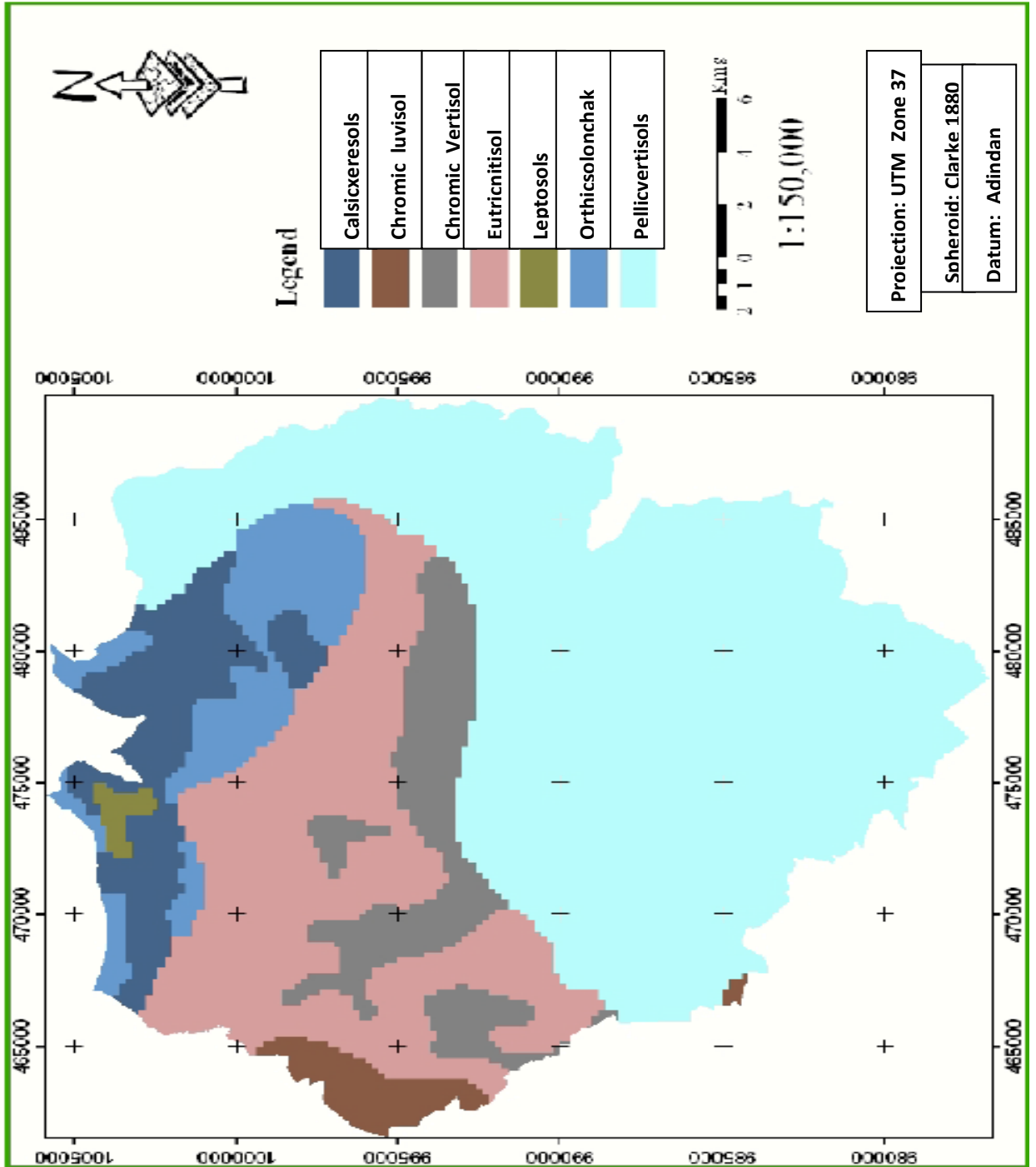


Fig3.2 Shows Soil map of Addis Ababa

### **3.3.1 Physical properties of Pellic Vertisol**

These groups of soils are heavy textured soils which occur extensively in the tropics, subtropics and warm temperature zones and known as dark clay and black cotton soils and have high water holding capacity (ICRISAT).

The basic properties of Vertisols that endows them with a high moisture holding capacity is their clay content which commonly lies between 40% to 60% it may be as high as 80% (Dudal 1965, Devos and Virgo 1969)

The dominant clay mineral in most of the Vertisols appears to be montmorillonite. This plus the high clay content appears to be the main reason for the high water holding capacity of vertisol.

From the laboratory tests, which are carried out by various researchers to determine the range for the property of expansive soil of Addis Ababa, the clay content for the expansive soil of Addis Ababa is found to be as high as 80% and the amount of montmorillonite is 70-80% [Table 3.1]. These soils have the ability to hold significant amount of water that affects the shear strength, as well as, shrinkage and swelling characteristics

Clay Minerals	Mineral content in (%)	
	Black clays	Gray clays
Montmorillonite	70-80	70-75
Illite	10-15	25-30
Kaolinite	10-15	10-15

Table3.1 Mineralogical composition of Addis Ababa expansive soils (source; Assessment of damages of buildings constructed in expansive soil by Afewerk Sisay 2004)

### 3.4 Data collection and Analysis

The failure data has been assessed from the Addis Ababa Water and Sewerage Authority. As tried to mention before, AAWSA has a crew of maintenance under the heavy water supply line maintenance and lay team. Accordingly, the team has collected the information about the failure of water supply line from different sources like; customers and the damage causing party. Gathered information is recorded as where and when the damage occurred. The cause of damages also recorded as due to; construction, age, poor workmanship and pressure. According to the crew information, most damages that have no cause for the damage is recorded as the damage caused by pressure.

የአድዳ አባይ ወንዝ ስርዓት

ተ.ቁ	አድዳ የደረሰበት ቀን/ሰዓት	አድዳ የደረሰበት ቦታ	አድዳ የደረሰበት የውሃ መጠን (ሊትር/ሰከ)	በአድዳ ግዝግብ ውስጥ የደረሰበት ለገጽ ብዛት	አድዳ የደረሰበት ምክንያት	አድዳ የደረሰበት ለክልል	ገንዘብ ተጠናቅቆ የሰጠበት ቀን/ሰዓት	የተጠናቀቀው ለገጽ ለገጽ ብዛት	ከገንዘብ ለገጽ ገንዘብ ለገጽ ብዛት (አገር/ቀበሌ/ወይን)	የደመወዝ
1	11/04/07	ጎረቤት	0.20	-	አገልግሎት	አገልግሎት	11/04/07	ጎረቤት ጎረቤት	-	2.6
2	11/04/07	አገልግሎት ስርዓት	0.30	-	አገልግሎት	አገልግሎት	12/04/07	አገልግሎት ስርዓት	-	2
3	12/04/07	አገልግሎት	0.30	-	አገልግሎት	አገልግሎት	12/04/07	አገልግሎት ስርዓት	-	18
4	13/04/07	አገልግሎት	0.30	-	አገልግሎት	አገልግሎት	13/04/07	አገልግሎት ስርዓት	-	6
5	14/04/07	አገልግሎት	0.45	-	አገልግሎት	አገልግሎት	14/04/07	አገልግሎት ስርዓት	-	18
6	14/04/07	አገልግሎት	0.20	-	አገልግሎት	አገልግሎት	14/04/07	አገልግሎት ስርዓት	-	12
7	15/04/07	አገልግሎት	0.15	-	አገልግሎት	አገልግሎት	15/04/07	አገልግሎት ስርዓት	-	6
8	15/04/07	አገልግሎት	0.20	-	አገልግሎት	አገልግሎት	15/04/07	አገልግሎት ስርዓት	-	4
9	16/04/07	አገልግሎት	0.20	-	አገልግሎት	አገልግሎት	16/04/07	አገልግሎት ስርዓት	-	-
10	16/04/07	አገልግሎት	0.25	-	አገልግሎት	አገልግሎት	16/04/07	አገልግሎት ስርዓት	-	10
11	17/04/07	አገልግሎት	0.25	-	አገልግሎት	አገልግሎት	17/04/07	አገልግሎት ስርዓት	-	18
12	18/04/07	አገልግሎት	0.25	1.20	አገልግሎት	አገልግሎት	18/04/07	አገልግሎት ስርዓት	-	-
13	17	አገልግሎት	0.15	-	አገልግሎት	አገልግሎት	18/04/07	አገልግሎት ስርዓት	-	8
14	19/04/07	አገልግሎት	0.20	-	አገልግሎት	አገልግሎት	19/04/07	አገልግሎት ስርዓት	-	-
15	20/04/07	አገልግሎት	0.20	-	አገልግሎት	አገልግሎት	20/04/07	አገልግሎት ስርዓት	-	-
16	21/04/07	አገልግሎት	0.20	0.20	አገልግሎት	አገልግሎት	21/04/07	አገልግሎት ስርዓት	-	10
17	22/04/07	አገልግሎት	0.15	-	አገልግሎት	አገልግሎት	22/04/07	አገልግሎት ስርዓት	-	8
18	23/04/07	አገልግሎት	0.15	-	አገልግሎት	አገልግሎት	23/04/07	አገልግሎት ስርዓት	-	8
19	24/04/07	አገልግሎት	0.15	0.30	አገልግሎት	አገልግሎት	24/04/07	አገልግሎት ስርዓት	-	12
20	25/04/07	አገልግሎት	0.15	-	አገልግሎት	አገልግሎት	25/04/07	አገልግሎት ስርዓት	-	-
21	25/04/07	አገልግሎት	0.20	-	አገልግሎት	አገልግሎት	25/04/07	አገልግሎት ስርዓት	-	9
22	26/04/07	አገልግሎት	0.15	-	አገልግሎት	አገልግሎት	26/04/07	አገልግሎት ስርዓት	-	-
23	29/04/07	አገልግሎት	0.15	2.00	አገልግሎት	አገልግሎት	29/04/07	አገልግሎት ስርዓት	-	-
24	30/04/07	አገልግሎት	0.15	-	አገልግሎት	አገልግሎት	30/04/07	አገልግሎት ስርዓት	-	-
25										

Fig 3.3 shows sample failure and maintenance report format

The above table indicates Addis Ababa water supply main maintenance report format in Amharic. The first column shows the serial number for the failure data. Second column shows the day damage found and recorded. Third column indicates the location where the damage occurred. Fourth column shows the quantity of water loss due to the damage. However, during the data assessment, there was a difficulty to quantify loss of water quantity and amount in birr. Because of the data sheet that didn't have fully recorded quantity of loss in volume and damages in length. Summarized table format for the failure data is shown in annex.

<b>Months</b>	<b>No. of failures (2007 E.C)</b>	<b>No. of failures (2008 E.C)</b>
September	7	16
October	12	21
November	14	19
December	8	13
January	17	16
February	6	19
March	15	26
April	19	27
May	17	28
Jun	15	20
July	25	24
August	30	27

Table 3.2 Monthly pipe failure data in Addis Ababa

<b>Sub-cities</b>	<b>No. of failures (2007 E.C)</b>	<b>No. of failures (2008 E.C)</b>
Addis Ketema	0	6
AkakiKality	29	43
Arada	8	4
Bole	66	64
Gulele	10	7
Kirkos	4	8
KolfeKeranio	21	29
Lideta	12	4
NifasS.Lafto	23	63
Yeka	12	25

Table 3.3 Failure distribution on sub-cities of Addis Ababa

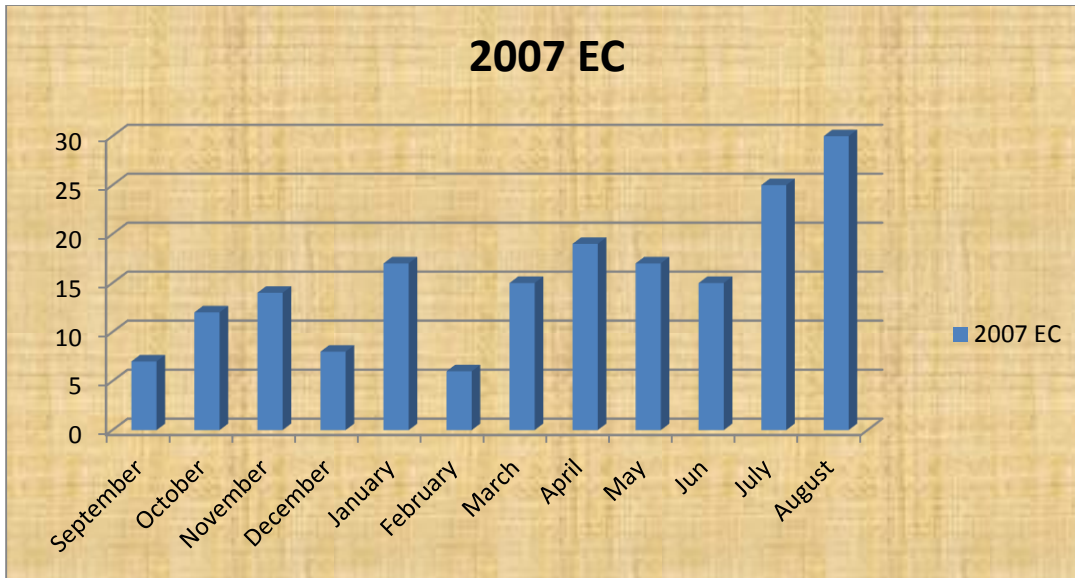


Fig 3.4 shows monthly failure on 2007

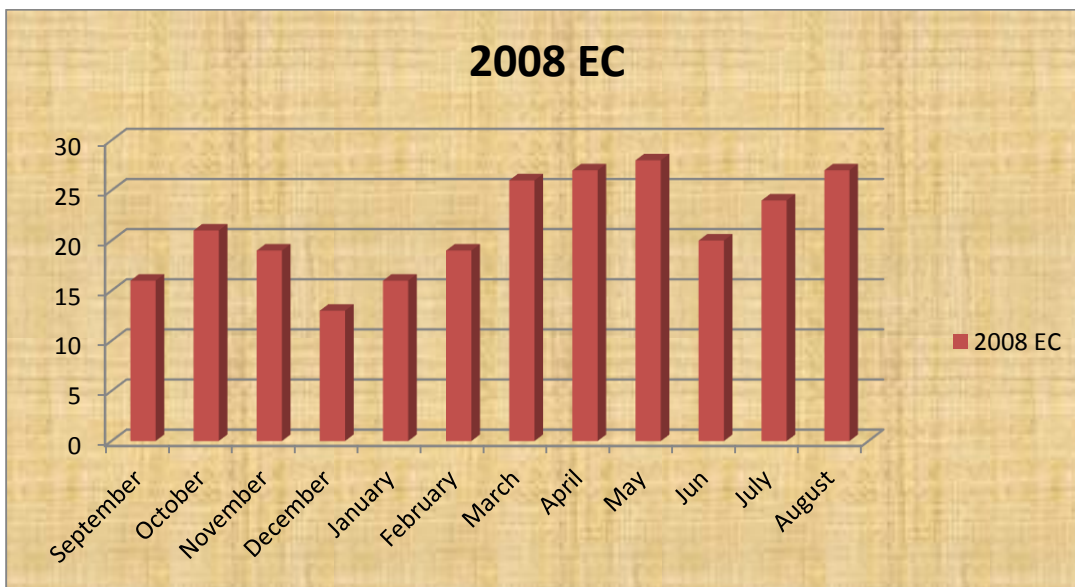


Fig 3.5 shows monthly failure on 2008

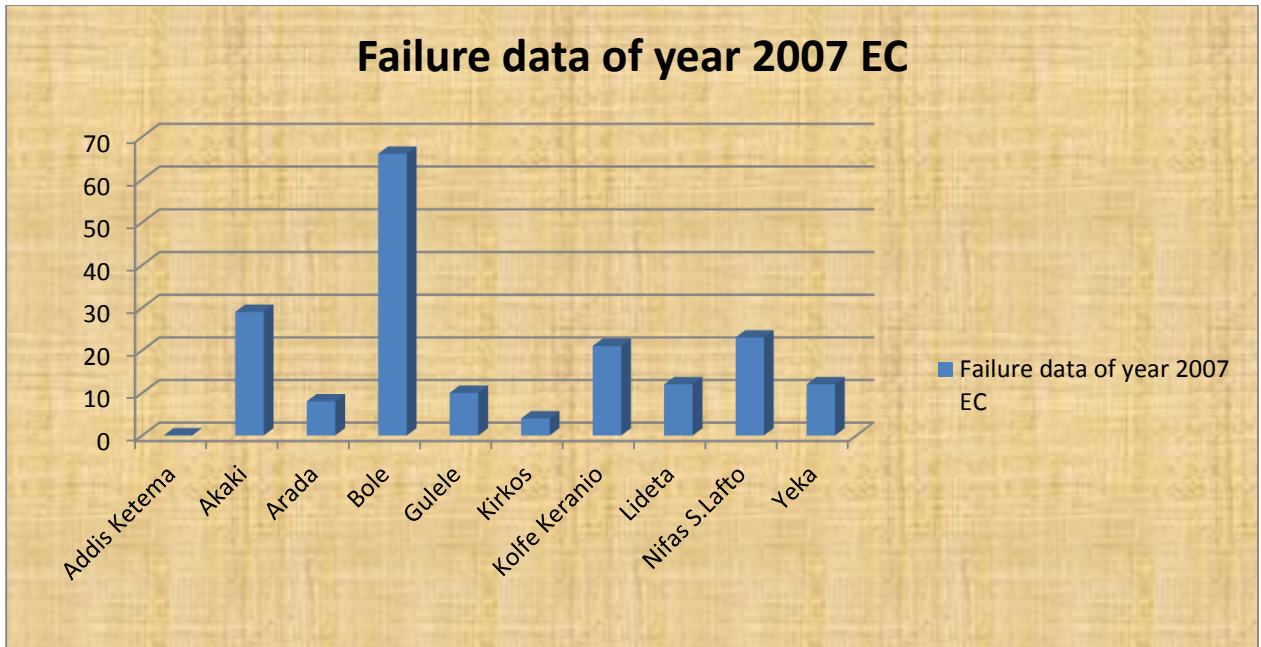


Fig 3.6 shows failure distribution in sub-cities for 2007

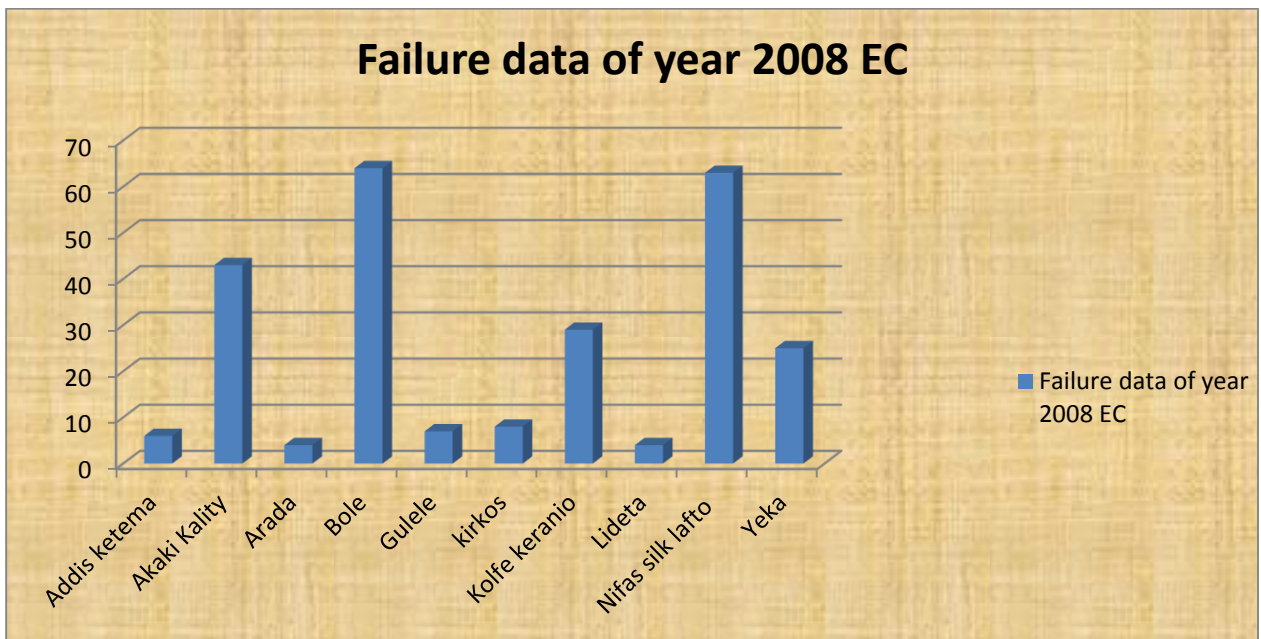


Fig3.7 shows failure distribution in sub-cities for 2008

### 3.5 Buried pipe design

According to cheuk.et.all.2005, for a buried pipe to be deflected upward, the uplift force of the pipe has to be greater than the uplift resistance force acting above the pipe.

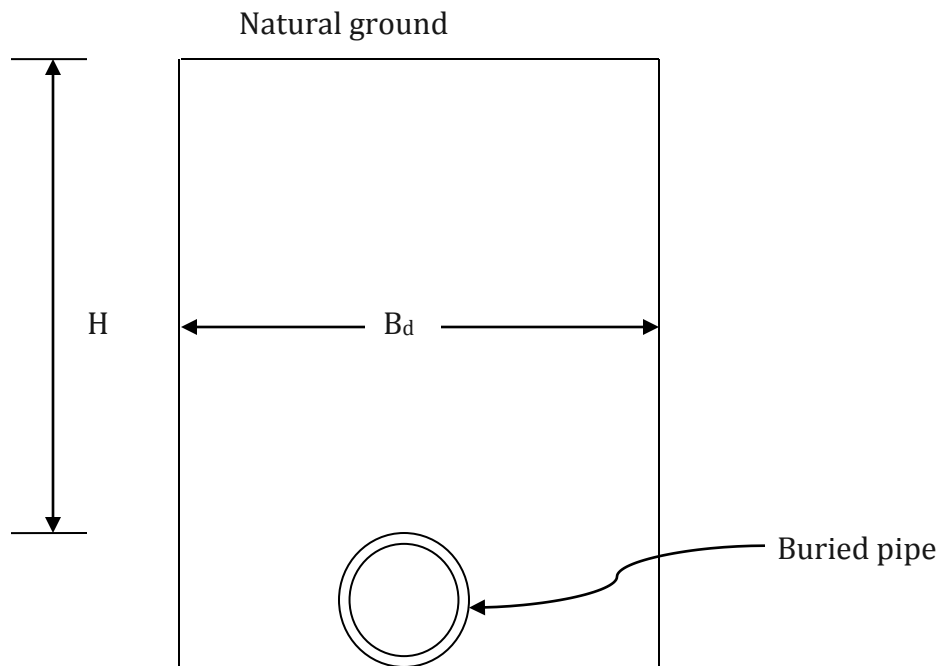


Fig3.8 sectional view of buried pipe

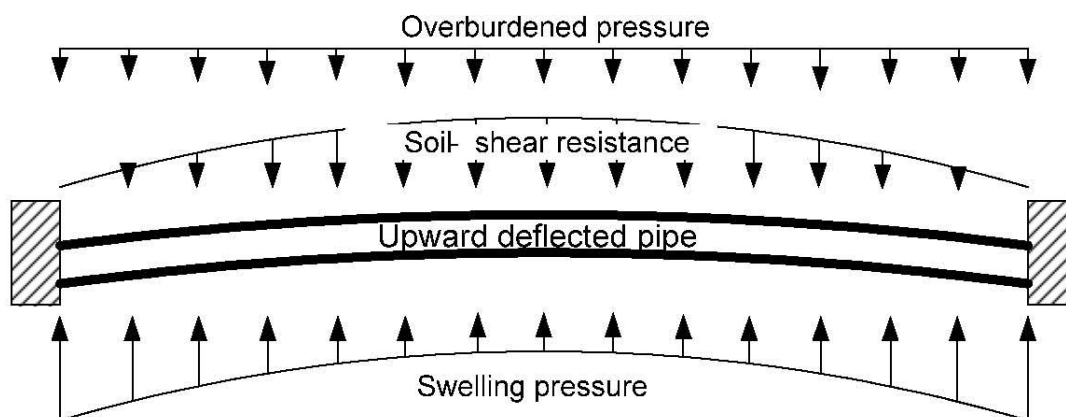


Fig3.9 upward deflected pipe due to swelling pressure

The resistive force of swelling applied by the backfill material is

$$P = \gamma HD$$

Where P is applied force due to the backfill material

$\gamma$  is the unit weight of backfill material

H is the depth of buried pipe from the original ground level

D is the buried pipe diameter

B<sub>d</sub> is the width of the trench

Whereas the uplift force exerted on the pipe due to expansive soil is

$$P = SpD$$

Where P is uplift force exerted on buried pipe

Sp is the Swelling pressure

D is the external diameter of the buried pipe

The expansive soil sample taken from the different parts of Addis Ababa is summarized and tabulated as follows

Soil property	Magnitude of the soil property in (%)
Liquid limit (LL %)	79-121
Plastic Limit (PL %)	25-50
Plasticity Index (PI %)	38-84
% retained in 2 $\mu$ m sieve	48-82
% finer than 75 $\mu$ m	95-99
Free swell (FS %)	64-140

Table 3.4 Range of values of index properties for expansive soil of Addis Ababa (Daniel T.)

The expansive soil data that has been collected by Daniel Tekle from the different locations of Addis Ababa is also used as the primary data for this project. The soil samples were collected with in average depth of 1.3m

Cloure	X-Coordinate	Y-Coordinate	$\omega$ %	LL%	PL%	PI%	$\gamma_d$ (g/cc)	Clay content	Specific Gravity (Gs)	LogSp	Sp (kPa)
Black	476936	994652	38.4	101	43	58	1.25	46	2.77	2.62	420
Black	476839	993360	37.5	110	34	46	1.24	65	2.78	2.48	300
Black	485893	997096	37.6	96	42	54	1.24	60	2.79	2.43	267

Table 3.5 Samples of expansive soil of Addis Ababa taken from different parts of Addis Ababa (Daniel T.)

- ❖ The exerted force on the buried pipe due to the swelling pressure of expansive soil is

$$P = SP \cdot D$$

- Consider the pipe diameter 160mm which is in the range of heavy water main according to the Addis Ababa Water and Sewerage Authority (AAWSA)

For sample 1

$$Sp = 420 \text{ kPa}$$

$$D = 0.16\text{m}$$

$$P = 420\text{kPa} \times 0.16\text{m}$$

$$= 67.2\text{kN/m}$$

For sample 2

$$Sp = 300 \text{ kPa}$$

$$P = 300\text{kPa} \times 0.16\text{m}$$

$$= 48\text{kN/m}$$

For sample 3

$$Sp = 267 \text{ kPa}$$

$$P = 267\text{kPa} \times 0.16\text{m}$$

$$= 42.72\text{kN/m}$$

- Consider another water main pipe diameter 200mm

For sample 1

$$Sp = 420 \text{ kPa}$$

$$D = 0.2\text{m}$$

$$P = 420\text{kPa} \times 0.2\text{m}$$

$$= 84\text{kN/m}$$

For sample 2

$$Sp = 300\text{kPa}$$

$$P = 300\text{kPa} \times 0.2\text{m}$$

$$= 60\text{kN/m}$$

For sample 3

$$Sp = 267\text{kPa}$$

$$P = 267\text{kPa} \times 0.2\text{m}$$

$$= 53.4\text{kN/m}$$

- Consider another water main pipe diameter 300mm

For sample 1

$$Sp = 420 \text{ kPa}$$

$$D = 0.3\text{m}$$

$$P = 420\text{kPa} \times 0.3\text{m}$$

$$= 126\text{kN/m}$$

For sample 2

$$Sp = 300 \text{ kPa}$$

$$P = 300\text{kPa} \times 0.3\text{m}$$

$$= 90\text{kN/m}$$

For sample 3

$$Sp = 267\text{kPa}$$

$$P = 267\text{kPa} \times 0.3\text{m}$$

$$= 80.1\text{kN/m}$$

Sample	For D = 160mm	For D= 200mm	Fore D = 300mm
	Uplift force (kN/m)	Uplift force (kN/m)	Uplift force (kN/m)
1	67.2	84	126
2	48	60	90
3	42.72	53.4	80.1

Table 3.6 Uplift force of expansive soil of Addis Ababa taken from different parts of Addis Ababa (Daniel T.)

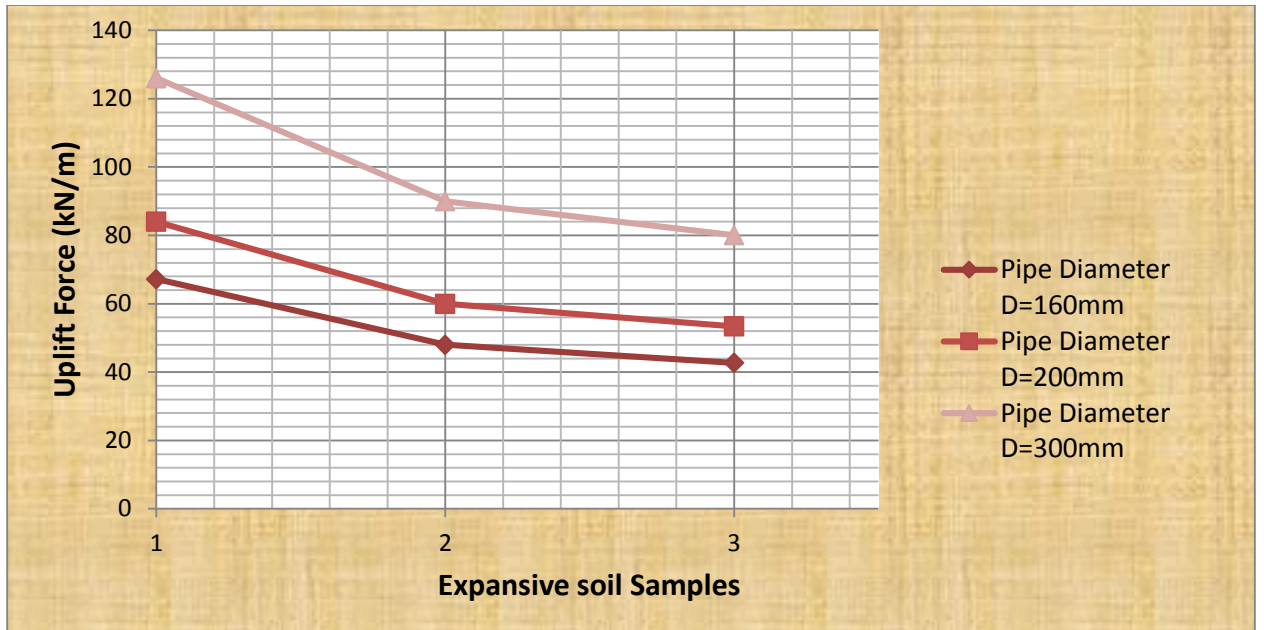


Fig3.10 upward Vs Expansive soil samples for different pipe diameter

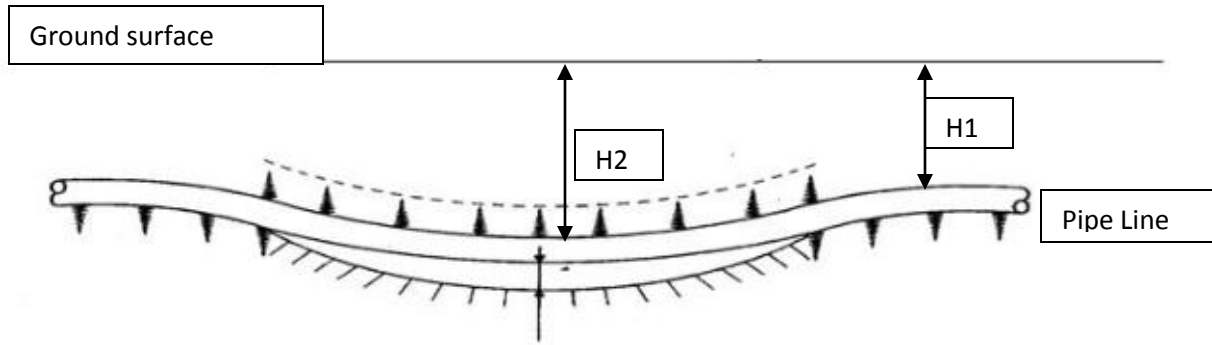


Fig 3.11 Downward deflection of pipe during dry season

$$P = \gamma HD$$

Where P is applied force due to the backfill material

$\gamma$  is the unit weight of backfill material

H is the depth of buried pipe from the original ground level

D is the buried pipe diameter

The exerted force on the buried pipe during dry season is the stress of the soil itself.

- Here by considering the pipe installation depths as 1.3m below the ground level.

Sample No	Cloure	X-coordinate	Y-coordinate	Moisture content ( $\omega\%$ )	Dry density ( $\rho_{\delta} = \text{g/cc}$ )	Specific gravity(Gs)
1	Black	476936	994652	38.4	1.25	2.77
2	Black	476839	993360	37.5	1.24	2.78
3	Black	485893	997096	37.6	1.24	2.79

Table 3.7 Samples of expansive soil of Addis Ababa taken from different parts of

Addis

From the Weight-Volume relationships of soil

$$\rho_d = \frac{G_s \rho_w}{1 + e}$$

$$\gamma_d = \frac{G_s \gamma_w}{1 + e} = \frac{\gamma}{1 + w}$$

$$\gamma = \gamma_d (1 + w)$$

Where  $\rho_d$  dry density of soil  $\gamma_d$  is dry unit weight of soil,  $\rho_w$  density of water (1000kg/m<sup>3</sup>),  $\gamma_w$  unit weight of water (9.81kN/m<sup>3</sup>)  $e$  Void ratio of soil and  $\gamma$  bulk unit weight of soil.

Then from the above equations, the bulk unit weight can be calculated for farther calculation of applied force due to the soil on the buried pipe for each sample.

For sample 1

$$e = -1 + \frac{2.77 * 1000 \text{ kg/m}^3}{1250 \text{ kg/m}^3} = 1.216$$

$$\gamma_d = \frac{2.77 * 9.81 \text{ kN/m}^3}{1 + 1.216} = 12.262 \text{ kN/m}^3$$

$$\gamma = 12.262 \text{ kN/m}^3 (1 + 0.384) = 16.97 \text{ kN/m}^3$$

(H = 1.3m for all soil samples which were collected with in average depth)

and take diameter of the pipe = 0.16m

Therefore the force (p) exerted on pipe is

$$P = 16.97 \text{ kN/m}^3 \times 1.3 \text{ m} \times 0.16 \text{ m}$$

$$= 3.53 \text{ kN/m}$$

For sample 2

$$e = -1 + \frac{2.78 \cdot 1000 \text{ kg/m}^3}{1240 \text{ kg/m}^3} = 1.242$$

$$\gamma_d = \frac{2.78 \cdot 9.81 \text{ kN/m}^3}{1 + 1.242} = 12.164 \text{ kN/m}^3$$

$$\gamma = 12.164 \text{ kN/m}^3 (1 + 0.375) = 16.725 \text{ kN/m}^3$$

$$P = 16.725 \text{ kN/m}^3 \times 1.3 \text{ m} \times 0.16 \text{ m}$$

$$= \mathbf{3.479 \text{ kN/m}}$$

For sample 3

$$e = -1 + \frac{2.79 \cdot 1000 \text{ kg/m}^3}{1240 \text{ kg/m}^3} = 1.25$$

$$\gamma_d = \frac{2.79 \cdot 9.81 \text{ kN/m}^3}{1 + 1.25} = 12.164 \text{ kN/m}^3$$

$$\gamma = 12.164 \text{ kN/m}^3 (1 + 0.376) = 16.74 \text{ kN/m}^3$$

$$P = 16.74 \text{ kN/m}^3 \times 1.3 \text{ m} \times 0.16 \text{ m}$$

$$= \mathbf{3.48 \text{ kN/m}}$$

- Consider another water main pipe diameter 200mm

For sample 1

$$P = 16.97 \text{ kN/m}^3 \times 1.3 \text{ m} \times 0.2 \text{ m}$$

$$= \mathbf{4.41 \text{ kN/m}}$$

For sample 2

$$P = 16.725 \text{ kN/m}^3 \times 1.3 \text{ m} \times 0.2 \text{ m}$$

$$= \mathbf{4.35 \text{ kN/m}}$$

For sample 3

$$P = 16.74\text{kN/m}^3 \times 1.3\text{m} \times 0.2\text{m}$$
$$= \mathbf{4.35\text{kN/m}}$$

- Consider another water main pipe diameter 300mm

For sample 1

$$P = 16.97\text{kN/m}^3 \times 1.3\text{m} \times 0.3\text{m}$$
$$= \mathbf{6.62\text{kN/m}}$$

For sample 2

$$P = 16.725\text{kN/m}^3 \times 1.3\text{m} \times 0.3\text{m}$$
$$= \mathbf{6.52\text{kN/m}}$$

For sample 3

$$P = 16.74\text{kN/m}^3 \times 1.3\text{m} \times 0.3\text{m}$$
$$= \mathbf{6.53\text{kN/m}}$$

Sample	For D = 160mm	For D= 200mm	Fore D = 300mm
	Downward force (kN/m)	Downward force (kN/m)	Downward force (kN/m)
1	3.53	4.41	6.62
2	3.479	4.35	6.52
3	3.48	4.35	6.53

Table 3.8 Downward force of expansive soil of Addis Ababa taken from different parts of Addis Ababa

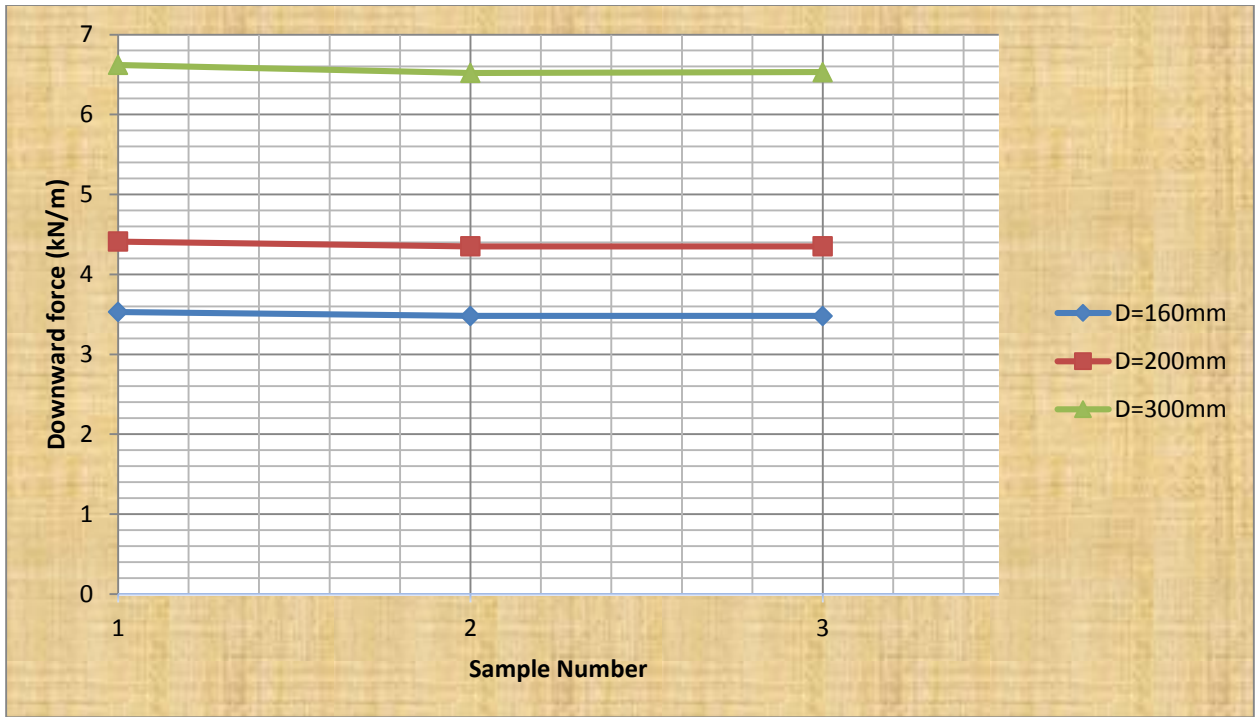


Fig3.12 Downward Vs Expansive soil samples for different pipe diameter

# Chapter four

## Results and Discussions

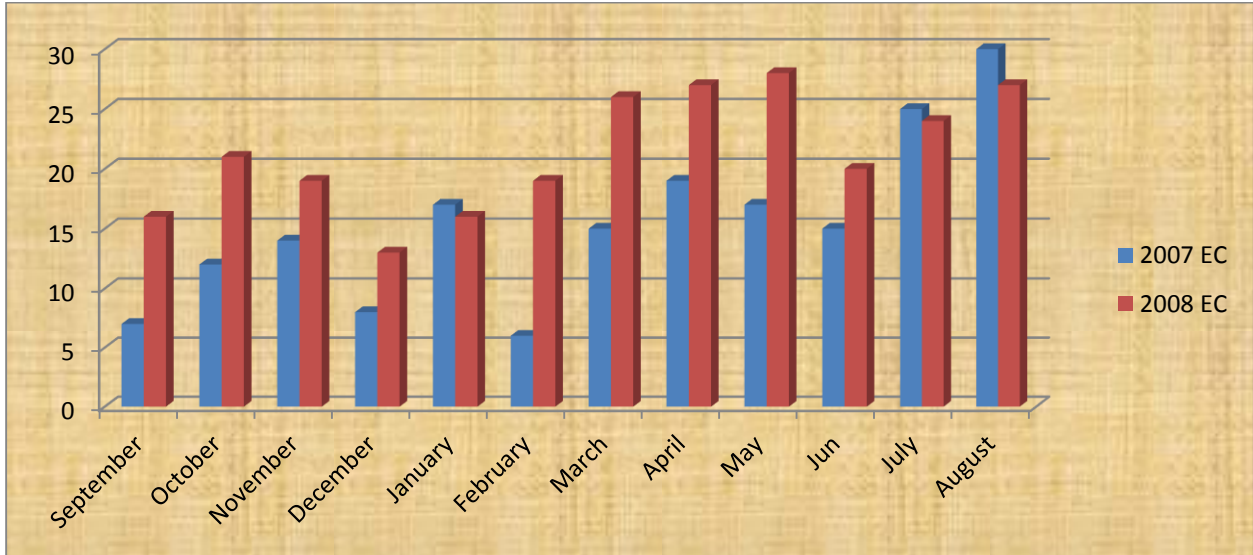


Fig 4.1 shows combined monthly failure data for two years

From the literature and several references, the behavior of expansive soil has been discussed. From the data that has been collected from AAWSA and shown in a combined chart, most failure occurs during rainy time.

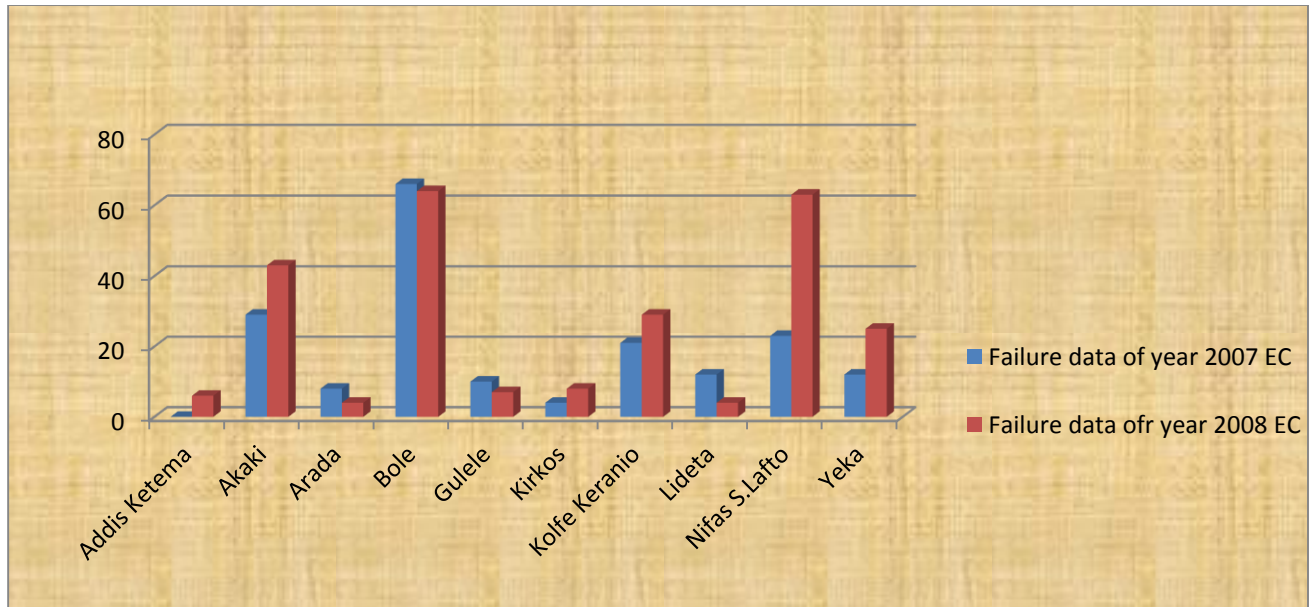


Fig 4.2 shows combined failure distribution in each sub-city

From the failure distribution chart, more failure were observed in the sub-cities of Bole, Akaki-kality, Nifas silk Lafto, Kolfekeraniyo and Yeka

## **Chapter five**

### **CONCLUSIONS AND RECOMMENDATIONS**

#### **5.1 Conclusions**

1. During the rainy season, expansive soil absorbs more water and tends to be expanding.
2. When the soil get expanding, uplift pressure is exerted on the pipe from the soil and then may cause the cracks on it. Therefore, that is why the failure is more during the rainy season
3. From the Addis Ababa soil map, the expansive soil (black cotton) distribution is mostly dominant in Kolfekeraniyo, Nifas-Silk Lafto, AkakiKality, Bole and Yeka. The failure distribution of the water main which has been collected is also show that more damages of the water main has been occurred in these sub-cities reference to the other sub-cities
4. The uplift force exerted on the buried pipe is increased with increasing of pipe diameter. Therefore with in same soil type the larger diameter is more susceptible to the swelling pressure

#### **5.2 Recommendations**

1. Remove the expansive soil and replace with non-expansive soil
2. Placing the water main below the active zone is recommendable to reduce the damage due to the expansive soil

3. Flexible pipes have the ability to deflect when they are subjected to swelling and shrinkage force. Choosing the flexible pipe rather than the ridged pipe can also reduce the damage.

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## ANNEX

Pipe failure data collected from AAWSA in 2007 E.C

September				
		Location	Cause	Sub-City
1	13/01/07	Semit	Pressure	Bole
2	14/01/07	Gofa	Pressure	Nifas S.Lafto
3	15/01/07	Gofa	Pressure	Nifas S.Lafto
4	24/01/07	Ayat	Pressure	Bole
5	27/01/07	Lebu	Pressure	Nifas S.Lafto
6	28/01/07	Salitemihret	Pressure	Bole
7	30/01/07	Saris Gumuruk	Pressure	Akaki Kalitiy
October				
1	1/2/2007	Saris Gumuruk	Pressure	Akaki Kalitiy
2	13/02/07	industry mender	Pressure	Bole
3	18/02/07	Jomo	Pressure	Nifas S.Lafto
4	20/02/07	Hana mariam	Pressure	Nifas S.Lafto
5	20/02/07	Piasa catedral	Pressure	Arada
6	21/02/07	R.Fana	Pressure	Nifas S.Lafto
7	21/02/07	Jomo	Pressure	Nifas S.Lafto
8	23/02/07	Megenagna(ankorc)	Pressure	Yeka
9	26/02/07	Asko Georgis	Pressure	Kolfe Keranio
10	26/02/07	Asko Georgis	Pressure	Kolfe Keranio
11	29/02/07	Mexico	Pressure	Lideta
12	30/02/07	Urael	Pressure	Bole
November				
1	27/03/07	Lebu	Pressure	Nifas S.Lafto
2	12/3/2007	Bole W.sefer	Pressure	Bole
3	26/03/07	Ayat	Pressure	Bole
4	26/03/07	Ayat	Pressure	Bole
5	27/03/07	Ayat	Pressure	Bole
6	30/03/07	Ayat	Pressure	Bole
7	1/3/2007	Terminal	Pressure	Bole
8	4/3/2007	Ayat (industry.V)	Pressure	Bole
9	4/3/2007	Ayat (industry.V)	Pressure	Bole
10	6/3/2007	Bambis	Pressure	Bole
11	7/3/2007	Kara	Pressure	Nifas S.Lafto
12	24/03/07	Ayat	Pressure	Bole
13	25/03/07	Goro	Pressure	Bole
14	26/03/07	Ayat	Pressure	Bole

December				
		Location	Cause	Sub-City
1	21/04/07	Shero meda	Pressure	Gulele
2	1/4/2007	industry mender	Pressure	Bole
3	2/4/2007	Semit pepsi Factory	Pressure	Bole
4	6/4/2007	Megenagna(ankorcl	Pressure	Yeka
5	11/4/2007	Yeka Adebabay	Pressure	Yeka
6	19/04/07	Abinet	Pressure	Lideta
7	23/04/07	Ayat zon 8	Pressure	Bole
8	30/04/07	Jomo	Pressure	Nifas S.Lafto
January				
1	7/5/2007	F.Legasion	Pressure	Yeka
2	10/5/2007	Asko liz sefer	Pressure	Kolfe Keranio
3	22/05/07	Asko Georgis	Pressure	Kolfe Keranio
4	14/05/07	Asko liz sefer	Pressure	Kolfe Keranio
5	17/05/07	Asko Georgis	Pressure	Kolfe Keranio
6	19/05/07	site 20(Jomo)	Pressure	Nifas S.Lafto
7	19/05/07	Chew berenda	Pressure	Lideta
8	27/05/07	Jomo	Pressure	Nifas S.Lafto
9	1/5/2007	industry mender	Pressure	Bole
10	2/5/2007	industry mender	Pressure	Bole
11	4/5/2007	Goro	Pressure	Bole
12	9/5/2007	Asko Georgis	Pressure	Kolfe Keranio
13	6/5/2007	Bole Lemi	Pressure	Bole
14	8/5/2007	industry mender	Pressure	Bole
15	9/5/2007	industry mender	Pressure	Bole
16	26/05/07	Ayat	Pressure	Bole
17	14/05/07	Yerer	Pressure	Bole
February				
1	5/6/2007	Jomo	Pressure	Nifas S.Lafto
2	6/6/2007	Jomo	Pressure	Nifas S.Lafto
3	7/6/2007	Jomo	Pressure	Nifas S.Lafto
4	7/6/2007	Asko	Pressure	Kolfe Keranio
5	18/06/07	Old head office	Pressure	Gulele
6	21/06/07	Saint Joseph	Pressure	Kirkos

March				
		Location	Cause	Sub-City
1	5/7/2007	Cherchl	Pressure	Arada
2	1/7/2007	Jomo	Pressure	Nifas S.Lafto
3	9/7/2007	Ayer Tena School	Pressure	Kolfe Keranio
4	11/7/2007	Jomo	Pressure	Nifas S.Lafto
5	12/7/2007	Jomo	Pressure	Nifas S.Lafto
6	16/07/07	Jomo	Pressure	Nifas S.Lafto
7	17/07/07	Shero meda	Pressure	Gulele
8	17/07/07	Shero meda	Pressure	Gulele
9	17/07/07	Shero meda	Pressure	Gulele
10	20/07/07	Lideta (geja)	Pressure	Lideta
11	20/07/07	Atlas clinic	Pressure	Bole
12	23/07/07	Jomo	Pressure	Nifas S.Lafto
13	27/07/07	R.Fana	Pressure	Kolfe Keranio
14	6/7/2007	Bole Lemi	Pressure	Bole
15	20/07/07	Bole Lemi	Pressure	Bole
April				
1	15/08/07	Torhiloch	Pressure	Lideta
2	1/8/2007	Torhiloch	Pressure	Lideta
3	1/8/2007	Torhiloch	Pressure	Lideta
4	5/8/2007	Shero meda	Pressure	Gulele
5	6/8/2007	Winget	Pressure	Kolfe Keranio
6	7/8/2007	Winget	Pressure	Kolfe Keranio
7	8/8/2007	Jomo	Pressure	Nifas S.Lafto
8	10/8/2007	Piasa	Pressure	Arada
9	11/8/2007	Piasa	Pressure	Arada
10	15/08/07	Winget	Pressure	Kolfe Keranio
11	22/08/07	Asko Geogis	Pressure	Kolfe Keranio
12	23/08/07	Asko Georgis	Pressure	Kolfe Keranio
13	24/08/07	R.Fana	Pressure	Kolfe Keranio
14	25/08/07	Lideta	Pressure	Lideta
15	27/08/07	Abadir	Pressure	Yeka
16	15/08/07	Lideta (geja)	Pressure	Lideta
17	16/08/07	Bulbula	Pressure	Bole
18	17/08/07	Bulbula	Pressure	Bole
19	20/08/07	Hana mariam	Pressure	Nifas S.Lafto

May				
		Location	Cause	Sub-City
1	25/09/07	Winget	Pressure	Kolfe Keranio
2	2/9/2007	Abadir	Pressure	Yeka
3	3/9/2007	Asko Gebriel	Pressure	Kolfe Keranio
4	5/9/2007	Meshoalekia	Pressure	Kirkos
5	15/09/07	R.Fana	Pressure	Kolfe Keranio
6	14/09/07	R.Fana	Pressure	Kolfe Keranio
7	16/09/07	R.Fana	Pressure	Kolfe Keranio
8	17/09/07	Old head office	Pressure	Gulele
9	25/09/07	addisu gebeya	Pressure	Gulele
10	5/9/2007	Hana mariam	Pressure	Nifas S.Lafto
11	8/9/2007	Ayat	Pressure	Bole
12	9/9/2007	Ayat	Pressure	Bole
13	10/9/2007	Urael	Pressure	Bole
14	11/9/2007	Legehar	Pressure	Kirkos
15	11/9/2007	Urael	Pressure	Bole
16	13/09/07	Ferensay	Pressure	Yeka
17	14/09/07	BoleAirport	Pressure	Bole
Jun				
1	26/10/07	Bethel	Pressure	Kolfe Keranio
2	27/10/07	Ayat	Pressure	Bole
3	27/10/07	Ayat	Pressure	Bole
4		Ayat	Pressure	Bole
5	17/10/07	Mikililand	Pressure	Akaki Kality
6	19/10/07	R.Fana	Pressure	Kolfe Keranio
7	20/10/07	R.Fana	Pressure	Kolfe Keranio
8	21/10/07	Jomo	Pressure	Nifas S.Lafto
9	22/10/07	Jomo	Pressure	Nifas S.Lafto
10	1/10/2007	Bulgaria	Pressure	Kirkos
11	3/10/2007	Lideta	Pressure	Lideta
12	5/10/2007	Lideta(geja)	Pressure	Lideta
13	6/10/2007	Lideta(geja)	Pressure	Lideta
14	19/10/07	Kotebe	Pressure	Yeka
15	19/10/07	Ayat	Pressure	Bole

July				
		Location	Cause	Sub-City
1	21/11/07	R.Fana	Pressure	Kolfe Keranio
2	19/11/07	Dama hotel	Pressure	Akaki Kality
3	27/11/07	Lebu	Pressure	Nifas S.Lafto
4	28/11/07	Lebu	Pressure	Nifas S.Lafto
5	1/11/2007	industry mender	Pressure	Bole
6	5/11/2007	Yerer	Pressure	Bole
7	6/11/2007	Goro	Pressure	Bole
8	14/11/07	industry mender	Pressure	Bole
9	9/11/2007	Piasa habesha Bldng	Pressure	Arada
10	13/11/07	Legetafo	Pressure	Bole
11	21/11/07	Dama hotel	Pressure	Akaki Kality
12	22/11/07	Dama hotel	Pressure	Akaki Kality
13	28/11/07	Kotebe(Dehninet)	Pressure	Yeka
14	7/11/2007	industry mender	Pressure	Bole
15	8/11/2007	industry mender	Pressure	Bole
16	8/11/2007	industry mender	Pressure	Bole
17	9/11/2007	Bole Arabsa	Pressure	Bole
18	15/11/07	industry mender	Pressure	Bole
19	17/11/07	Lebu	Pressure	Bole
20	18/11/07	Shero meda	Pressure	Gulele
21	22/11/07	Goro	Pressure	Bole
22	23/11/07	Semit reservior	Pressure	Bole
23	26/11/07	industry mender	Pressure	Bole
24	29/11/07	Ayat zon 8	Pressure	Bole
25	30/11/07	Goro	Pressure	Bole
August				
1	6/12/2007	Lomi meda	Pressure	Bole
2	9/12/2007	Jomo	Pressure	Nifas S.Lafto
3	16/12/07	industry mender	Pressure	Bole
4	8/12/2007	R.Fana	Pressure	Kolfe Keranio
5	10/12/2007	kidane mihret	Pressure	Gulele
6	18/12/07	Adwa Adebabay	Pressure	Arada
7	18/12/07	Megenagna(ankorcl	Pressure	Yeka
8	20/12/07	Semi	Pressure	Bole
9	20/12/07	semit	Pressure	Bole
10	20/12/07	semit	Pressure	Bole
11	20/12/07	semit	Pressure	Bole
12	23/12/07	Ayat	Pressure	Bole
13	23/12/07	Ayat	Pressure	Bole
14	23/12/07	Ayat	Pressure	Bole
15	23/12/07	Ayat	Pressure	Bole
16	23/12/07	Ayat	Pressure	Bole
17	9/12/2007	SANSUSI	Pressure	Kolfe Keranio
18	10/12/2007	Semen Mezegaja	Pressure	Arada
19	5/12/2007	Urael	Pressure	Bole
20	6/12/2007	Ferensay	Pressure	Arada
21	4/12/2007	Dama hotel	Pressure	Akaki Kality
22	30/12/07	Kara Degnet	Pressure	Kolfe Keranio
23	1/12/2007	Goro	Pressure	Bole
24	10/12/2007	Bole Arabsa	Pressure	Bole
25	17/12/07	industry mender	Pressure	Bole
26	17/12/07	Yeka Abado	Pressure	Yeka
27	20/12/07	industry mender	Pressure	Bole
28	21/12/07	Yerer hospital	Pressure	Bole
29	26/12/07	Kotebe dehninet	Pressure	Yeka
30	27/12/07	industry mender	Pressure	Bole

Table 3.3 Pipe failure data collected from AAWSA in 2008 E.C

September				
		Location	Case	Sub-city
1	12/1/2008	Addisu gebeya	Pressure	Arada
2	19/01/08	SANSUSI	Pressure	Kolfe keranio
3	2/1/2008	Asko menahria	Pressure	Kolfe keranio
4	3/1/2008	Kara degnet	Pressure	Kolfe keranio
5	6/1/2008	Kara degnet	Pressure	Kolfe keranio
6	9/1/2008	Ayer tena	Pressure	Kolfe keranio
7	11/1/2008	Addisu gebeya	Pressure	Gulele
8	13/01/08	R.fana	Pressure	Kolfe keranio
9	16/01/08	Kara degnet	Pressure	Kolfe keranio
10	17/01/08	Lebu Express	Pressure	Nifas silk lafto
11	11/1/2008	Abasamuel	Pressure	Akaki Kality
12	14/01/08	Lebu	Pressure	Nifas silk lafto
13	14/01/08	Akaki	Pressure	Akaki Kality
14	28/01/08	Kilinto	Pressure	Akaki Kality
15	29/01/08	Tulu dimtu	Pressure	Akaki Kality
16	30/01/08	Dama Hotel	Pressure	Akaki Kality
October				
1	28/02/08	R.fana	Pressure	Nifas silk lafto
2	28/02/08	R.fana	Pressure	Nifas silk lafto
3	6/2/2008	Tsion	Pressure	Gulele
4	12/2/2008	Akaki	Pressure	Akaki Kality
5	6/2/2008	Kara degnet	Pressure	Kolfe keranio
6	15/02/08	6kilo	Pressure	Arada
7	18/02/08	Gelan total	Pressure	Akaki Kality
8	23/02/08	Alembank	unkoun	Kolfe keranio
9	26/02/08	Asko geogis	Pressure	Kolfe keranio
10	3/2/2008	Kuyefeche	Pressure	Akaki Kality
11	6/2/2008	Kuyefeche	Pressure	Akaki Kality
12	6/2/2008	Gelan	Pressure	Akaki Kality
13	5/2/2008	Bole Arabsa	Pressure	Bole
14	2/2/2008	Bole Beshale	Pressure	Bole
15	11/2/2008	ICT	Pressure	Yeka
16	13/02/08	ICT	Pressure	Yeka
17	14/02/08	Ras hailu	Pressure	Addis ketema
18	27/02/08	ICT	Pressure	Yeka
19	28/02/08	Gerad Hintsa	Pressure	Lideta
20	29/02/08	Ayat	Pressure	Bole
21	30/02/08	ICT	Pressure	Yeka

November				
		Location	Case	Sub-city
1	14/03/08	Megenagna(Ankorcha)	Pressure	Yeka
2	8/3/2008	Kuyefeche	Pressure	Akaki Kality
3	14/03/08	Tulu dimtu	Pressure	Akaki Kality
4	1/3/2008	Semit	Pressure	Bole
5	2/3/2008	Industry mender	Pressure	Bole
6	3/3/2008	ICT	Pressure	Yeka
7	4/3/2008	ICT	Pressure	Yeka
8	6/3/2008	Ayat	Pressure	Bole
9	7/3/2008	Ayat	Pressure	Bole
10	9/3/2008	Goro	Pressure	Bole
11	10/3/2008	Goro gebreal	Pressure	Bole
12	11/3/2008	Goro	Pressure	Bole
13	17/03/08	Goro	Pressure	Bole
14	18/03/08	Goro	Pressure	Bole
15	18/03/08	Beshale ayat	Pressure	Bole
16	19/03/08	Ayat	Pressure	Bole
17	20/03/08	Ayat	Pressure	Bole
18	21/03/08	Goro	Pressure	Bole
19	24/03/08	ICT	Pressure	Nifas silk lafto
December				
1	18/04/08	Winge	Pressure	Kolfe keranio
2	19/04/08	Bethel	Pressure	Kolfe keranio
3	10/4/2008	Jomo	Pressure	Nifas silk lafto
4	12/4/2008	Lebu	Pressure	Nifas silk lafto
5	27/04/08	Hana mariam	Pressure	Nifas silk lafto
6	2/4/2008	Dehninet	Pressure	Yeka
7	6/4/2008	Dehninet	Pressure	Yeka
8	6/4/2008	Beshale ayat	Pressure	Bole
9	7/4/2008	Ayat	Pressure	Bole
10	8/4/2008	Altad	Pressure	Bole
11	17/04/08	Ayat	Pressure	Bole
12	21/04/08	Goro	Pressure	Bole
13	22/04/08	Ayat kutr 2	Pressure	Bole

January				
		Location	Case	Sub-city
1	14/05/08	R.fana	Pressure	Nifas silk lafto
2	15/05/08	Zerfeshiwal School	Pressure	Bole
3	16/05/08	Zerfeshiwal School	Pressure	Bole
4	17/05/08	Zerfeshiwal School	Pressure	Bole
5	18/05/08	Zerfeshiwal School	Pressure	Bole
6	7/5/2008	Yeka Abado	Pressure	Yeka
7	19/05/08	Ayer tena School	Pressure	Kolfe keranio
8	22/05/08	Jomo Michael	Pressure	Nifas silk lafto
9	29/05/08	Weira sefer	Pressure	Kolfe keranio
10	13/05/08	Goro Michael	Pressure	Bole
11	15/05/08	R.fana	Pressure	Kolfe keranio
12	20/05/08	Ayat	Pressure	Bole
13	22/05/08	Yeka W.12	Pressure	Yeka
14	23/05/08	Yerer Goro	Pressure	Bole
15	24/05/08	Industry mender	Pressure	Bole
16	28/05/08	22 mazorja	Pressure	Bole
February				
1	14/06/08	Mekanisa esrael embas	Pressure	Nifas silk lafto
2	19/06/08	Saris Abo	Pressure	Akaki Kality
3	13/06/08	Jomo	Pressure	Nifas silk lafto
4	15/06/08	Jomo	Pressure	Nifas silk lafto
5	19/06/08	R.fana	Pressure	Kolfe keranio
6	21/06/08	SANSUSI	Pressure	Kolfe keranio
7	12/6/2008	Ras hailu	Pressure	Addis ketema
8	12/6/2008	Semen mazedgaja	Pressure	Arada
9	13/06/08	Ras hailu	Pressure	Addis ketema
10	15/06/08	Ras hailu	Pressure	Addis ketema
11	21/06/08	Hana mariam	Pressure	Nifas silk lafto
12	6/6/2008	Kuyefeché	Pressure	Akaki Kality
13	6/6/2008	Kuyefeché	Pressure	Akaki Kality
14	19/06/08	Kilinto	Pressure	Akaki Kality
15	20/06/08	Tulu dimtu	Pressure	Akaki Kality
16	3/6/2008	ICT	Pressure	Yeka
17	3/6/2008	Hana mariam	Pressure	Nifas silk lafto
18	7/6/2008	ICT	Pressure	Nifas silk lafto
19	30/06/08	Mesalemia	Pressure	Addis ketema

March				
		Location	Case	Sub-city
1	7/7/2008	Semit	uknoun	Bole
2	8/7/2008	Kara loke	uknoun	Yeka
3	10/7/2008	Semit	Pressure	Bole
4	20/07/08	Jomo	Pressure	Nifas silk lafto
5	21/07/08	Jomo	Pressure	Nifas silk lafto
6	2/7/2008	SANSUSI	Pressure	Kolfe keranio
7	20/07/08	Bulbula	Pressure	Bole
8	3/7/2008	Mekanisa	Pressure	Nifas silk lafto
9	15/07/08	Lebu Express Hile garm	Pressure	Nifas silk lafto
10	18/07/08	Varnero	Pressure	Nifas silk lafto
11	20/07/08	Varnero	Pressure	Nifas silk lafto
12	21/07/08	Jomo Michael	Pressure	Nifas silk lafto
13	23/07/08	Koshe (Ayer tena)	Pressure	Nifas silk lafto
14	24/07/08	Gotera	Pressure	kirkos
15	26/07/08	Dama Hotel	Pressure	Akaki Kality
16	5/7/2008	Tulu dimtu	Pressure	Akaki Kality
17	8/7/2008	Kality gebreal	Pressure	Akaki Kality
18	13/07/08	Kuyefeché	Pressure	Akaki Kality
19	19/07/08	Lebu	Pressure	Nifas silk lafto
20	2/7/2008	Augusta	Pressure	Kolfe keranio
21	13/07/08	Industry mender	Pressure	Bole
22	14/07/08	Industry mender	Pressure	Bole
23	15/07/08	Bole Beshale	Pressure	Bole
24	27/07/08	Semit	Pressure	Bole
25	28/07/08	Industry mender	Pressure	Bole
26	30/07/08	Bole Arabsa	Pressure	Bole
April				
1	21/08/08	Gibi Gebreal	Pressure	Arada
2	8/8/2008	Gofa	Pressure	Nifas silk lafto
3	1/8/2008	Jomo	Pressure	Nifas silk lafto
4	3/8/2008	Jomo	Pressure	Nifas silk lafto
5	5/8/2008	Koshe (Ayer tena)	Pressure	Nifas silk lafto
6	7/8/2008	Jomo Site 18 & 26	Pressure	Nifas silk lafto
7	8/8/2008	Kara kore	Pressure	Nifas silk lafto
8	9/8/2008	Lebu Haile garment	Pressure	Nifas silk lafto
9	9/8/2008	Garment	Pressure	Nifas silk lafto
10	10/8/2008	Garment	Pressure	Nifas silk lafto
11	19/08/08	Nahom Adebabay	Pressure	Bole
12	20/08/08	Varnero adebabay	Pressure	Nifas silk lafto
13	21/08/08	Varnero adebabay	Pressure	Nifas silk lafto
14	1/8/2007	Kilinto	Pressure	Akaki Kality
15	5/8/2007	Kilinto	Pressure	Akaki Kality
16	20/08/08	Varnero	Pressure	Nifas silk lafto
17	14/08/08	Lebu	Pressure	Nifas silk lafto
18	1/8/2008	Industry mender	Pressure	Bole
19	8/8/2008	ICT	Pressure	Yeka
20	8/8/2008	Legetafo	Pressure	Akaki Kality
21	9/8/2008	Yeka Abado	Pressure	Yeka
22	10/8/2008	Ayat	Pressure	Bole
23	11/8/2008	ICT	Pressure	Yeka
24	12/8/2008	Meri	Pressure	Bole
25	13/08/08	Meri	Pressure	Bole
26	14/08/08	Ict	Pressure	Yeka
27	20/08/08	Lebu Adebabay	Pressure	Nifas silk lafto

May				
		Location	Case	Sub-city
1	10/9/2008	Semit pepsi factory	Pressure	Bole
2	11/9/2008	Bulbula	Pressure	Bole
3	14/09/08	Varnero adebabay	Pressure	Nifas silk lafto
4	18/09/08	Mikililand	Pressure	Akaki Kality
5	22/09/08	Mikililand	Pressure	Akaki Kality
6	25/09/08	Gerji	Pressure	Bole
7	26/09/08	Semit	Pressure	Bole
8	27/09/08	Dama Hotel	Pressure	Akaki Kality
9	23/09/08	SANSUSI	Pressure	Nifas silk lafto
10	11/9/2008	Lebu Varnero	Pressure	Nifas silk lafto
11	14/09/08	Lebu Varnero	Pressure	Nifas silk lafto
12	17/09/08	R.fana	Pressure	Kolfe keranio
13	18/09/08	R.fana	Pressure	Kolfe keranio
14	19/09/08	Degnet	Pressure	Kolfe keranio
15	20/09/08	Jomo	Pressure	Nifas silk lafto
16	28/09/08	Jakros	Pressure	Bole
17	3/9/2008	Garment	Pressure	Nifas silk lafto
18	4/9/2008	Garment	Pressure	Nifas silk lafto
19	5/9/2008	Kuyefeche	Pressure	Kolfe keranio
20	7/9/2008	Gelan	Pressure	Akaki Kality
21	10/9/2008	Tulu dimtu	Pressure	Akaki Kality
22	14/09/08	Jomo	Pressure	Nifas silk lafto
23	23/09/08	Nahom Adebabay	Pressure	Bole
24	23/09/08	Kilinto	Pressure	Akaki Kality
25	25/09/08	Tulu dimtu	Pressure	Akaki Kality
26	26/09/08	Dama Hotel	Pressure	Akaki Kality
27	30/09/08	Tulu dimtu	Pressure	Akaki Kality
28	11/9/2008	Meri	Pressure	Bole
June				
1	5/10/2008	Megenagna(Ankorcha)	Pressure	Yeka
2	1/10/2008	Eyasus	Pressure	Yeka
3	11/10/2008	glass factory	Pressure	Nifas silk lafto
4	19/10/08	kale materakemia	Pressure	Yeka
5	26/10/08	arogew	Pressure	Gulele
6	27/10/08	arogew	Pressure	Gulele
7	1/10/2008	Jomo	Pressure	Nifas silk lafto
8	20/10/08	R.fana	Pressure	Kolfe keranio
9	21/10/08	Jomo	Pressure	Nifas silk lafto
10	22/10/08	Jomo	Pressure	Nifas silk lafto
11	11/10/2008	Lebu	Pressure	Nifas silk lafto
12	26/10/08	Jomo	Pressure	Nifas silk lafto
13	27/10/08	Gotera	Pressure	kirkos
14	28/10/08	Gotera	Pressure	kirkos
15	29/10/08	Gotera	Pressure	kirkos
16	5/10/2008	Kilinto	Pressure	Akaki Kality
17	18/10/08	New CT	Pressure	Akaki Kality
18	19/10/08	New CT	Pressure	Akaki Kality
19	21/10/08	Kuyefeche	Pressure	Akaki Kality
20	28/10/08	Cheralea jerba	Pressure	Akaki Kality

July				
		Location	Case	Sub-city
1	11/11/2008	Asko geogis	Pressure	Kolfe keranio
2	12/11/2008	Asko geogis	Pressure	Kolfe keranio
3	9/11/2008	Chew berenda	Pressure	Lideta
4	9/11/2008	Chew berenda	Pressure	Lideta
5	10/11/2008	Chew berenda	Pressure	Lideta
6	18/11/08	Mesgid Wabi chama	Pressure	
7	19/11/08	Mesgid Wabi chama	Pressure	
8	2/11/2008	ICT	Pressure	Gulele
9	4/11/2008	ICT	Pressure	Gulele
10	8/11/2008	Tafo	Pressure	Yeka
11	12/11/2008	Meri	Pressure	Bole
12	14/11/08	Meri	Pressure	Bole
13	30/11/08	Bole Beshale	Pressure	Bole
14	1/12/2008	Bole Beshale	Pressure	Bole
15	1/11/2008	Gotera	Pressure	kirkos
16	2/11/2008	Gotera	Pressure	kirkos
17	4/11/2008	Arsema church	Pressure	Nifas silk lafto
18	6/11/2008	Gotera G-3	Pressure	kirkos
19	8/11/2008	Arsema church	Pressure	Nifas silk lafto
20	10/11/2008	SANSUSI	Pressure	Kolfe keranio
21	12/11/2008	Dartu	Pressure	
22	13/11/08	Arsema church	Pressure	Nifas silk lafto
23	15/11/08	Ayertena	Pressure	Kolfe keranio
24	20/11/08	Saris Abo	Pressure	Akaki Kality
August				
1	1/12/2008	Kuyefeche	Pressure	Akaki Kality
2	3/12/2008	Hana mariam	Pressure	Nifas silk lafto
3	1/12/2008	Ferensay	Pressure	Gulele
4	1/12/2008	Bole Beshale	Pressure	Bole
5	3/12/2008	Yeka Ayat	Pressure	Yeka
6	5/12/2008	Yeka Ayat	Pressure	Yeka
7	5/12/2008	semit	Pressure	Bole
8	7/12/2008	Ayat adebabay	Pressure	Bole
9	8/12/2008	Ayat adebabay	Pressure	Bole
10	13/12/08	Ayat	Pressure	Bole
11	13/12/08	Yeka Ayat	Pressure	Bole
12	14/12/08	Ayat	Pressure	Yeka
13	19/12/08	Yeka Abado	Pressure	Yeka
14	3/13/2008	Lebu	Pressure	Nifas silk lafto
15	5/13/2008	Asko geogis	Pressure	Kolfe keranio
16	22/12/08	Sarbet	Pressure	Nifas silk lafto
17	7/12/2008	Mesalemia Ehl berenda	Pressure	Addis ketema
18	15/12/08	Lebu Express Hile garm	Pressure	Nifas silk lafto
19	19/12/08	Varnero	Pressure	Nifas silk lafto
20	21/12/08	Varnero	Pressure	Nifas silk lafto
21	23/12/08	Gotera	Pressure	kirkos
22	3/12/2008	Tulu dimtu	Pressure	Akaki Kality
23	6/12/2008	Tulu dimtu	Pressure	Akaki Kality
24	16/12/08	Varnero	Pressure	Nifas silk lafto
25	3/12/2008	Tulu dimtu	Pressure	Akaki Kality
26	19/12/08	Industry mender	Pressure	Bole
27	28/12/08	Industry mender	Pressure	Bole