



**ADDIS ABABA UNIVERSITY  
SCHOOL OF GRADUATE STUDIES  
FACULTY OF TECHNOLOGY  
DEPARTEMENT OF CIVIL ENGINEERING**

**INDEPTH INVESTIGATION OF RELATIONSHIP BETWEEN  
INDEX PROPERTY AND SWELLING CHARACTERISTIC OF  
EXPANSIVE SOIL IN BAHIR DAR**

A Thesis Submitted to the School of Graduate Studies of Addis Ababa University in partial fulfillment of the Requirement of the Degree of Master of Science in Civil Engineering (Geotechniques)

Advisor: Professor Alemayehu Teferra

By

Dagmawe Negussie

February 2007



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## DECLARATION

I, the undersigned, declare that this thesis is my work and that all sources of material used for the thesis have been duly acknowledged.

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## List of Symbols

$A_c$ = Activity

$\omega_l$  or LL= Liquid Limit

$\omega_p$  or PL= Plastic Limit

$\omega$  = Natural Moisture Content

SL= Shrinkage Limit

PI= Plasticity Index

$G_s$ = Specific Gravity of Solids

$\gamma_d$ = dry density

CEC= Cation Exchange Capacity

$S_p$ = Swelling Pressure

$I_s$ = Swell Index =  $\omega/\omega_l$

$\omega_{max,24}$ = Water content of a soil after 24 hrs of inundation

$\omega_{max,72}$ = Water content of a soil after 72 hrs of inundation

## Abstract

In this study, the relationship between Index Property and Swelling characteristic of Expansive soil of Bahir Dar is examined.

The test results showed that the Specific Gravity ranges from 2.55 to 2.81. The Index Property Test showed that Plasticity Index ranges from 44.5 to 76.42%. The clay content of the soil is from 55.4 to 87%. Free Swell tests conducted on the collected samples showed a range from 78 to 215%.

According to the Unified Soil Classification System. The soil is categorized as Fat or Organic Clay with a potential of expansion.

AASHTO Classification System also shows that the soil is Plastic Clay with high volume change capacity.

The dry density of the soil, which samples were taken from, ranges between 1.04 and 1.39 gm/cc. Another test conducted using one-dimensional consolidometer showed that the Swelling Pressure of the area ranges between 75.95 and 547.52 kpa.

Relationship observed between Index Property and swelling characteristic of the area showed that with the increment of clay content in the soil the Plasticity Index, the Cation Exchange Capacity and the  $\omega_{\max 24}$  is increased. The increment of the Plasticity Index is in turn reflected in increasing the swelling pressure of the soil.

Dry Density of the soil also increases the swelling pressure. On the other hand Natural Moisture content affects the swelling pressure negatively.

A single Index Property is not a reliable means of predicting the swelling pressure of the soil while a better estimation is observed when different Index Properties are involved in prediction the swelling pressure

The relation of  $(\omega_{\max 24}/\omega)*\gamma_d$  or  $(\omega_{\max 24}/\omega)$  with swelling pressure showed a better indicative value than the PI for the study area.

# 1. Introduction

## 1.1 General

Bahir Dar is founded in the 14<sup>th</sup> century along with the establishment of the Kidane Mihret church near lake Tana. The place was known as Bahir Dar Kidane Mihret until the 17<sup>th</sup> century. After the establishment of the St. George church however, the name was changed to Bahir Dar Giorgis which was in use until the advent of the Italians in the 1930s. The Italians then abolished the administration of the area by the church and the town started to be simply known as Bahir Dar [15].

According to NUPI 1996, the geographical location of Bahir Dar is at 11<sup>o</sup> 38' North latitude and 37<sup>o</sup> 10' East longitudes. The town is located at about 565 km North West of Addis Ababa and it lies in an area characterized by a general flat topography in the southern shore of lake Tana.

Since Bahir Dar is an important center of Amhara National Regional state, development activities are flourishing and the town is expanding in all directions (except to lake Tana). According to the recent demarcation of the town, areas previously considered as rural 'Kebeles' are now recognized as part of the town which significantly increases the total area of the boundary to 15,455 hectare [ Fig. 1,2 ].

Previous rural kebeles demarcated recently as town are:

Zenzelma	4,200 ha
Wereb	1,780 ha
Dishet Abaraj	2,250 ha
Weramit	4,200 ha
Sebatamit	525 ha

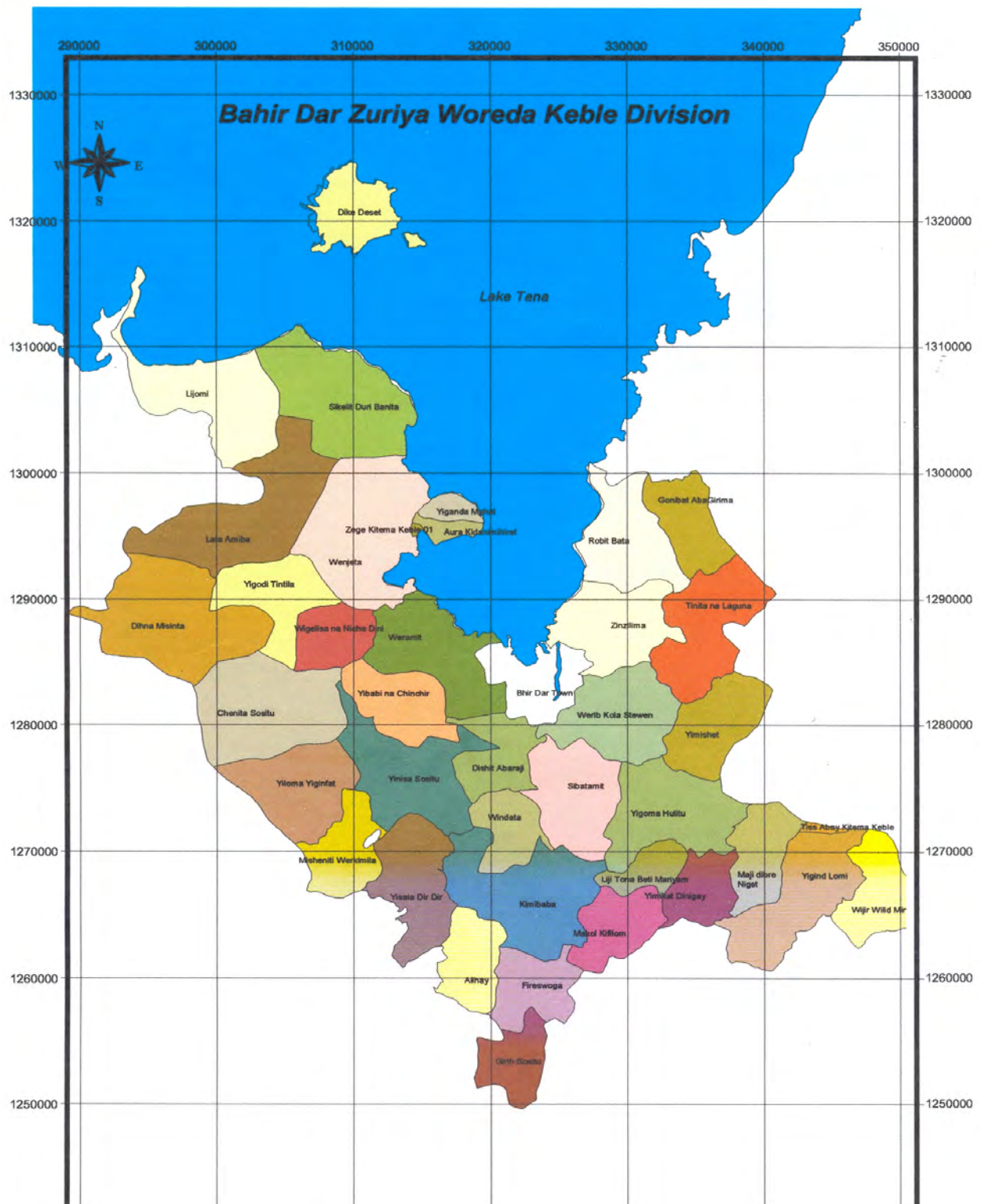


Fig. 1 Map of Bahirdar Zuria Wereda Kebele Division  
 Source GIS of ANRS BoFED

# Recent Map of Bahir Dar Area According to the Revised Delineation

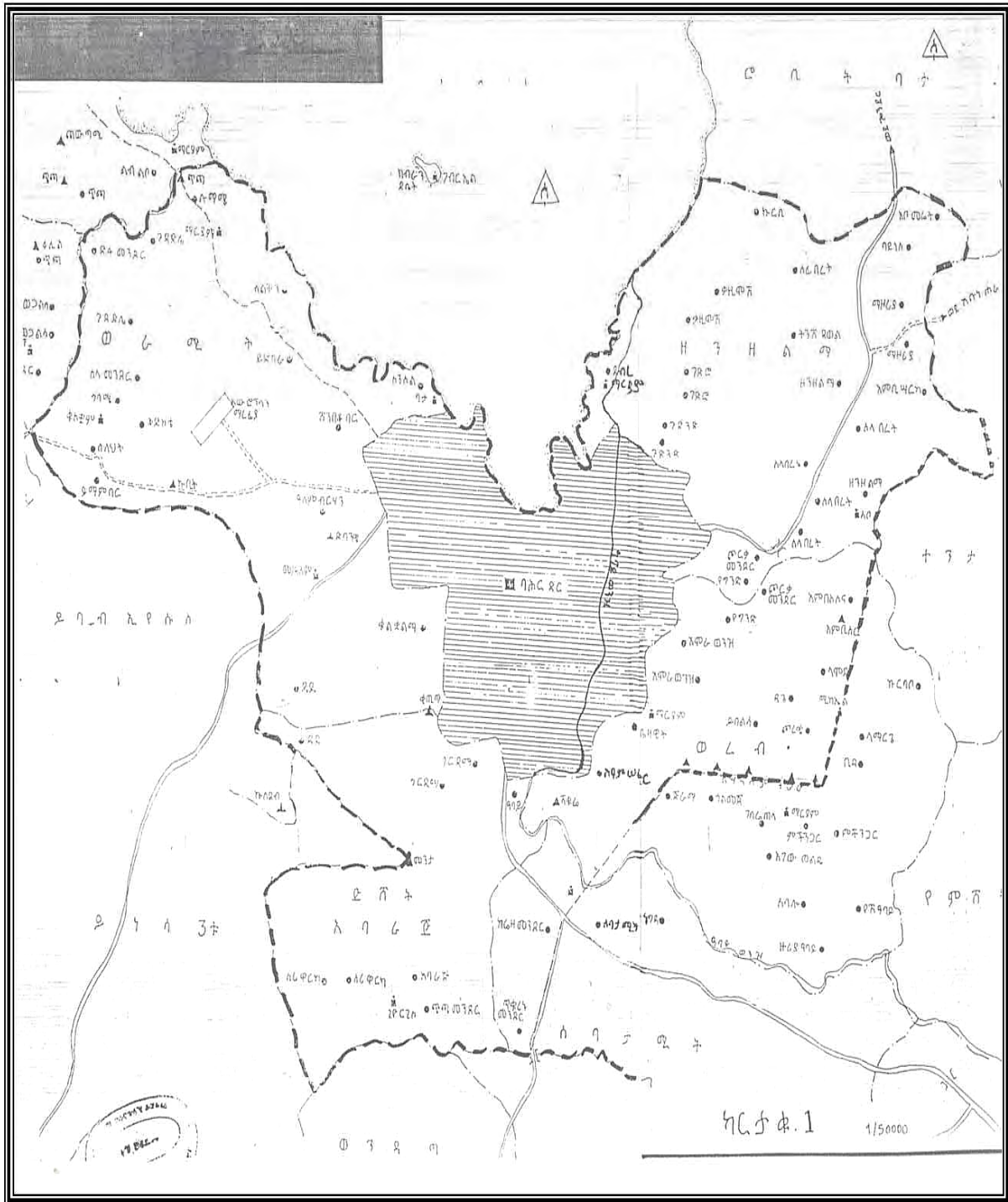


Fig. 2 Recent Map of Bahirdar area According to the Revised Delineation

Source: Bahir Dar Municipality Bureau

## 1.2 Topography Characteristics

Elevation variations in the area ranges from 1768 m.a.s.l in Sebatamit to 1917 m.a.s.l in Zenzelma.

However, most of the town stretches over a predominantly flat land with imperceptible slope changes except for small rises in its eastern and western peripheries. There are also scattered and slightly depressed areas within the town's boundary which form temporary swamps where rain water settles for short to prolonged period of the year.

## 1.3 Climatic Characteristics

Data collected for 27 years shows that the mean annual rainfall in Bahir Dar reaches 1384 mm. There is a considerable seasonal variation of this rainfall depth in which the highest is recorded in the 'kiremt' time (Table 1).

Table 1: Mean Monthly Rainfall of Bahir Dar (1980 -2006), [3]and [8]

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Rainfall (mm)	1.25	1.73	10.12	23.21	77.07	188.49	414.25	371.63	193.12	90.98	11.76	-

The average temperature of the town recorded for 27 years showed that the range of temperature variation throughout the year is between 17 and 23 °C ( Table 2).

Table 2: Mean Monthly Temperature of Bahir Dar (1980 -2006), [3]and [8]

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Temperature (°C)	17.92	19.54	21.06	22.18	21.99	20.82	19.42	19.25	19.38	20.08	18.45	-

## **1.4 Lithologic Units and Soils**

Residual fine soils, like clays and silt-clays, developed on basaltic bedrock mainly represent the soil in Bahir Dar area. These soils are of two main types. The first type is red clay soil the color of which is the result of reduction of magnetic minerals. These soils widely occur in the northern part of the town, along the lakeshore at the central part of the town [15].

The second type includes the dark and dark brown soil which mainly occupies the area south and south west of the town.

Two rock units cover the area of Bahir Dar. The older being Tertiary Ashange Group volcanics which is Paleocene Oligocene in age and Alkaline Olivine Basalt in genetics. It covers the southeastern part of the lakeshore and eastern part of the city. The second and the younger part is the Quaternary Volcanic Product. This volcanic product covers much of the southern Tana basin and out crops in most part of the city of Bahir Dar [7].

## **1.5 Brief Review of Previous Works.**

Some researches have been conducted on the area in the previous years. Especially an M.Sc thesis done by Delelegn Alemu (2004) [7 ], and Getaneh Biru (2005) [8], have relevance to expansive soils of the area. The works mainly focused on classifying the soil and investigating its engineering characteristics.

## **1.6 Difference between the Recent Study and the Previous Works**

- In the recent study, areas not included in the mentioned works are considered.
- Inter-relationship between the index properties and relationship between the index property and Swelling characteristics is examined.
- Some new parameters (not used in the mentioned works), which could describe the relationship better are employed.
- Predictive equations, which help in estimating the Swelling Pressure of the area, are developed.

## **1.7 Objective and Methodology**

### **1.7.1 Objective**

The objective of this study is:

- To investigate the relationship between the index property and swelling characteristic of the soil
- To develop empirical equations which help in estimating the swelling pressure of the soil.

### **1.7.2 Methodology**

The Methodology Used is:

- Location of expansive soil of the area is identified.
- Disturbed and Undisturbed samples are taken from twenty four different places
- Index Property Tests, Chemical Analysis and Swelling Pressure Determination Tests are conducted on all the samples.
- A Computer Program (SPSS 13) is used to develop the empirical equations.

## **2. Literature Review**

### **2.1 General**

Plastic clays exhibiting volume changes when subjected to moisture variations due to seasonal climatic conditions or artificial causes are termed expansive soil. These soils are commonly known as black clays. The fact that they are found favorable in some regions for growing cotton in India has also given them the name black cotton soil [1]. Expansive soil in most cases has adverse effect on any engineering structure built on it. Deformations occurring in the soil, affects the structure negatively and the consequence causes tremendous loss on the economy of a country. For example some studies showed that the annual average loss in the United States in 1981 due to failure of structures built on expansive soil was about \$ 9 billion [14].

### **2.2 Factors Responsible for Shrink-Swell Phenomena Occurring in Expansive Soil**

Shrink and Swell in expansive soil can be induced by different factors. Generally, these factors are categorized into three groups namely the soil characteristics, the environmental factors and the state of stress.

#### **2.2.1 The Soil Characteristics**

The soil characteristics influence the basic nature of the internal force field between particles. The following properties are categorized in this group.

- **Clay mineralogy**

A clay mineral has two fundamental units which forms its structure. These fundamental units are a tetrahedral unit which silicon atom is in the center and four oxygen ions arranged tetrahedrally and Octahedral unit which has an aluminum atom in the center and six Oxygen or hydroxyl ions arranged octahedrally around the aluminum .

The combination of these units in different arrangement leads to the formation of different clay minerals. Some of the major minerals include Kaolinite, Montmorillonite and Illite.

The existence of Montmorillonite minerals is more responsible for the swelling of the soil. This is because the bond between the fundamental units which forms the structure is weaker than the other mineral and it is easily affected by water [12]

- **Dry density**

Density in general shows the spacing of particles in a system. As dry density increases there is a closer spacing between particles and swelling potential increases [14].

- **Plasticity**

Soils exhibiting plastic behavior over wide range of moisture content and that have high liquid limits have greater potential for swelling and shrinking. Plasticity is an indicator of swell potential [14].

- **Soil structure and fabric**

The term fabric refers to the arrangement of particles, particle groups and pore spaces in a soil. Structure has a broader meaning of the combined effect of fabric, composition and interparticle force.

The unique relationship between water content of a soil and matric suction is influenced by soil fabric which in turn affects the swelling potential of the soil [5].

- **Soil suction**

Soil suction is a measure of a soil's affinity for water and it is a parameter, which indicates the intensity with which it will attract water. Higher soil suction shows higher affinity for water and vice versa. Since expansion of a soil is predicted on the assumption that the volume change is equal to the volume of water taken up by the soil, higher soil suction could be used as an indication of swelling potential [5].

- **Soil water chemistry**

Soil water has different type of dissolved minerals, which can react with the clay. Clay particles are platelets like in shape and they have negative charges on their surface and positive charges on their edge. The negative charges on the surface of these particles are balanced by the cations from the soil water.

These cations are sodium, calcium, magnesium and potassium, which dissolve in the soil water and are adsorbed on the clay surface as exchangeable cations to balance the negative electrical surface charge.

If the soil water chemistry is changed either by changing the amount of water or the chemical composition, the inter particle force field which is dependant on the negative surface charge and electro chemistry of the soil water will change.

This change disturbs the equilibrium and the system tries to adjust itself to the new condition which is manifested as shrinkage or swelling [12].

## **2.2.2 Environmental Factors**

Environmental factors influence the changes that may occur in the internal force system.

These factors are mostly associated with moisture. They are:

- Initial moisture condition
- Climate
- Ground water
- Drainage and manmade water sources
- Vegetation

### **2.2.3 Stress Condition**

Over consolidation, magnitude of surcharge load, thickness and location of potentially expansive layers influence shrink-swell phenomenon occurring in the system. These include the following

- Stress history
- Loading
- Soil profile

## **2.3 Identification of Expansive Soils**

One of the most important measures to be taken prior to any design is to investigate whether a soil is potentially expansive or not. This can be done through a number of ways namely:

- Mineralogical Method
- Direct Measurement
- Indirect Method

### **2.3.1 Mineralogical Methods**

Type of clay mineral is a fundamental factor, which determines the expansive behavior of a soil. Mineralogical test is used to identify this mineral. There are different types of techniques, which are used to identify the clay mineralogy. The common types of these techniques are:

- X –ray diffraction
- Differential thermal analysis and
- Electron microscopy

Others also include infrared spectroscopy, dye adsorption and radio frequency electrical dispersion [14].

### **2.3.2 Direct Measurement**

This type of test directly measures the pressure that a swelling soil exerts on any structure resting on it. It is a convenient and more reliable test because it directly tells the likely insitu response of the soil for moisture variations.

The test can be done by the use of a conventional one-dimensional Consolidometer which is available in most soil mechanics laboratories.

### **2.3.3 Indirect Methods**

This method is used to investigate the swelling potential of a soil by examining other parameters, which indirectly give information about the soil property. These include Index Property Tests, Cation Exchange Capacity (CEC), and Potential Volume Change (PVC) test.

Grain Size Analysis, Atterberg Limit and Free Swell tests are some, among the index property tests.

The grain size analysis helps to determine the amount of colloidal sized particles existing in a soil. The term colloid describes a particle whose behavior is controlled by surface force (i.e electrostatic and adsorptive force) rather than by gravitational force and smaller than 0.001 mm in diameter. These colloidal particles greatly influence the plasticity characteristics and volume change behavior of the soil

In this identification method, Atterberg limit and clay contents are combined to define activity.

## **2.4 Classification of Expansive Soils**

Once a soil is identified as expansive, it has to be classified according to the property it exhibits.

There are different classification schemes, which use different basics for the purpose. Among these, the Unified Soil Classification System (USCS) and the American Association of State Highway and Transport Officials (AASHTO) method makes use of index property for classification.

Other methods do also exist which are specific to expansive soils.

### **3. Identification of Soil in the Study Area**

#### **3.1 General**

The primary task of this study was identifying the location of expansive soil in the study area.

Visual investigation and information from local farmers was used for this purpose and 24 places were selected from different locations. Both disturbed and undisturbed samples were then taken. Depth of excavation was dependent on the existing condition of the ground. In some places boulder was encountered and in others the ground water table was very near to the surface. On average, samples were generally taken from depth of 1m to 3m. Studies conducted on the area showed that the average ground water fluctuation range is from 0.2m to 3.4m [7].

Table 3 shows the location and description of the test pits taken from the area.

Test results from [8] are taken as an additional input in classifying the soil of the study area. But for investigation of relationships and for the development of new empirical equations, these test results are left out. This is because, the properties that are used for analysis in the present study are not determined in the previous test.

**Table 3: Location of Sample Areas**

<b>Location</b>	<b>Color</b>	<b>Depth</b>	<b>Northing</b>	<b>Easting</b>	<b>Elevation</b>
Tikurit Mender	Black	2.5	1273834	0325339	1768
Zenzelma Abo	Brown	2.0	1283804	0332604	1903
Gobame	Dark Grey	2.0	1284753	0314278	1811
Gordema	Black	1.5	1277529	0324482	1797
Gudadle	Dark Grey	2.0	1285037	0314294	1812
Baynes (Pit 2)	Brown	2.5	1287231	0332130	1903
Baynes (Pit 1)	Brown	1.0	1287375	0332072	1897
Kereza Mender	Black	2.0	1275462	0325155	1781
Chorka Mender	Dark Brown	1.5	1282045	0330853	1897
Sesa Beret (Pit 1)	Dark Brown	2.5	1284159	0332526	1904
Sesa Beret (Pit 2)	Dark Brown	2.0	1283945	0332518	1901
Lumame (Pit 1)	Dark Grey	1.0	1286277	0317032	1799
Lumame (Pit 2)	Dark Grey	1.5	1286451	0316926	1800
Mazoria	Brown	1.5	1285613	0332944	1917
Sensela Bata	Black	2.5	1284203	0322099	1787
Kebele 16	Black	1.5	1281637	0322866	1795
Kebele 9	Dark Grey	2.0	1281175	0325880	1801
Kebele 7 (pit 1)	Black	2.5	1280771	0324579	1801
Kebele 10	Black	1.5	1282627	0325688	1796
Kebele 8 (pit 1)	Black	2.5	1281330	0325272	1803
Kebele 15	Brown	1.0	1280636	0323631	1806
Kebele 13	Dark Brown	1.0	1283340	0321903	1794
Kebele 7 (pit 2)	Black	1.5	1279967	0325305	1799
Kebele 8 (pit 2)	Black	2.0	1281037	0325445	1802
Tp1-1	Black	1.5	1283352	0321335	-
Tp2-1	Black	1.5	-	-	-
Tp3-1	Black	1.5	-	-	-

<b>Location</b>	<b>Color</b>	<b>Depth</b>	<b>Northing</b>	<b>Easting</b>	<b>Elevation</b>
Tp4-1	Black	2	1283326	0322073	-
Tp5-1	Black	1.5	1281952	0325770	-
Tp6-1	Black	1.5	-	-	-
Tp7-1	Grey	2	1282221	0322970	-
Tp8-1	Grey	2	-	-	-
Tp9-1	Grey	2	-	-	-
Tp10-1	Black	2	1280808	0323210	-
Tp11-1	Black	1.5	-	-	-
Tp12-1	Black	1.5	-	-	-
Tp13-1	Black	1.5	1282037	0323931	-

## **3.2 Index property**

Index property is a property, which helps in distinguishing the characteristics of a soil. Soil grain property and soil aggregate property are two main categories under this term. Soil grain property is based on the individual grains and depends on size, shape and mineralogical characteristics. Soil aggregate property, on the other hand is based on the property of the soil mass as a whole.

Atterberg limit test, hydrometer analysis, specific gravity and free swell tests are among the tests which show the index property of a soil.

### **3.2.1 Atterberg and Shrinkage Limit Test**

Atterberg and Shrinkage limit tests are conducted on the samples taken from the study area. The results of the test are given in Table 4. ASTM D 4318-95 and ASTM 427-93 [ 2 ] are followed for the testing procedure.

**Table 4. Atterberg and Shrinkage Limit Test Result of the Study Area**

<b>Location</b>	<b>Depth</b>	<b>Liquid Limit (%)</b>	<b>Plastic Limit (%)</b>	<b>PI (%)</b>	<b>Volumetric Shrinkage (%)</b>
Tikurit Mender	2.5	91.41	29.84	61.57	8.38
Zenzelma Abo	2.0	96.47	36.67	59.8	8.20
Gobame	2.0	99.51	33.53	65.98	13.95
Gordema	1.5	112.05	35.63	76.42	16.67
Gudadle	2.0	99.51	24.51	75	13.09
Baynes (Pit 2)	2.5	84.78	37.02	47.76	15.56
Baynes (Pit 1)	1.0	96.85	40.85	56	12.77
Kereza Mender	2.0	106.09	34.73	71.36	10.47
Chorka Mender	1.5	86.73	23.74	62.99	13.27
Sesa Beret (Pit 1)	2.5	88.11	21.41	66.7	13.78
Sesa Beret (Pit 2)	2.0	86.23	25.3	60.93	10.87
Lumame (Pit 1)	1.0	81.49	27.63	53.86	19.07
Lumame (Pit 2)	1.5	87.03	28.3	58.73	6.85
Mazoria	1.5	96.29	31.58	64.71	12.27
Sensela Bata	2.5	88.59	31.87	56.72	6.30
Kebele 16	1.5	93.93	34.4	59.53	12.86
Kebele 9	2.0	84.26	26.84	57.42	13.68
Kebele 7 (pit 1)	2.5	99.14	35.52	63.62	13.34
Kebele 10	1.5	93.49	37.16	56.33	16.40
Kebele 8 (pit 1)	2.5	90.66	32	58.66	11.74
Kebele 15	1.0	75	28.54	46.46	16.67
Kebele 13	1.0	82.19	32.18	50.01	10.63
Kebele 7 (pit 2)	1.5	78.5	28.27	50.23	15.18
Kebele 8 (pit 2)	2.0	89.39	44.84	44.55	15.18

<b>Location</b>	<b>Depth</b>	<b>Liquid Limit (%)</b>	<b>Plastic Limit (%)</b>	<b>PI (%)</b>	<b>Volumetric Shrinkage (%)</b>
Tp1-1	1.5	95.5	32.1	63.4	13.20
Tp2-1	1.5	82	28.3	53.7	17.00
Tp3-1	1.5	87.8	33	54.8	14.30
Tp4-1	2	81.3	27.6	53.7	15.20
Tp5-1	1.5	84.8	35.5	49.3	19.10
Tp6-1	1.5	90	29.1	60.9	16.00
Tp7-1	2	93.5	24.6	68.9	14.10
Tp8-1	2	93	31.4	61.6	17.70
Tp9-1	2	93.5	29.3	64.2	18.40
Tp10-1	2	82.8	31.7	51.1	14.80
Tp11-1	1.5	89.5	25.5	64	13.90
Tp12-1	1.5	80	25.4	54.6	17.90
Tp13-1	1.5	91	33.6	57.4	15.00

Note: Test Results from Tp1-Tp 13 are taken from [8 ]

According to Seed, Woodward and Lundgreen, Plasticity Index is a parameter which can be used as a preliminary indicator of the swelling characteristics of a soil. But it should be noted here that high index property doesn't necessarily mean high swelling potential while the converse may be true. The following values are proposed to relate swelling potential with index property.

<b>Swell Potential</b>	<b>Plasticity Index</b>
Low	0-15
Medium	10-35
High	20-55
Very High	35 and above

### Swelling Potential and Plasticity Index Ranges [5] :

Relating the Plasticity Index of the soil of the study area with the above given range reveals that the soil falls in the range of very high swelling potential.

Shrinkage Limit is used also as a guide to the determination of potential expansiveness. Altmayr suggested the following relation.

<b>Shrinkage Limit</b>	<b>Degree of Expansion</b>
Less than 10	Critical
10-12	Marginal
Greater than 12	Non Critical

### Shrinkage Limit and Degree of Expansion Range [5]:

#### 3.2.2 Specific Gravity Test

Specific gravity of soil is the ratio of the unit weight of solids in the soil to the unit weight of water. Determination of specific gravity is important for it is useful to determine the diameter of the soil grains in hydrometer analysis. For the study area the specific gravity of the samples is determined using ASTM D 854-83 [ 2 ] and the result is given in Table 5.

**Table 5 Specific Gravity of the Soil of the Study Area**

<b>Location</b>	<b>Depth</b>	<b>Gs</b>
Tikurit Mender	2.5	2.55
Zenzelma Abo	2.0	2.74
Gobame	2.0	2.64
Gordema	1.5	2.6
Gudadle	2.0	2.68
Baynes (Pit 2)	2.5	2.75
Baynes (Pit 1)	1.0	2.74
Kereza Mender	2.0	2.65
Chorka Mender	1.5	2.77
Sesa Beret (Pit 1)	2.5	2.72
Sesa Beret (Pit 2)	2.0	2.76
Lumame (Pit 1)	1.0	2.74
Lumame (Pit 2)	1.5	2.72
Mazoria	2.0	2.75
Sensela Bata	2.5	2.75
Kebele 16	1.5	2.6
Kebele 9	2.0	2.58
Kebele 7 (pit 1)	2.5	2.66
Kebele 10	1.5	2.68
Kebele 8 (pit 1)	2.5	2.63
Kebele 15	1.0	2.63
Kebele 13	1.0	2.74
Kebele 7 (pit 2)	1.5	2.64
Kebele 8 (pit 2)	2.0	2.67
Tp1-1	1.5	2.74
Tp2-1	1.5	2.72
Tp3-1	2	2.71

<b>Location</b>	<b>Depth</b>	<b>Gs</b>
Tp4-1	1.5	2.78
Tp5-1	1.5	2.69
Tp6-1	2	2.81
Tp7-1	2	2.81
Tp8-1	2	2.8
Tp9-1	2	2.76
Tp10-1	1.5	2.77
Tp11-1	1.5	2.73
Tp12-1	1.5	2.72

### **3.2.3 Grain Size Analysis**

Since grain size analysis is one of the index property tests, the soil of the study area is examined for its grain size distribution. Grain size divides soil into two distinctive groups, namely cohesionless and cohesive soil. Soil particles, which are coarser than 0.075 mm, are generally termed as cohesionless and the finer ones like silt and clay are considered fine grained [13].

The property of cohesionless soil is greatly based on grain size distribution while the property of fine-grained soil is influenced by interparticle force. Hence, the behavior of a soil mass is dependent on the size of the particles it has.

It is quite necessary then, to clearly know the proportion of different grains or particles a soil system contains.

For coarse-grained soils this is done by sieve analysis. For fine-grained soils another method called hydrometer analysis is used for this purpose.

In the present study, Hydrometer and sieve analysis is performed on all the samples and a plot of percent finer against size of soil particle in millimeter on a semi-log scale is

plotted. From this curve the proportion and type of soil grains is determined. The result of the test is given in Table 6.

**Table 6. Grain Size Distribution of the Study Area**

<b>Location</b>	<b>Depth</b>	<b>Sand (%)</b>	<b>Silt(%)</b>	<b>Clay (%)</b>
Tikurit Mender	2.5	6.92	16.08	77
Zenzelma Abo	2.0	4	23	73
Gobame	2.0	1.4	11.6	87
Gordema	1.5	3.77	10.23	86
Gudadle	2.0	2.4	12.6	85
Baynes (Pit 2)	2.5	1.21	16.79	82
Baynes (Pit 1)	1.0	7.5	19.5	73
Kereza Mender	2.0	0.61	21.39	78
Chorka Mender	1.5	3.15	16.85	80
Sesa Beret (Pit 1)	2.5	4.48	13.52	82
Sesa Beret (Pit 2)	2.0	2.2	20.8	77
Lumame (Pit 1)	1.0	4.3	22.7	73
Lumame (Pit 2)	1.5	6.67	19.33	83.5
Mazoria	2.0	4.12	26.88	69
Sensela Bata	2.5	1.84	17.16	81
Kebele 16	1.5	2.26	17.74	80
Kebele 9	2.0	3.68	11.32	85
Kebele 7 (pit 1)	2.5	1.84	21.16	77
Kebele 10	1.5	1.63	18.37	80
Kebele 8 (pit 1)	2.5	3.17	16.83	80
Kebele 15	1.0	16.16	16.84	67
Kebele 13	1.0	4.57	14.63	81
Kebele 7 (Pit 2)	1.5	16.15	17.85	66
Kebele 8 (pit 2)	2.0	1.25	15.75	83
Tp1-1	1.5	21.9	20.0	58.1
Tp2-1	1.5	12.5	16.6	70.9
Tp3-1	1.5	17.1	18.5	64.4

Location	Depth	Sand (%)	Silt(%)	Clay (%)
Tp4-1	2	9.1	19.6	71.3
Tp5-1	1.5	9.3	20.4	70.3
Tp6-1	1.5	13.1	18.5	68.4
Tp7-1	2	10.0	26.3	63.7
Tp8-1	2	15	23.0	62
Tp9-1	2	25	19.6	55.4
Tp10-1	2	9.2	20.2	70.6
Tp11-1	1.5	10.6	22.1	67.3
Tp12-1	1.5	15.4	23.1	61.5
Tp13-1	1.5	11.7	20.4	67.9

### 3.2.4 Moisture Content

The change in water content in a soil's environment plays a major role in determining the degree of swelling and shrinking. A desiccated expansive soil has higher affinity for water and with the higher the affinity the more swell it exhibits. The same soil with higher initial moisture content will have a lesser affinity and exhibits less swelling. But upon drying the initially wet soil loses water more readily than the relatively dry soil and it exhibits higher shrinkage.

Generally, moisture content has an influence on the swelling potential of expansive soils.

Natural moisture content of a soil is affected by climate, vegetation cover of the area and other artificial factors. Hence the same soil could have different moisture contents in different seasons of a year and in different times. Since such type of moisture content is likely to fluctuate any time it may not indicate the general property of the soil.

Zeynal Abiddin [16] proposed a rather stable parameter, which he used for predicting swelling parameter of Ankara clay. It is called  $\omega_{\max, 24,72}$ , which is maximum water content of a soil after it, is inundated for 24 and 72 hrs.

He suggested that for  $\omega_{\max, 24,72}$  test, about 400g soil sample is transferred into a 200 or 300 ml jar and then distilled water is introduced to the soil. The mixture is repeatedly

stirred by a metal bar about 5-6 min until viscous material is obtained. The mixture is left in the jar for 24 and 72 hr. After 24 hr the jar is laid down and kept in this position about 15-20 min to remove the water accumulated at the surface of the soil, and finally water content of the soil is determined by taking about 25-30g soil sample form the jar. In this simple test any specially prepared sample is not needed and disturbed or undisturbed sample can be directly used. In his study he reported that a major difference was not observed between  $\omega_{\max, 24}$  and  $\omega_{\max, 72}$ . Thus he used  $\omega_{\max, 24}$  for analysis.

In the present study, following the suggestion,  $\omega_{\max, 24}$  is determined for all the samples and for comparison  $\omega_{\max, 72}$  is also determined on randomly selected samples. The results are given in Table 7 and 8

**Table 7 :  $\omega_{\max, 24}$  values of the Study Area.**

<b>Location</b>	<b>Depth</b>	<b><math>\omega_{\max 24}</math> (%)</b>
Tikurit Mender	2.5	107.01
Zenzelma Abo	2.0	84.90
Gobame	2.0	105.66
Gordema	1.5	106.72
Gudadle	2.0	110.68
Baynes (Pit 2)	2.5	91.46
Baynes (Pit 1)	1.0	124
Kereza Mender	2.0	92.92
Chorka Mender	1.5	99.58
Sesa Beret (Pit 1)	2.5	100.25
Sesa Beret (Pit 2)	2.0	105.71
Lumame (Pit 1)	1.0	91.74
Lumame (Pit 2)	1.5	88.01
Mazoria	2.0	86.71
Sensela Bata	2.5	106.85
Kebele 16	1.5	110.83

Location	Depth	$\omega_{24}$ (%)
Kebele 9	2.0	105.09
Kebele 7 (pit 1)	2.5	109.98
Kebele 10	1.5	128.25
Kebele 8 (pit 1)	2.5	108.97
Kebele 15	1.0	77.42
Kebele 13	1.0	119.71
Kebele 7 (pit 2)	1.5	102.53
Kebele 8 (pit 2)	2.0	119.43

**Table 8: Comparison of  $\omega_{\max, 24}$  and  $\omega_{\max, 72}$  values of the Study Area**

Location	$\omega_{\max, 24}$	$\omega_{\max, 72}$
Lumame (Pit 1)	91.74	96.66
Zenzelma Abo	84.90	90.01
Gobame	105.66	114.36
Kebele 8 (pit 1)	108.97	113.61
Gudadle	110.68	121.01
Kebele 7(pit 1)	109.98	110.82
Bynes (pit2)	91.46	93.86
Mazoria	86.71	91.02

The  $\omega_{\max, 24,72}$  test can be taken as an indication for the soil's affinity for water. Since water plays an important role in swelling, affinity for water, together with other properties could be a strong indicator of swell potential. As seen on the result, here also much difference is not observed between the  $\omega_{\max, 24}$  and  $\omega_{\max, 72}$  tests. This indicates that most of the suction takes place within 24 hours.

### 3.2.5 Free Swell

The free swell test is one of the most commonly used simple tests for estimating soil swelling potential. This test is performed by pouring 10cc of dry soil, passing through sieve no 40 ( 0.425mm diameter), into a 100 cc graduated cylinder. The cylinder is then filled with distilled water and the swelled volume of the soil is measured after the material settles.

Free swell is then given by :

$$Fs = \frac{V - V_o}{V_o} \times 100$$

Where: Fs = Free Swell

V = Final Volume after swell

V<sub>o</sub> = Volume of dry soil, 10 cm<sup>3</sup>

Results of the free swell tests of the study area are given in Table 9

**Table 9 : Free Swell Test Results of the Study Area**

<b>Location</b>	<b>Depth</b>	<b>Free Swell</b>
Tikurit Mender	2.5	120
Zenzelma Abo	2.0	110
Gobame	2.0	150
Gordema	1.5	170
Gudadle	2.0	160
Baynes (Pit 2)	2.5	100
Baynes (Pit 1)	1.0	110
Kereza Mender	2.0	215
Chorka Mender	1.5	120
Sesa Beret (Pit 1)	2.5	80
Sesa Beret (Pit 2)	2.0	90
Lumame (Pit 1)	1.0	105
Lumame (Pit 2)	1.5	138
Mazoria	2.0	130
Sensela Bata	2.5	110
Kebele 16	1.5	200
Kebele 9	2.0	190
Kebele 7 (pit 1)	2.5	120
Kebele 10	1.5	170
Kebele 8 (pit 1)	2.5	200
Kebele 15	1.0	120
Kebele 13	1.0	130
Kebele 7 (pit 2)	1.5	150
Kebele 8 (pit 2)	2.0	180
Tp1-1	1.5	78
Tp2-1	1.5	86
Tp3-1	1.5	98
Tp4-1	2	120
Tp5-1	1.5	110

Location	Depth	Free Swell
Tp6-1	1.5	116
Tp7-1	2	113
Tp8-1	2	114
Tp9-1	2	125
Tp10-1	2	108
Tp11-1	1.5	124
Tp12-1	1.5	114
Tp13-1	1.5	95

### 3.2.6 Cation Exchange Capacity (CEC)

Clay minerals are platelets like in shape and have negative charges on their surface. These negative charges readily attract cations till the surface is balanced. The amount the clay particle attracts cations depends on the type of mineral it is made of and it is expressed by Cation Exchange Capacity (CEC).

Thus, CEC is the quantity of exchangeable cations required to balance the negative charge on the surface of the clay particle. A high CEC value indicates a high surface activity and a higher swell potential [14 ].

Different clay minerals have different CEC .In Table 10 the different values are given [5].

**Table 10: Range of CEC Values [5]**

Clay Mineral	CEC (meq*/100gm)
Kaolinite	3-15
Illite	10-40
Montmorilonite	70-80

\* miliequivalent per 100 gm

For the study area the CEC is determined for all the samples and the values are compared to the ranges given in Table 8. This shows that except one sample which is taken from Kebele 15 all the rest showed CEC greater than 40.

Another test is also conducted to determine the  $\text{Na}^+$  concentration in the soil of the study area.  $\text{Na}^+$ ,  $\text{Mg}^{2+}$  and  $\text{Ca}^{2+}$  ions have their own role in the shrink-swell property of expansive soil. These cations balance the negative surface charge of clay particles. Especially the cations are held close to the surface in air-dry soil. But when water is available the hydration energy opposes the inter particle force which held these cations to the clay surface. As the amount of water increases in the soil, the cations start to enlarge and they tend to diffuse to the more dilute solution. But at the same time the negative surface force of the clay particle increases and this phenomenon attracts more cations towards the surface and cations accumulate around the clay particle. This accumulation of cations forms a layer, which is called diffused double layer (DDL). The DDL formed around every other clay particles overlaps and this overlapping produces repulsion force which is expressed as swelling pressure. The thicker the DDL the more is the swelling potential. The thickness of the DDL is governed by the presence of cations with low valance. Thus more swelling would occur in a soil having exchangeable sodium ( $\text{Na}^+$ ) cations than same soil with calcium ( $\text{Ca}^{2+}$ ) or magnesium ( $\text{Mg}^{2+}$ ) cations [14].

For this reason the  $\text{Na}^+$  concentration of the soil of the study area is determined through a laboratory analysis and the result is given in Table 11

**Table 11: CEC and Na+ Content of the Study Area.**

<b>Location</b>	<b>Depth</b>	<b>CEC (Meq/100g)</b>	<b>Na+ (Meq/100g)</b>
Tikurit Mender	2.5	51.57	3.63
Zenzelma Abo	2.0	64.41	0.37
Gobame	2.0	57.35	0.92
Gordema (Pit 2)	1.5	62.27	3.93
Gudadle	2.0	60.56	4.06
Baynes (Pit 2)	2.5	51.36	3.42
Baynes (Pit 1)	1.0	61.2	0.79
Kereza Mender	2.0	68.27	0.46
Chorka Mender	1.5	62.48	1.34
Sesa Beret (Pit 1)	2.5	49.86	1.25
Sesa Beret (Pit 2)	2.0	61.63	2.3
Lumame (Pit 1)	1.0	43.87	2.8
Lumame (Pit 2)	1.5	46.22	3.51
Mazoria	2.0	54.36	6.44
Sensela Bata	2.5	70.88	0.63
Kebele 16	1.5	50.08	1.58
Kebele 9	2.0	67.45	3.51
Kebele 7	2.5	67.62	4.43
Kebele 10	1.5	57.57	1.63
Kebele 8	2.5	67.41	0.42
Kebele 15	1.0	28.03	1.71
Kebele 13	1.0	48.36	8.11
Kebele 7	1.5	52	1.71
Kebele 8	2.0	77.51	3.88

## **4. Soil Classification**

Soil classification is an important aspect of laboratory test, which tells the characteristic of the soil under interest. There are different methods of classification based on the identification tests performed on the soil.

Unified Soil Classification System (USCS) and the American Association of State Highway Transport Officials (AASHTO) method are among the widely used schemes of soil classification. There are also other classification methods specifically proposed for expansive soils.

### **4.1 USCS and AASHTO Classification**

The basis for USCS (Unified Soil Classification System) is Liquid Limit and Plasticity Index of a soil. An “ A-line” which is defined by an equation (I.e,  $0.73*(LL-20)$ ) separates the ‘MH or OH’ and the ‘CH or OH’ designation.

In USCS MH means elastic silt, CH means fat clay and OH means organic clay or silt.

According to this classification scheme most of the soil of the study area falls in CH or OH region, which shows that the soil is potentially expansive (Fig 3).

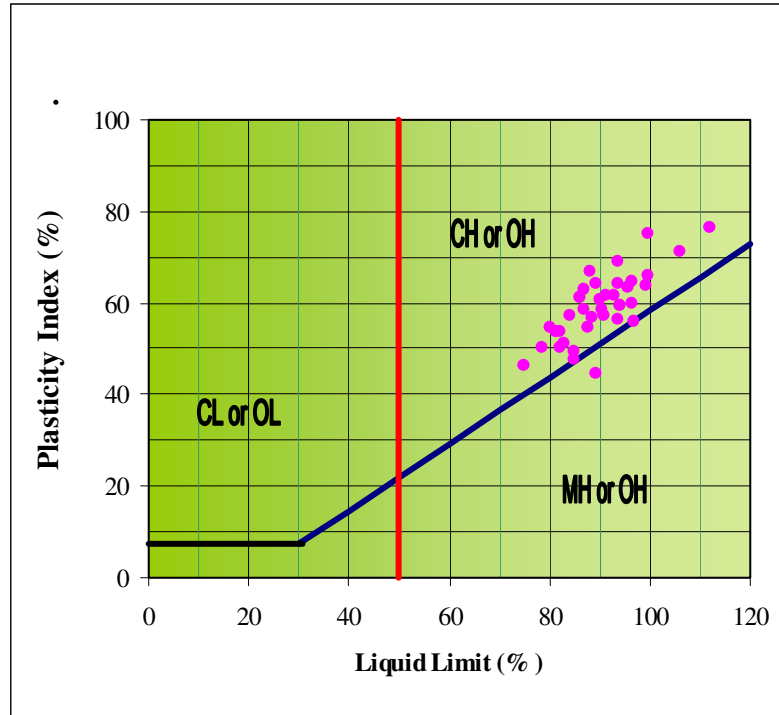


Fig. 3 Plasticity chart of the soil of the study area, according to Unified Soil Classification System (UCSC) [8]

The AASHTO system uses similar techniques but the dividing line has an equation of the form  $PI = LL - 30$ . It generally classifies a soil broadly into granular material and silt-clay material.

The granular material is further divided into three groups which are called A-1, A-2 and A-3. The silt-clay material is in turn divided into four groups namely, A-4, A-5, A-6 and A-7.

According to this system the soil of the study area falls in the region of A-2-7, A-7-5 and A-7-6 (Fig. 4).

This means the soil under interest is plastic clay which has a high volume change capacity between wet and dry states.

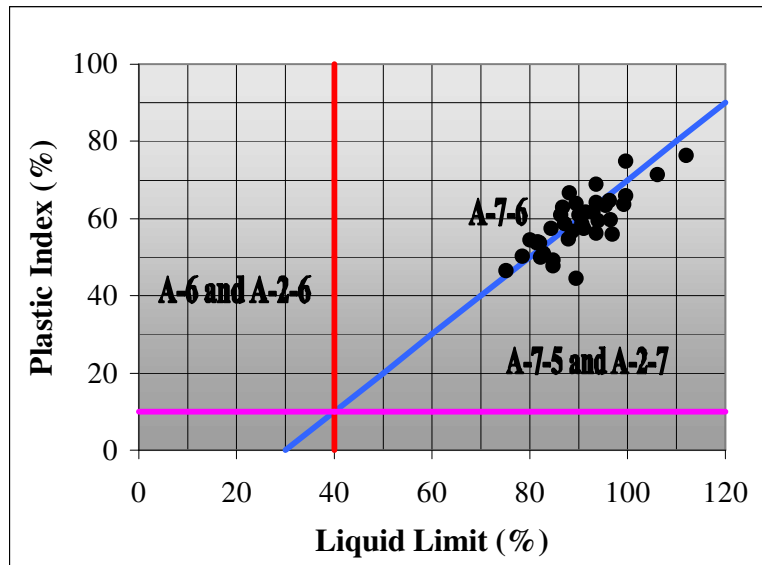


Fig.4 Classification of the Soil of the Study Area According To AASHTO System [8]

## 4.2 Other Classifications

Activity which is defined as the ratio of the plastic index to percent of clay fraction finer than 0.002mm is one means of classifying expansive soils based on their index property.

According to Skempton, clays are classified with respect to their activity and the following values show this classification scheme [1].

<b>Degree of Activity</b>	<b>Activity</b>
Inactive Clay	Less than 0.75
Normal Clay	0.75 - 1.25
Active Clay	Greater than 1.25

These values are presented in the form of chart, which is called Activity Chart, and the soil of the study area is compared to the values and it falls in the range of normal to active clay ( Fig. 5).

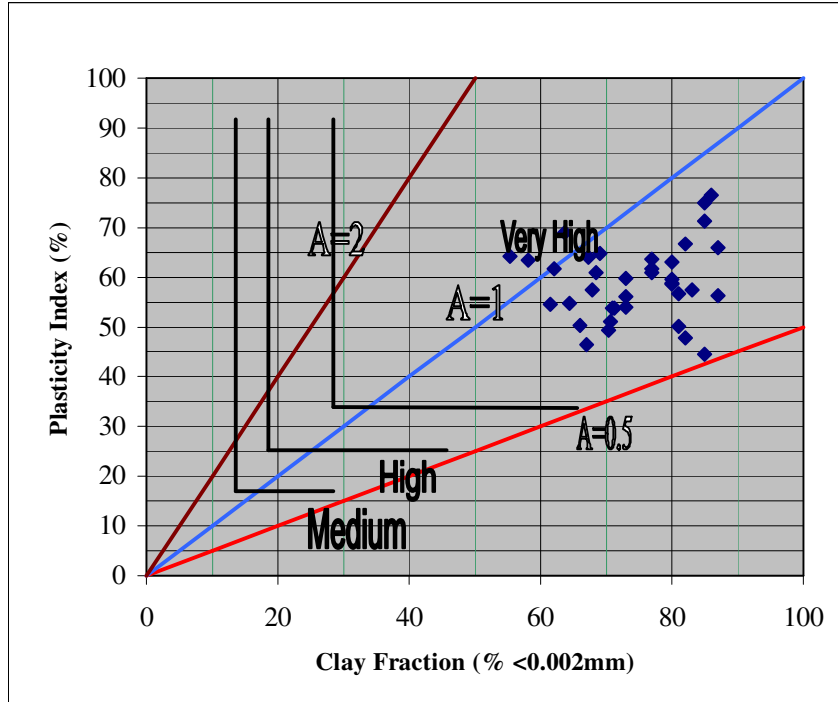


Fig. 5 Activity Chart of the soil of the study area

#### 4.2.1 Charts specific to the Study Area

Different types of charts are prepared to show the relationship between different properties of the soils of the study area. Figures 6 and 7 show relation between Clay Content of the soil and its Plasticity Index and Water Content at 24 hr.

All the results showed that as the clay content increases, the Plasticity Index and the water holding capacity increases in different manners.

## I) Clay Content and Plasticity Index

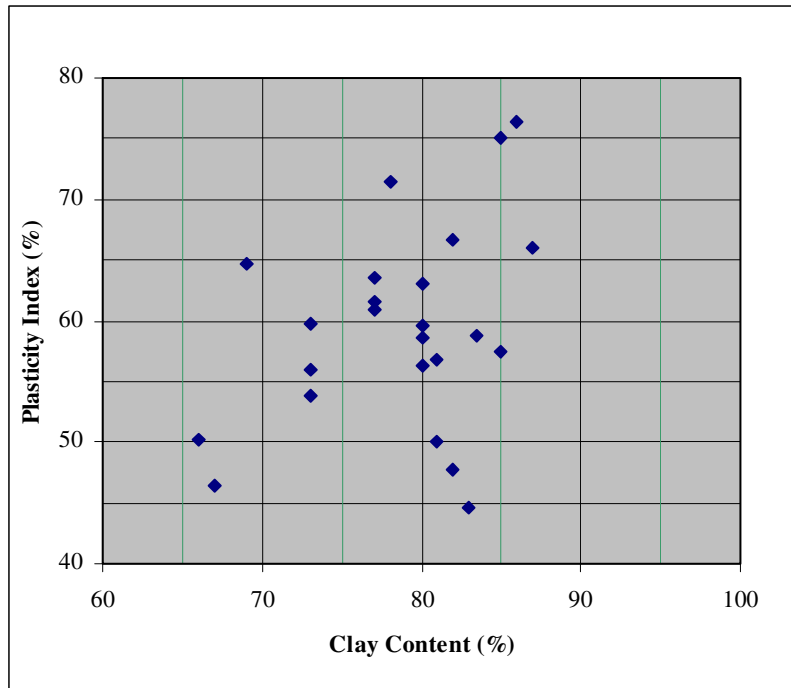


Fig. 6 Plasticity Index and Clay content Relation of the study area.

## II) $\omega_{\max 24}$ , and Clay Content.

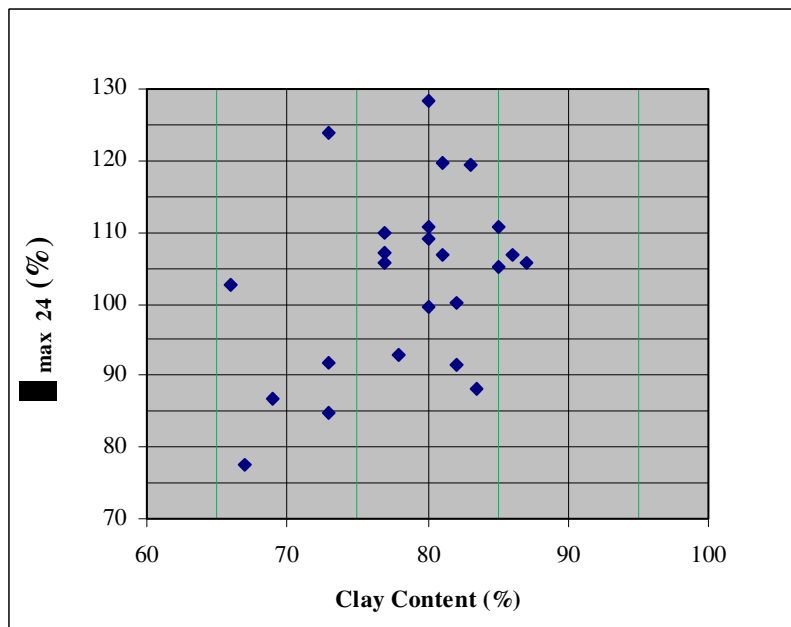


Fig. 7  $\omega_{\max 24}$  and Clay content Relation of the study area.

### III) Clay Content and CEC

Cation exchange capacity can be explained simply as the amount of exchangeable cations attracted by the clay surface. It is known that the type of clay mineral plays a major role in determining this capacity. But it may also be reasonable to expect some relation with CEC and available amount of clay in a soil since it may not be practical at all to talk about CEC without the availability of clay. Thus a graph of clay fraction against CEC is drawn and it is seen that the CEC of the study area increases as the percentage of clay fraction in the sample increases.( Fig. 8)

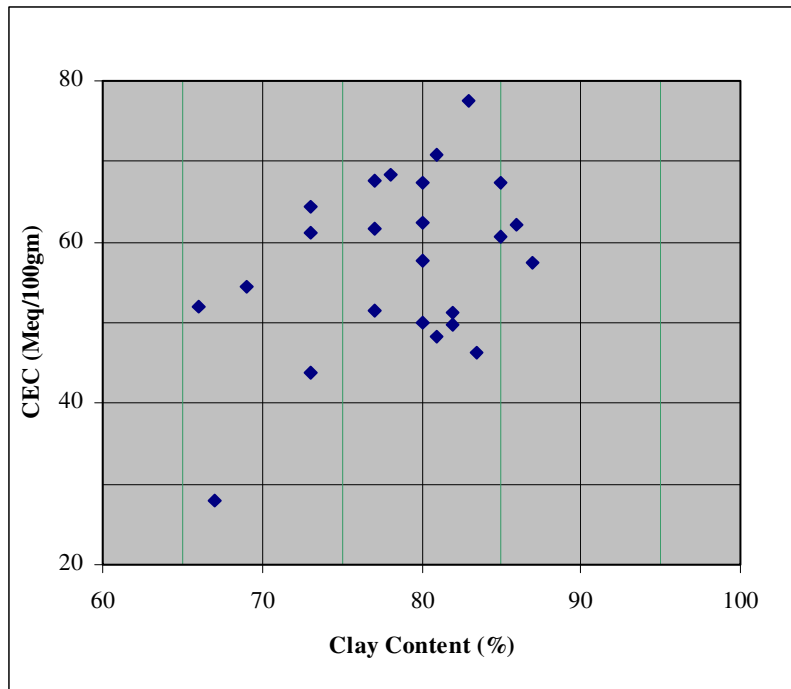


Fig. 8 CEC and Clay content Relationship of the study area.

This could be attributed to the amount of exchangeable cations required to saturate the charge deficiency on the clay surface increases as the clay content increases.

## **5 Determination of Swelling Pressure**

Swelling Pressure is the amount of pressure a soil exerts upon swelling. The most reliable means of measuring swelling pressure is laboratory determination using one-dimensional consolidometer.

This method is called direct measurement and the test is conducted on the soil of the study area. The results of the test are given in tabular form below ( Table 12).

Various types of graphs are then drawn to study the relationship between the swelling pressure and different index property values. A multiple regression analysis, finally, is performed to correlate the swelling pressure with these different index properties.

**Table 12: Swelling Pressure test results of the Study Area**

<b>Location</b>	<b>Depth</b>	$\gamma_d$ (gm/cc)	<b>Swelling Pressure</b> (Kpa)	<b>Natural Moisture Content, w</b> (%)
Tikurit Mender	2.5	1.28	547.52	26.51
Zenzelma Abo	2.0	1.39	344.50	31.2
Gobame	2.0	1.25	111.82	46.88
Gordema	1.5	1.29	514.61	28.11
Gudadle	2.0	1.22	175.38	40.1
Baynes (Pit 2)	2.5	1.36	165.60	40.39
Baynes (Pit 1)	1.0	1.18	377.27	41.15
Kereza Mender	2.0	1.05	79.95	61.24
Chorka Mender	1.5	1.39	379.24	28.14
Sesa Beret (Pit 1)	2.5	1.28	538.33	31.1
Sesa Beret (Pit 2)	2.0	1.29	202.27	38.14
Lumame (Pit 1)	1.0	1.35	296.91	34.09
Lumame (Pit 2)	1.5	1.35	135.74	38.74
Mazoria	2.0	1.34	197.41	32.9
Sensela Bata	1.5	1.38	264.76	32.75
Kebele 16	1.5	1.29	114.37	40.99
Kebele 9	2.0	1.26	495.81	35.13
Kebele 7 (pit 1)	2.5	1.24	186.80	41.96
Kebele 8 (pit 1)	2.5	1.18	298.11	40.8
Kebele 13	1.0	1.38	210.22	37.19
Kebele 7 (pit 2)	1.5	1.34	326.44	37.25
Kebele 8 (pit 2)	2.0	1.17	140.64	48.61
Kebele 10	1.5	1.04	92.12	59.45
Kebele 15	1.0	1.48	128.09	34.2

## 5.1 Swelling Pressure and Index Property

Relationships between Swelling Pressure and different parameters have also been investigated.

### 5.1.1) Swelling Pressure Vs Plasticity Index

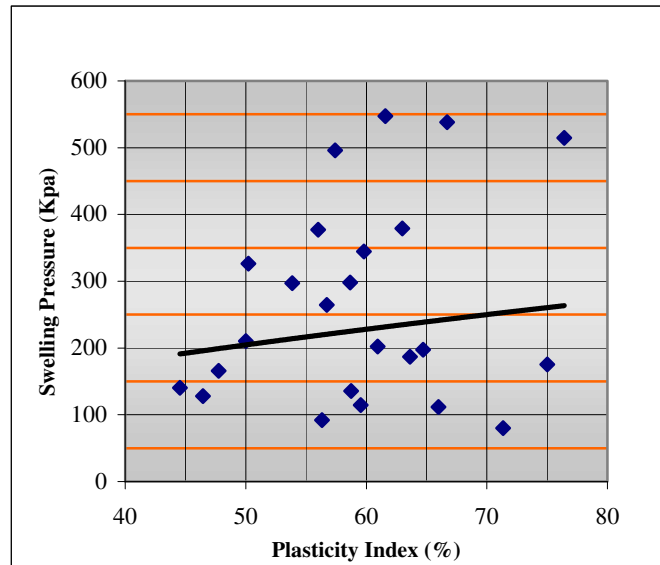


Fig. 9: Swelling Pressure Vs Plasticity Index of the Study Area

The swelling Pressure and the Plasticity index of the study area ( Fig. 9) shows that there is a tendency of increment of the swelling pressure as the plasticity index increases. However, the widely scattered points from the trend line show that the relationship is weak. This shows that the determination of the Plasticity Index alone cannot satisfactorily indicate the swelling behavior of the soil.

### 5.1.2) Swelling Pressure Vs Natural Moisture Content

Natural moisture content is one of the factors, which influence the swelling characteristic of expansive soils.

A graph is plotted to see how it affects the swelling pressure of the study area. The results show a general trend of decreasing swelling pressure with increment of natural moisture content manifested in a non-linear relation (Fig. 10).

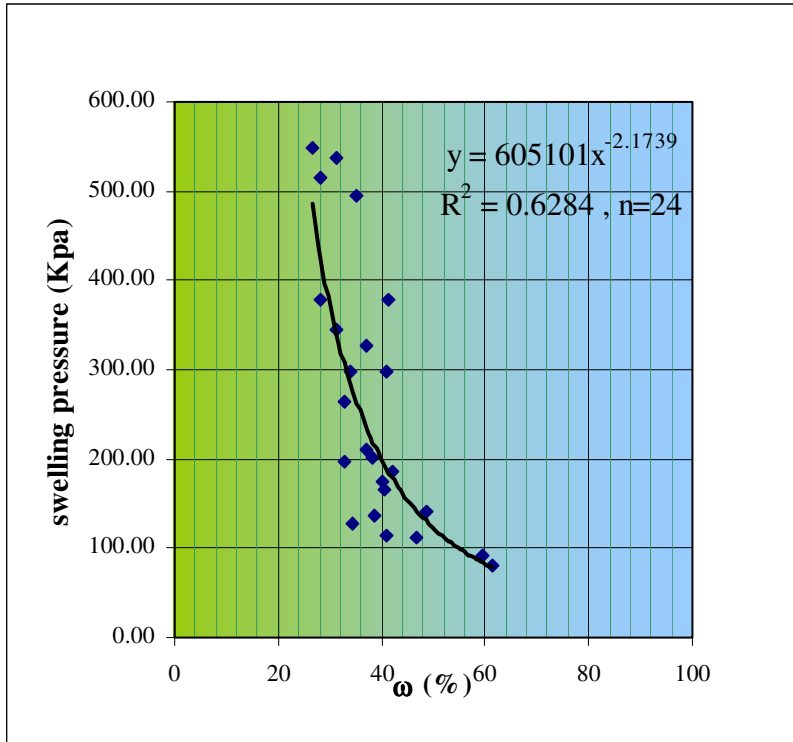


Fig 10 Swelling Pressure Vs Natural Moisture Content of the Study Area.

### 5.1.3) Swelling Pressure Vs Dry Density

Dry density, which is a measure of the compactness of soil grains, is also another factor, which plays a role in swelling characteristic of expansive soils. A graph is plotted to see the relationship between the dry density and swelling pressure of the study area. The result shows that there is a tendency of increment of swelling pressure as the dry density increases (Fig. 11).

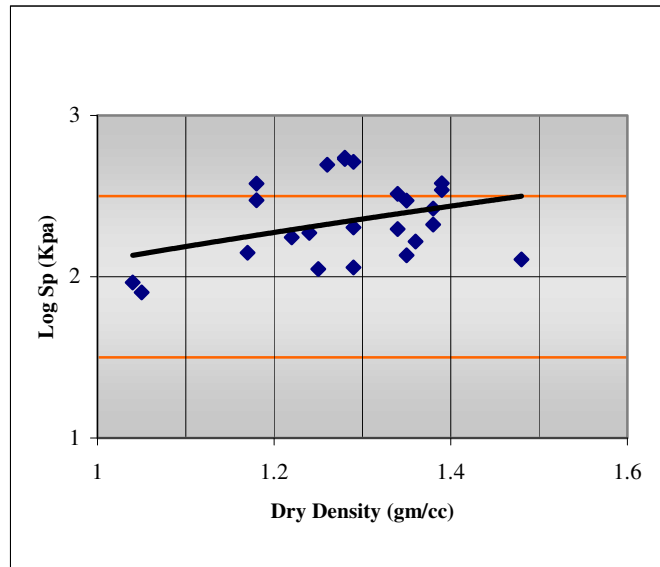


Fig. 11 : Swelling Pressure Vs Dry Density of the Study Area

#### 5.1.4) Swelling Pressure Vs $\omega$ and $\omega_{\max 24}$

It has been discussed previously that  $\omega_{\max 24}$  could be used as an indicator of the swelling characteristic of expansive soil. It is a measure of the water imbibing capacity of a soil. However, graphs plotted to see the relationship between these two parameters do not show a satisfactory correlation as expected. This is because the natural water content of the soil affects the swelling characteristic of the soil. Whatever is the  $\omega_{\max 24}$  value, if the natural moisture content is high, the soil does not exhibit swelling. Thus another strong parameter, which makes use of the  $\omega_{\max 24}$  value, is tried. It is the ratio of  $\omega_{\max 24}$  and  $\omega$ .

The graph is then plotted and a non-linear relationship between this value and the swelling pressure is observed. The relationship is even stronger than that observed between swelling pressure and natural moisture content ( Fig. 12).

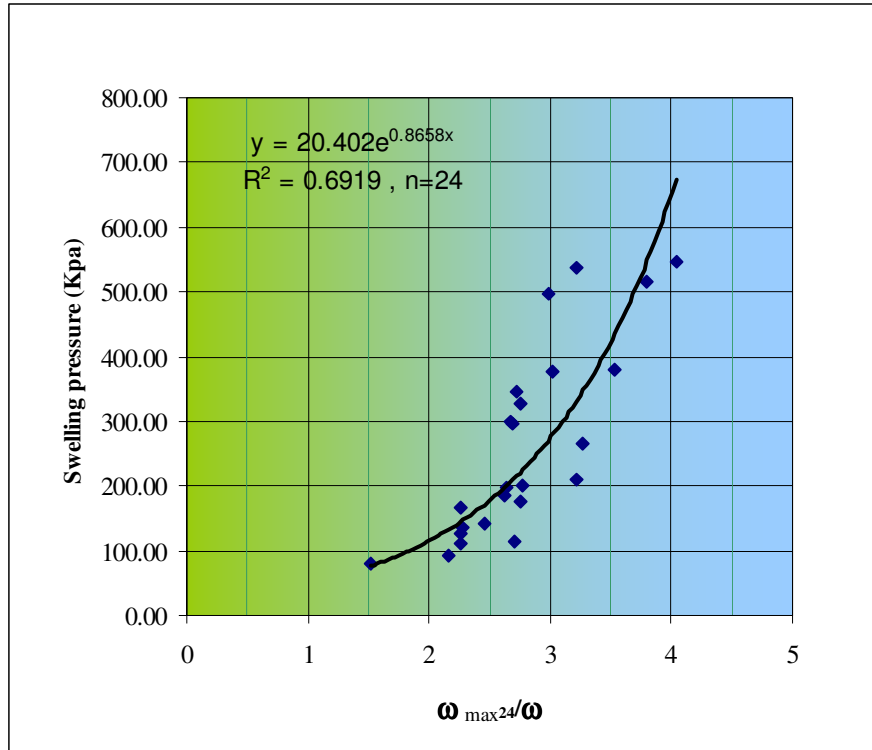


Fig. 12 Swelling Pressure Vs  $\omega_{\max 24} / \omega$  value

A non linear equation with the form:  $Y = 20.402 e^{0.866x}$ ,  $R^2=0.69$ ,  $n=24$  describes the relation.

Where: Y= Swelling Pressure (kpa)

$$X = \omega_{\max 24} / \omega$$

### 5.1.5) Swelling Pressure, Dry Density, $\omega_{\max 24}$ and $\omega$

As discussed above in (5.1.3) the swelling pressure increases with the increment of the dry density. However, as swelling pressure is a result of a combined effect of different phenomena, another parameter, which better describes the relation is sought.

Swelling Pressure Vs  $(\omega_{\max 24} / \omega) * \gamma_d$  is considered ( Fig. 13).

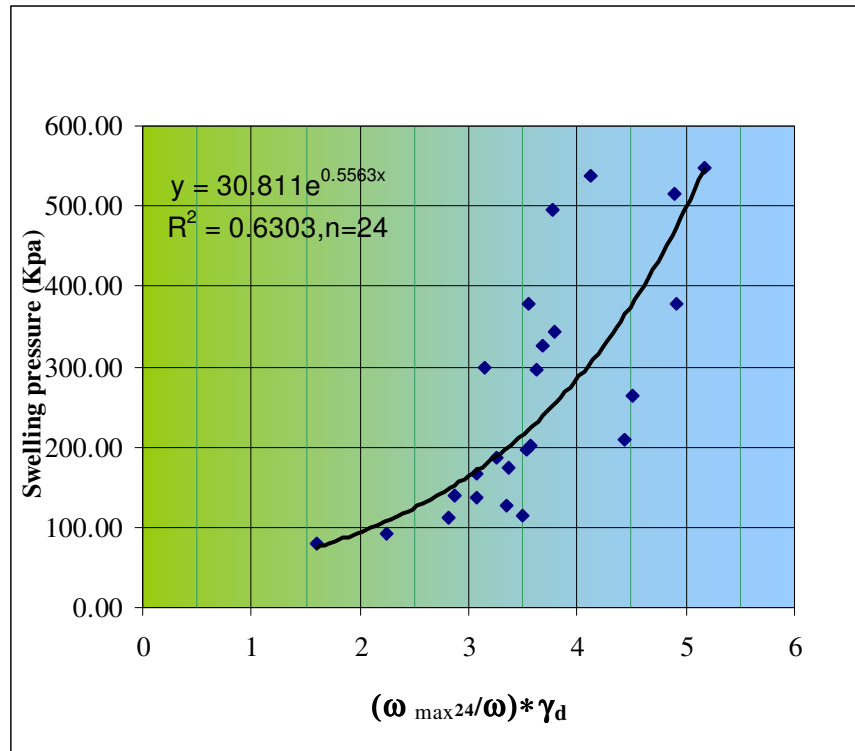


Fig. 13 Swelling Pressure Vs  $(\omega_{\max 24} / \omega) \gamma_d$  value

A non linear equation with the form:  $Y = 30.811 e^{0.556x}$  , $R^2=0.63$  , $n=24$  describes the relation.

Where: Y= Swelling Pressure (kpa)

$$X = (\omega_{\max 24} / \omega) \gamma_d$$

$\omega_{\max 24}$  and  $\omega$  in (%)

$\gamma_d$  in (gm/cc)

## **6. Swelling Behavior Predictive Models**

The evaluation of swell behavior of a soil using undisturbed samples is a difficult and expensive process. Therefore there is a need for simple routine tests to be performed on disturbed samples to achieve the same purpose. To facilitate this, empirical models had been put forwarded by different researchers to predict swell behavior of a soil.

These models comprise different soil parameters in different combinations. Index properties are the widely used parameters in these models because these properties have significance in indicating the swelling behavior of a soil.

In general, previously developed empirical equations and equations to be developed in the future are not to be expected to determine swelling pressure precisely and accurately for all soils. The formation and development of soil structure has very erratic nature and the swell potential is dependent on the geology, environmental factors, soil characteristics and many other factors, which vary from place to place. Therefore equations developed for soils in one place may not work at all if tested on soils of other place of the same region. Hence specific models have to be developed for specific areas in order to give fair evaluations.

## 6.1 Models Developed by Various Researchers

As mentioned previously, there are different empirical equations developed to determine the swelling behavior of a soil. Some of them are presented below.

### i) Komornik and David (1969) [4 ]

$$\log P_s = \bar{2}.132 + 0.0208(W_l) + 0.665(\gamma_d) - 0.0269(w) \quad \text{-----6.1}$$

Where :  $W_l$ = Liquid limit (%)

$P_s$ =swelling pressure (Kg/cm<sup>2</sup>)

$w$ =moisture content (%)

$\gamma_d$ =dry density (gm/cm<sup>3</sup>)

### ii) Daniel Teklu [6 ]

From multiple regression analysis he recommended the following two equations.

$$\text{Log } P_s = -5.00 - 0.0002064 \times LL + 0.003477 \times PI + 0.005827 \times \gamma_d \quad \text{---6.2}$$

$$\text{Log } P_s = -9.384 + 0.02748W + 0.006307PI + 0.008359\gamma_d \quad \text{----- 6.3}$$

Where :  $P_s$ =Kpa

$W$ ,  $LL$  and  $PI$  are in percentage

$\gamma_d$ =Kg/m<sup>3</sup>

In these equations index properties that are believed to have significance for swelling are used as independent variables. Obviously the proposed equations might have served their purpose in areas where they have been specifically developed.

At this point it is worthwhile to test these equations for the soil of the study area and to examine the outcome.

## **6.2 Evaluation of Previously Developed Models for Soils of the Study Area.**

The developed equations are tested on soils of the study area and the results are given in Table 13

**Table 13. Comparison of Previously Developed Equations with the Measured Value.**

<b>Location</b>	<b>Depth</b>	<b>Measured Swelling Pressure (Kpa)</b>	<b>Proposed Eqn. by Komornik and David (kpa)</b>	<b>Proposed Eqn. by Daniel Teklu (Kpa)</b>	
Tikurit Mender	2.5	547.52	145.57	450.58	270.61
Zenzelma Abo	2.0	344.58	164.18	1,938.85	2,948.12
Gobame	2.0	111.82	58.03	310.90	587.69
Gordema	1.5	514.61	359.75	574.67	450.35
Gudadle	2.0	175.38	84.35	223.45	244.88
Baynes (Pit 2)	2.5	165.60	50.70	1,183.81	2,485.30
Baynes (Pit 1)	1.0	377.27	65.45	112.35	91.96
Kereza Mender	2.0	79.95	24.06	22.11	33.57
Chorka Mender	1.5	379.24	124.46	1,998.23	2,544.34
Sesa Beret (Pit 1)	2.5	538.33	93.53	470.21	389.78
Sesa Beret (Pit 2)	2.0	202.27	56.12	513.91	678.40
Lumame (Pit 1)	1.0	296.91	63.01	1,088.68	1,503.62
Lumame (Pit 2)	1.5	135.74	61.59	1,128.99	2,165.88
Mazoria	2.0	197.41	135.70	1,031.10	1,346.72
Sensela Bata	1.5	264.76	100.71	1,660.31	2,565.21
Kebele 16	1.5	114.37	68.02	506.32	796.11
Kebele 9	2.0	495.81	58.77	334.41	299.13
Kebele 7 (pit 1)	2.5	186.80	76.15	266.82	343.14
Kebele 10	1.5	92.12	14.48	17.24	19.88
Kebele 8 (pit 1)	2.5	298.11	49.73	115.11	93.49
Kebele 15	1.0	128.09	55.96	5,888.73	16,601.95
Kebele 13	1.0	210.22	56.30	1,578.27	3,081.87
Kebele 7 (pit 2)	1.5	326.44	44.21	926.03	1,437.11
Kebele 8 (pit 2)	2.0	140.64	28.41	89.96	102.99

### 6.3 Development of New Empirical Equations

In developing new empirical equations for prediction of the swelling behavior of the study area, several functions [Appendix 2] composed of different parameters in different combinations were tested using the SPSS 13 computer program. Out of these, equations with higher correlation coefficient were selected and using these equations the swelling behavior of the soil of the study area were calculated. Then a graph is plotted which shows the measured value against the predicted or calculated value. Finally 7 equations are selected which predicted the measured value better than the others. This is done using a multiple regression analysis [Appendix 3].

$$\text{Eqn 1 : } \text{Log Sp} = 5.874 - 1.551 * \gamma_{\text{dry}} - 0.039 * \omega - 0.014 * \text{Na}^+ , R^2 = 0.776, n = 21$$

$$\text{Eqn 2 : } \text{Log Sp} = 7.324 - 2.067 * \gamma_{\text{dry}} - 0.042 * \omega - 0.008 * \omega_1 , R^2 = 0.817, n = 21$$

$$\text{Eqn 3 : } \text{Log Sp} = 7.042 - 1.926 * \gamma_{\text{dry}} - 0.046 * \omega - 0.609 * \text{Ac} , R^2 = 0.809, n = 21$$

$$\text{Eqn 4 : } \text{Log Sp} = 7.018 - 1.924 * \gamma_{\text{dry}} - 0.042 * \omega - 0.008 * \omega_1 + 0.003 * \text{CEC} \\ R^2 = 0.829, n = 21$$

$$\text{Eqn 5 : } \text{Log Sp} = 6.903 - 0.042 * \omega - 0.007 * \omega_1 - 1.896 * \gamma_{\text{dry}} + 0.002 * \omega_{\text{max 24}} \\ R^2 = 0.822, n = 21$$

$$\text{Eqn 6 : } \text{Log Sp} = 7.453 - 0.042 * \omega - 0.007 * \omega_1 - 2.075 * \gamma_{\text{dry}} - 0.002 * \text{Clay content} \\ R^2 = 0.820, n = 21$$

$$\text{Eqn 7 : } \text{Log Sp} = 7.509 - 0.045 * \omega - 0.005 * \omega_1 - 2.099 * \gamma_{\text{dry}} - 0.337 * \text{Ac} \\ R^2 = 0.827, n = 21$$

Where :  $\gamma_{\text{dry}}$  = gm /cc ; CEC,  $\text{Na}^+$  = meq/100gm  
 $\omega, \omega_{\text{max 24}}, \omega_1$  = % and Sp in Kpa

Using the above new equations the swelling pressure of the study area is calculated. The swelling pressure of the control samples is also calculated to see how well the developed equations have predicted the swelling pressure. The results of the analysis are given in Table 14

**Table 14 : Comparison of Measured value with Calculated Value.**

	Measured Value	Calculated Value						
Location	Swelling Pressure(Kpa)	Eqn. 1	Eqn. 2	Eqn. 3	Eqn. 4	Eqn. 5	Eqn. 6	Eqn. 7
Tikurit Mender	547.52	636.81	681.62	741.82	733.31	864.67	775.73	799.49
Zenzelma Abo	344.58	313.42	233.73	269.64	284.91	282.92	273.56	268.52
Gobame	111.82	124.18	94.45	103.79	104.72	119.89	104.65	105.32
Gordema	514.61	527.11	380.67	528.74	442.42	507.73	435.79	474.93
Gudadle	175.38	229.64	209.88	204.33	235.57	269.44	234.82	223.26
Baynes (Pit 2)	165.60	138.53	137.49	162.18	151.64	165.01	150.37	164.68
Baynes (Pit 1)	377.27	267.86	240.90	256.59	268.03	321.71	283.30	273.94
Chorka Mender	379.24	399.84	375.97	389.86	452.23	476.13	416.64	422.76
Sesa Beret (Pit 1)	538.33	455.32	464.69	447.46	494.06	567.09	512.90	510.63
Sesa Beret (Pit 2)	202.27	225.71	232.19	209.47	268.66	290.46	261.07	243.88
Lumame (Pit 1)	296.91	257.92	281.78	265.76	294.15	334.75	318.86	305.68
Lumame (Pit 2)	135.74	166.02	162.27	170.42	172.16	191.92	177.20	181.92
Mazoria	197.41	264.48	252.41	238.03	282.36	301.96	301.07	262.02
Sensela Bata	264.76	280.25	243.96	282.60	309.96	319.59	270.31	288.20
Kebele 16	114.37	178.85	152.95	165.48	163.40	199.40	172.65	172.31
Kebele 9	495.81	316.61	371.57	387.14	443.17	455.97	401.07	430.98
Kebele 7 (pit 1)	186.80	178.77	160.50	166.12	190.40	206.83	186.08	175.35
Kebele 8 (pit 1)	298.11	279.73	279.29	279.24	324.36	343.12	313.53	313.17
Kebele 13	210.22	147.80	178.67	198.33	194.29	244.70	195.07	208.84
Kebele 7 (pit 2)	326.44	208.43	230.00	192.39	253.13	284.07	266.99	235.02
Kebele 8 (pit 2)	140.64	128.59	140.89	168.13	174.87	180.38	155.56	172.94

### Results of the Control Samples

Table 15 : Comparison of Measured value with Calculated Value for Control Samples

	Measured Value	Predicted Value						
Location	Swelling Pressure(Kpa)	Eqn. 1	Eqn. 2	Eqn. 3	Eqn. 4	Eqn. 5	Eqn. 6	Eqn. 7
Kereza Mender	79.95	70.90	54.06	49.13	60.51	60.72	61.59	54.44
Kebele 10	92.12	164.14	176.95	181.40	183.35	226.30	194.10	202.41
Kebele 15	128.09	166.26	169.22	157.04	165.26	195.15	193.46	179.80

#### 6.4 Graphical Representation of the Measured and Calculated Values

The following graphs are plotted to investigate the approximation accuracy of the newly developed formulas. The measured and calculated values are plotted ( Fig.14 to Fig. 20) trend lines are drawn to observe the gap between the measured and the calculated values.

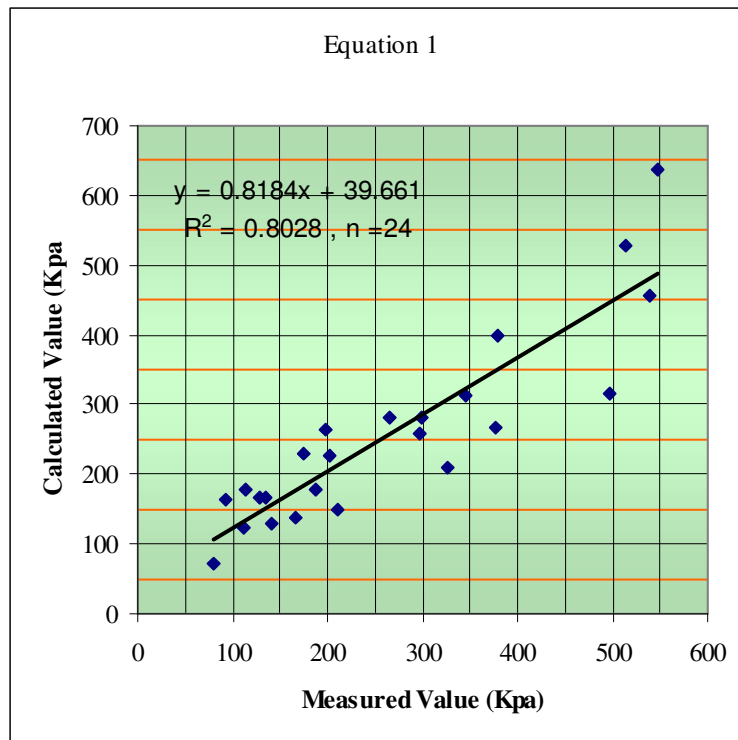


Fig. 14 Plot of Equation 1  $V_s$  Measured Value

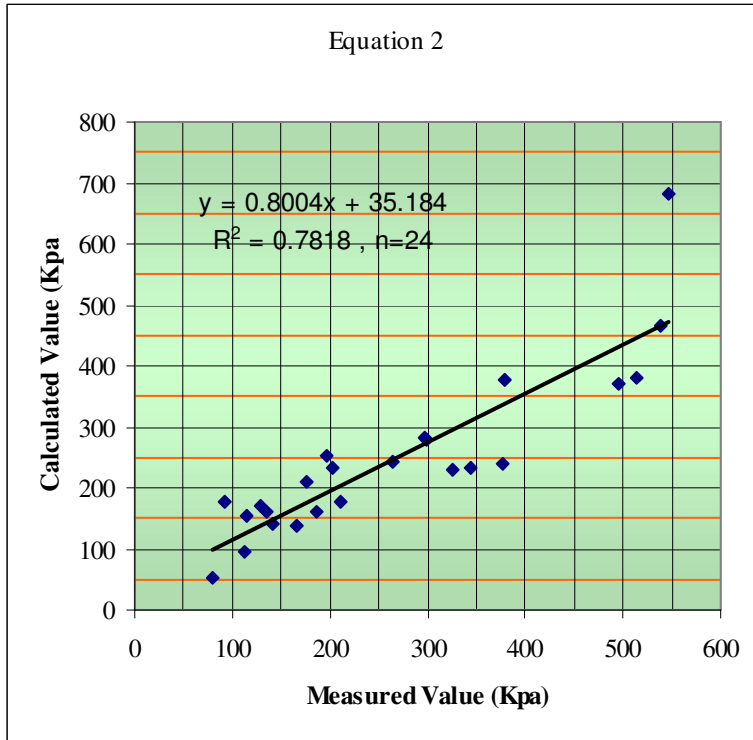


Fig. 15 Plot of Equation 2  $V_s$  Measured Value

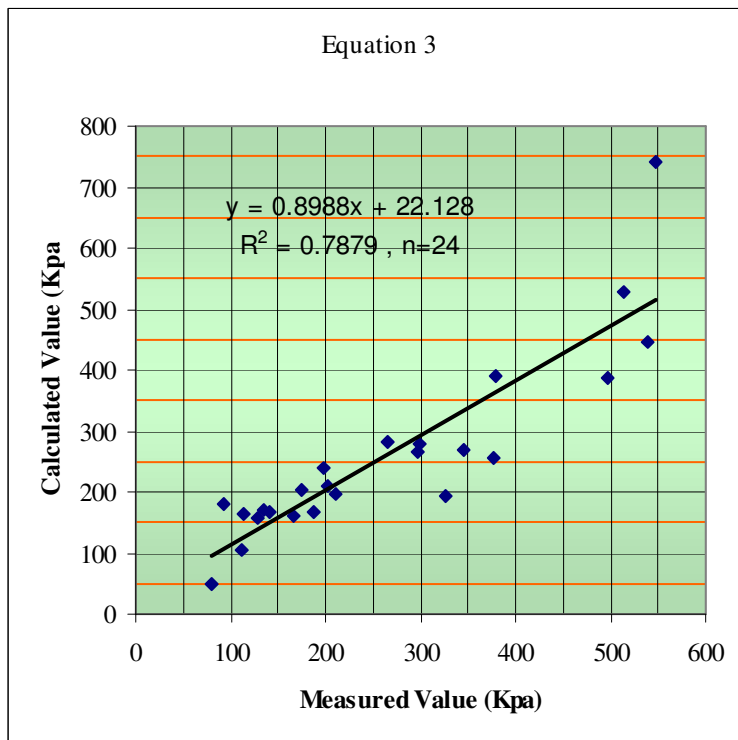


Fig. 16 Plot of Equation 3  $V_s$  Measured Value

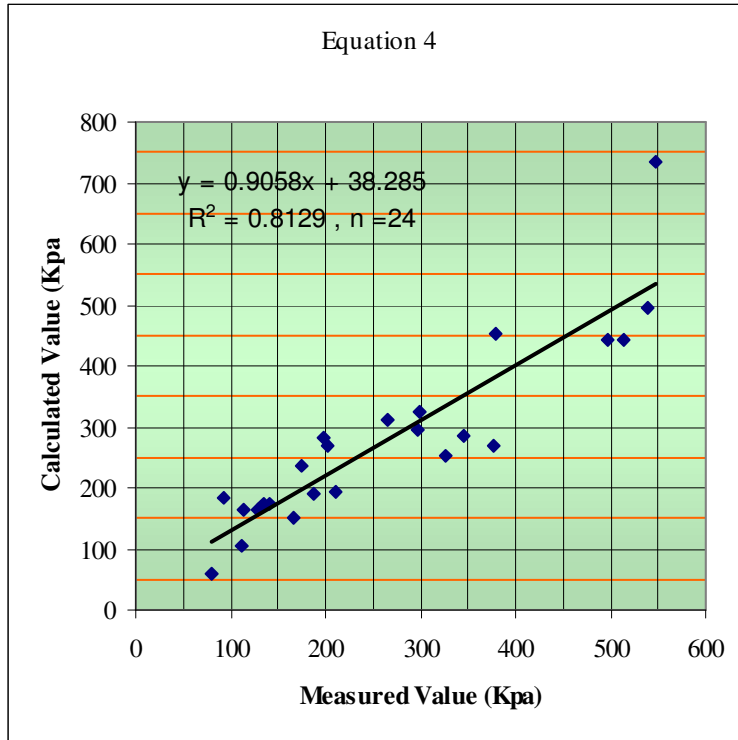


Fig.17 Plot of Equation 4  $V_s$  Measured Value

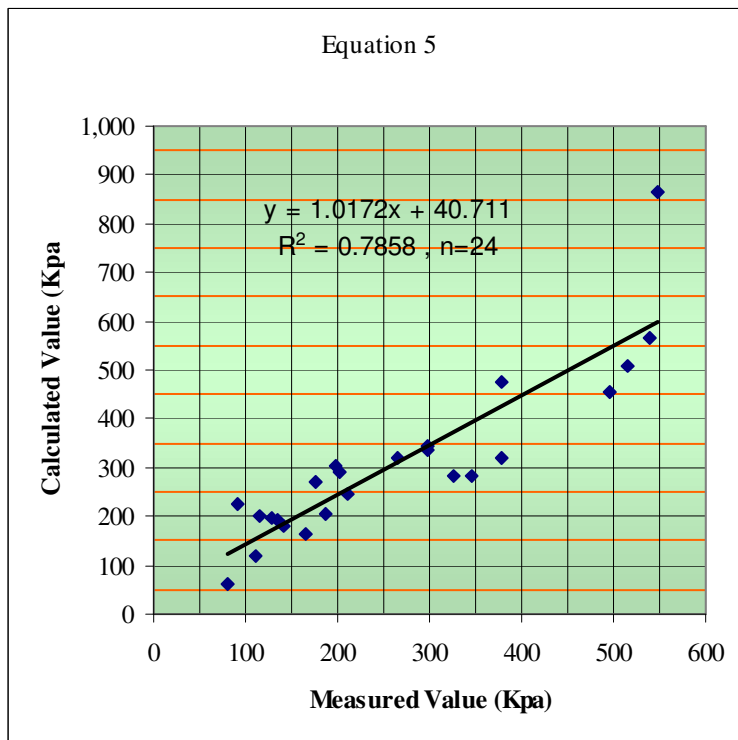


Fig. 18 Plot of Equation 5  $V_s$  Measured Value

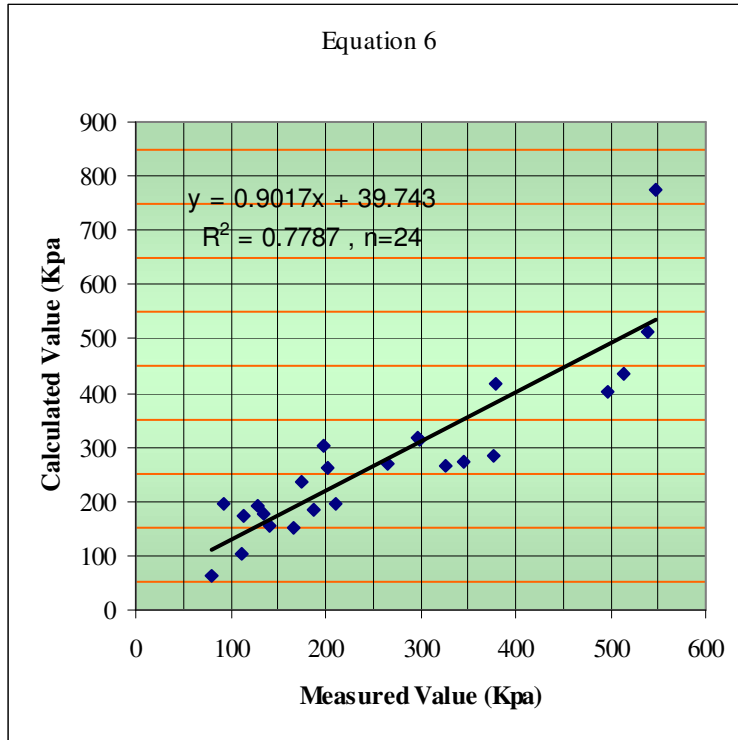


Fig. 19 Plot of Equation 6  $V_s$  Measured Value

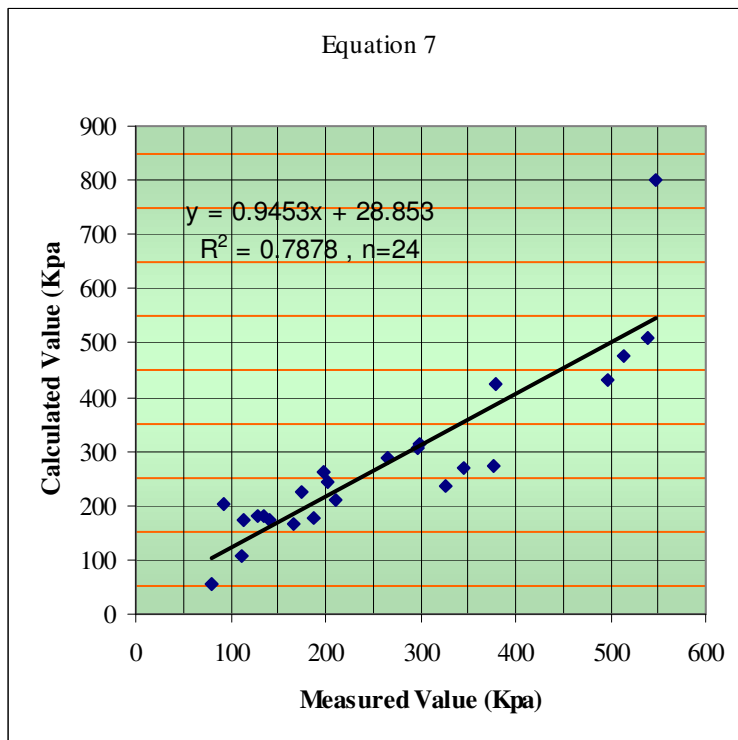


Fig. 20 Plot of Equation 7  $V_s$  Measured Value

As seen from the graphs, Equations 1, 3 and 4 gave a better estimation of the measured swelling pressure with the coefficient of determination of 0.80,0.79 and 0.81 respectively. Among the three equations, equation 4 describes the relation better than the others. However, equation 3 has parameters that could easily be determined in soil mechanics laboratories. Thus, one may use these suggested equations for the estimation of the swelling pressure of the study area alternatively.

## Conclusion and Recommendation

1. The Regression Analysis showed that there is a relationship between Index Properties and Swelling Characteristics of Expansive Soil of Bahir Dar
2. For the soil of the Study Area, the single parameter,  $(\omega_{\max,24}/\omega)$  indicates the swelling property much better than other single parameters.
3. Evaluation of the previously developed equations with the present study area showed the necessity of formulation of specific equations for specific areas.
4. Cation Exchange Capacity, in combination with other parameters is a powerful tool for prediction of Swelling Characteristics of Bahir Dar.
5. The newly developed equations could be used for estimation of Swelling Characteristic of the Study Area.

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