ADDIS ABABA UNIVERSITY
School of earth and planetary sciences
College of Natural Sciences

Geological and Environmental Appraisal for the New Sanitary Landfill Site at Chebe Weregenu, North East of Addis Ababa, Ethiopia

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Addis Ababa University
School of Earth and Planetary Science
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Geological and Environmental Appraisal for the New Sanitary Landfill Site at Chebe Weregenu, North East of Addis Ababa, Ethiopia

By
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DECLARATION

I hereby declare that the thesis is my original work under the supervision of Dr. Asfawossen Asrat and Dr.Tarun Kumar Raghuvanshi, School of Earth sciences, Addis Ababa University during the year 2012 as part of Master of Science Program in Environmental Geology. I further declare that this work has not been submitted to any other University or institution for the award of any degree or diploma and all sources of materials used for the thesis have duly acknowledged.

Netsanet Mengistie

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IV. List of Acronyms

Abbreviation	Full Length
AAU	Addis Ababa University
App	Apparent
BS	British Standard
C	Cohesion
Ca	Calcium
CaCO3	Calcium Carbonate
CC	Compression Index
CEC	Cation Exchange Capacity
Cl	Chloride
CLI	Clay Liner
CO_3^{-2}	Carbonate
Cv	Coefficient of consolidation
EC	Electron Conductivity
ESP	Exchangeable Sodium Percentage

e_o	Void ratio
ELE	Engineering Laboratory Equipment
F	Volume change factor
GSE	Geological Survey of Ethiopia
HCO_3	Bicarbonate
H_2O	Water
K	Coefficient of Permeability
K	Potassium
KN/m^2	Kilo Newton per meter squared
Kpa	Kilo Pascal
LL	Liquid Limit
m.a.s.l	meter above sea level
meq/l	milli equivalent per litre
Mg	Magnesium
µS	micro Siemens
ms	Milli Siemens
Mv	Volume Compressibility
MDD	Maximum Dry Density
Na	Sodium
NMC	Natural Moisture Content
NTU	Nephelometric Turbidity Unit
OMC	Optimum Moisture Content
OM	OrganicMatter
ỏe	Change in void ratio
ỏp	Change in pressure
P	Phosphorus
PH	Potential hydrogen
PI	Plastic Index
PL	Plastic Limit
SAR	Sodium Absorption Ratio
SL	Shrinkage Limit
S_o	Degree of Saturation
SO_4^{-2}	Sulphate
TP	Test Pit
UCS	Unconfined Compressive Strength
USCS	Unified Soil Classification System
UTM	Universal Transverse Mar cater
WHO	World Health Organization
WWDSE	Water Works Design and Supervision Enterprise
Ø	Angle of Friction

ABSTRACT

The Addis Ababa City Administration started a project to establish a new sanitary landfill site at Chebe Weregenu, which is 26 km from the city center of Addis Ababa. The project feasibility studies were already conducted. It is now under design study phase.

In the feasibility studies, one of the main gaps noted was on the permeability of the residual soil, $1.164x10^{-4}$ to $2.329x10^{-4}$cm/sec which is below the standard. The standard requirement for sanitary landfill should be $1x10^{-7}$cm/sec or less. The permeability test result in the present research was found$1.897\ X10^{-7}$ to $1.085x10^{-8}$ cm/sec which is within the standard. The other gap was, both studies stated that the existing residual soil 0-5 meters is black cotton soil. In the present research, based on site investigation and test data the residual soil 0-4.5 meters have different soil profiles, black cotton soil and tuff material.

The purpose of this research work is to identify possible gaps in the feasibility studies and to conduct geological and environmental appraisal of the Chebe Weregenu Sanitary Landfill Project.

Eleven representative soil samples, two rocks and four water samples were collected from the site and were tested for the purpose of geological and environmental appraisal of the landfill site application. All representative soil sample test results complied with the standard requirements of permeability for clay cap and clay liner application. Regarding plasticity, the liquid limit value of seven out of ten samples complied with the standard requirement, but three are above the standard. The water quality test result was found fit for drinking purpose as per WHO standard. The water quality and soil fertility test results are base line data to be used as a reference point during the operational phase.

This research filled the gap of the feasibility studies and further established different findings based on the primary data. Those results found within the standard range were presented as acceptable values and those test results out of the range were recommended for further investigation during the design study.

CHAPTER -1 INTRODUCTION

1.1 Background

The expansion of Addis Ababa, the Capital City of Ethiopia, in all directions and the growing population is creating sizeable strain on the environment. This situation requires the need for organized and systematic waste management system. It also demands an effective waste management practice from house hold level up to an efficient landfill system.

The only open landfill system in operation for the last 45 years in the capital city is "Koshe". It has been very inefficient and contributing to widespread air, water and soil pollution (Tadesse, 2004). Due to Koshe reaching peak capacity as well as the pollution problems, the Addis Ababa City Government identified different sites and conducted prefeasibility study. Accordingly, Chebe Weregenu site was selected.

Chebe Weregenu is located in the Northeastern part of Addis Ababa, in the Oromia regional state, east of Legetafo town. The site is 26 kms from the city center along Ayat road. The selected site covers about 136.6 hectares.

The Addis Ababa City Government entered into agreement with two organizations for the feasibility study of Chebe Weregenu Sanitary Landfill Site. Both organizations assessed different aspects of the landfill project and came up with a conclusion that the landfill site is feasible for sanitary landfill application.

The project is now moving towards conducting the design work. The design work is already awarded to an international consultant, and it is expected to commence in the near future.

The Chebe Weregenu sanitary landfill project is planned to have a leachate and a gas collection system. In addition, there are three transfer stations which are located at separate site to handle the waste (Addis Ababa City Administration project office).

The Chebe Weregenu Sanitary landfill project is the first of its kind in the country. There is no prior local experience in project implementation of a modern waste management system and also

in the management of the system operation. Thus, the success of this project is the concern of all stake holders.

The first objective of the present research was to identify any possible gaps in the feasibility studies. The other objective of the current project is to contribute towards the success of the project by studying the geological and environmental context of the New Chebe Weregenu Sanitary Landfill Site in order to provide accurate baseline geological data (petrographic, mineralogic, geotechnical) as well as environmental data (soil, water, landuse/landcover) which will help during the design of the project as well as during operation phase.

The present research is based on primary and secondary data. The primary data were generated by collecting rocks, soil and water samples from the project site and conducting different test parameters related to sanitary landfill. Secondary data on various parameters from different sources has also procured and utilized.

As the design of the sanitary landfill project work is yet to be made, it will be a great opportunity to consider and refer the output of this research work as an additional input for the design of the Chebe Sanitary Landfill.

This research contains discussion on the site from different perspectives, review of feasibility studies and establishing gaps, collection of samples and laboratory tests. Further a discussion of the test results including; soil fertility secondary data from Koshe open landfill and filling the gaps of the feasibility studies. Finally, the thesis provides conclusions of scientific data and recommendations for future action.

1.2 Landfill

Landfills are the most important option of municipal solid waste disposal worldwide. Landfill covers are designed to isolate waste from the environment by incorporating low-permeability barrier layers. The barrier layer minimizes and controls gas escaping from the waste and the amount of infiltrating moisture available for leachate generation. The most important performance parameter for compacted clay liner is its permeability (Daniel and Benson, 1990).

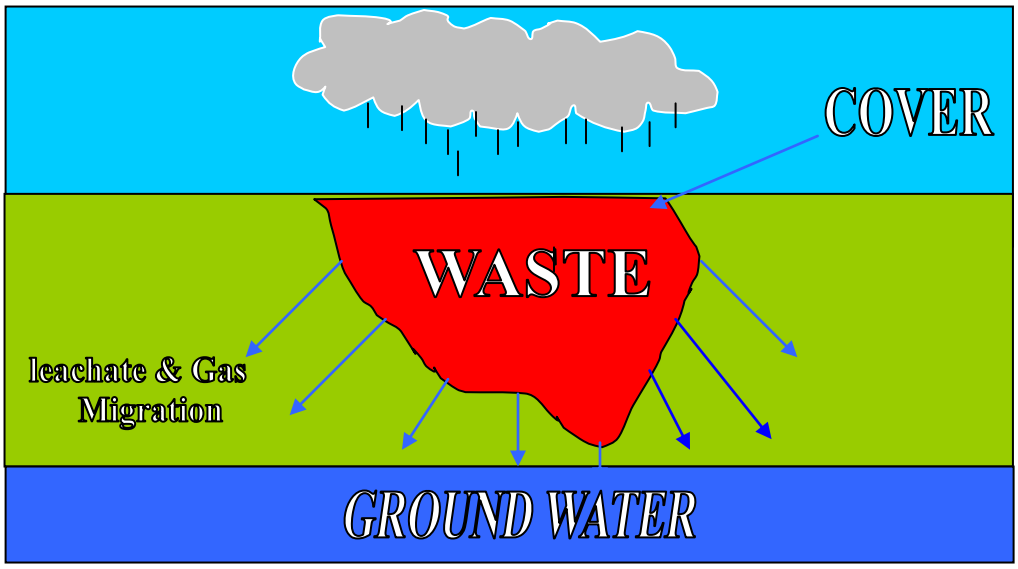

Fig. 1.1 Sketch showing how leachate and gas migrate in to the ground

(Source: http://www.igsl.ie/wp-conent/uploads/clay_liners_for_landfill_projets.pdf).

1.2.1 Types of landfill

There are two types of landfills; sanitary and open type. The sanitary landfill is properly made with impermeable material and completely isolates waste from water while open dump is the oldest and most common way to dispose of solid waste. Open dump is problematic regarding safety, health and environmental aesthetics (Brunner and Keller, 1972).

Open Dump Landfill

Open dump was the most primitive and most widely used means of solid-waste disposal that requires a minimum of effort and expense (Brunner and Keller, 1972).

Sanitary Landfill

According to (Brunner, 1972 and Keller, 1970), "Sanitary landfill" means a land disposal site employing an engineered method of disposing of solid wastes on land in a manner that minimizes environmental hazards by spreading the solid wastes in thin layers, compacting the solid wastes to the smallest practical volume, and applying compacting cover material at the end of each operating day.

1.3 Clay Liner and Clay Cap for Sanitary Landfill

1.3.1 Clay Liner or Bottom Liner

A bottom liner (or simply liner) is an engineered system to contain and control the pollution of the land and water environments surrounding the land disposal operation (Brunner and Keller, 1970).

There are three different materials used to construct landfill liner and final cover. These are clayey soil, synthetic membranes or other artificially manufactured materials, and amended soil or other admixtures. Each type has its own advantage and disadvantage that must be considered when choosing a particular liner material. Theoretically leakage through the base of a contaminant is unavoidable; however, it can be reduced to practically zero. Usually clay or synthetic material is used in lining a landfill. Synthetic materials allow less leakage but are difficult to protect from damage, whereas clay liners are not easily damaged. Hence clay is preferred as a liner in such landfills (Bagchi, 2004).

Clay Liners at the bottom of landfill body play a very important part in the whole multi barrier system for retaining pollutants. Porosity of clay particles is 40-70% and permeability (K) value of clay is less than $1x10^{-7}$ cm/sec and so the rate of advection transport through clay is very low and it is cheap (http://http://www.ejnet.org//landfills/the basics of landfill.htm).

According to Daniel and Wu (1993), the primary purpose of clay liner is to provide a low hydraulic conductivity ($1x10^{-7}$ cm/sec or less) barrier layer, either at the base or in the final cover. The criteria for choosing Clay are primarily based on the re-compacted permeability achievable under field conditions. A clay that can be compacted to obtain a low permeability ($1x10^{-7}$ cm/sec or less) sample when compacted to 90-95% of the maximum Proctor's dry density when wet or optimum moisture is chosen for landfill liner construction (Daniel and Wu,1993).

Although the detailed requirements for compacted clay liners (CCLs) vary, the following parameters usually apply for landfill.

- Coefficient of permeability (hydraulic conductivity) of $1x10^{-7}$ cm/s or less
- Minimum layer thickness of 1m

- Minimum clay content of 10%
- Minimum Fines (clay & silt) content >30%
- 10%<Plasticity index<65%
- Liquid limit < 90%
- Maximum particle size of 75mm

(http://www.igsl.ie/wp-content/uploads/clay_liners_for_landfill_projects.pdf)

1.3.2 Clay Cap or Final Cover

A landfill cover or cap is an umbrella over the landfill to keep water out (to prevent leach ate formation). It is the layer that is placed on the completed surface of the fill. It will generally consist of several sloped layers: clay or membrane liner to prevent rain from intruding.

(http://http://www.ejnet.org//landfills/ the basics of landfill.html)

1.3.3 Basic Theory

The Atterberg Limits

The Atterberg limits provide a means of measuring and describing the plasticity range in numerical terms.(K.H. Head Manual of Soil Laboratory Testing, Volume 1, 1984).

Classification

Classification is usually accomplished by means of the plasticity chart. This is a graphical plot of the liquid limit (LL) as ordinate against plasticity index (PI) as abscissa.

- Low plasticity (CL), liquid limits less than 30.
- Intermediate plasticity (CI), liquid limits from 30 to 50.
- High plasticity (CH), liquid limits exceeding 50.

Permeability

Permeability involves in all flow of water through soil, such as seepage of dams, the squeezing out of water from soil by the application of load, and drainage of sub grade, dams and backfill. (K.H. Head Manual of Soil Laboratory Testing, Volume 2, 1982)

In general, clays of high plasticity are likely to have a lower permeability, to be more compressible and to consolidate over a longer period of time under load than clays of low plasticity (K.H. Head Manual of Soil Laboratory Testing, Volume 2, 1982).

Table 1.1 Standard range of coefficient of Permeability

Degree of Permeability	Range of coefficient of Permeability, K(m/s)
High	Greater than 10^{-3}
Medium	10^{-3}-10^{-5}
Low	10^{-5}-10^{-7}
Very Low	10^{-7}-10^{-9}
Practically impermeable	Less than 10^{-9}

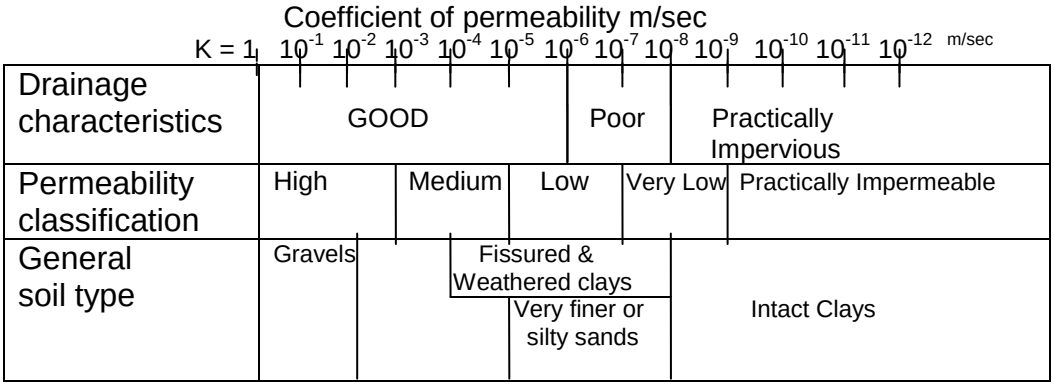

Fig. 1.2 Permeability and drainage characteristics of main soil types

Table 1.2 Typical permeability of various soils

Group Symbol	Description	Typical Permeability m/sec
GW	Well graded clean gravels, gravel sand mixtures	$2.5x10^{-4}$
GP	Poorly graded clean gravel sand mix	$5x10^{-4}$
GM	Silty gravels, poorly graded gravel-sand silt mix	$> 5x10^{-9}$
GC	Clayey gravel, poorly graded gravel –sand-clay mix	$> 5x10^{-10}$
SW	Well-graded clean sands, gravely sands	$> 5x10^{-6}$
SP	Poorly graded clean sand gravel	$5x10^{-6}$
SM	Silty sands, poorly graded sand-silt mix	$>2.5x10^{-7}$
SM-SC	Sand-silt clay mix with slightly plastic fines	$1x10^{-8}$
SC	Clayey sands, poorly graded sand-clay mix	$2.5x10^{-9}$
ML	Inorganic silts and clayey silts	$5x10^{-8}$

ML-CL	Mixture of inorganic silt and clay	$2.5x10^{-9}$
CL	Inorganic clays of low to medium plasticity	$5x10^{-9}$
OL	Organic silts and silt clays, low plasticity	$>5x10^{-9}$
MH	Inorganic clayey silts, elastic silts	$2.5x10^{-9}$
CH	Inorganic clays of high plasticity	$5x10^{-10}$
OH	Organic clays and silty clays	$1x10^{-9}$

(Source: NAVFAC, 1971)

- Note the trend of decreasing permeability with decreasing grain size (Daniel and Benson, 1990).

Shear Strength

Shear Strength is the resistance of soil to sliding of one mass against another. The shear strength of engineering soils has an important role in design, construction and long-term stability of structures on, in and with soil materials. Shear strength is possible when an unequal principal stress (force) is applied. But if equal force is applied in every direction, there will be no failure. The shear strength of cohesive soils is made up of two components: friction and cohesion.
(Source: K.H. Head Manual of Soil Laboratory Testing Volume 2).

Consistency of Clay Soils

Consistency is a term used to indicate the degree of firmness of cohesive soils. The consistency of natural cohesive soil deposits is expressed qualitatively by such terms as very soft, soft, stiff, very stiff and hard. Consistency of a soil can be expressed in terms of; Atterberg limits of soil and unconfined compressive strength of soils.

Table 1.3: Consistency of Clays

Consistency of Clays	Undrained shear strength (KN/m^2)
Very soft	<20
Soft	20-40
Soft to firm	40-50
Firm	50-75
Firm to stiff	75-100
Stiff	100-150
Very stiff	>150

(*Source: K.H.Head Manual of Soil Laboratory Testing, 1982*)

Activity of Clays

Skempton (1953) considers that the significant change in the volume of a clay soil during shrinking or swelling is a function of plasticity index and the quantity of colloidal clay particles present in soil. The clay soil can be classified inactive, normal or active (Skempton, 1953). The activity of clay is expressed as;

$$Activity\ A = \frac{Plasticity\ index,\ Ip}{Percent\ finer\ than\ 2\ micron} \quad .....eq.\ 1.1$$

The clay soil which has an activity value greater than 1.4 can be considered as belonging to the swelling type.

Specific Gravity

It is rarely possible to use specific gravity as an index for soils classification. But knowledge of the SG is essential in relation to some other soil tests, especially for calculating porosity and voids ratio, and is particularly important when compaction and consolidation properties are considered. The SG must also be known for the computation of particle size analysis from a sedimentation procedure (K.H. Head Manual of Soil Laboratory Testing Volume 2, 1982).

1.3.4 Environmental Law of Ethiopia

One of the objectives of the Ethiopian Federal Democratic Republic Constitution (Proclamation No, 1/1995) is to ensure the existence of a clean and healthy environment. It provides that all persons have the right to a clean and healthy environment. Based on the Constitution and to put the political will aiming to environmental protection in concrete form, several

laws/proclamations were promulgated in Ethiopia. Five proclamations have been put in force since 1997 among which Pollution Control Proclamation-2002 is the one.

Environmental Pollution Control Proclamation - December 2002

The quality of air, water and soil in Ethiopia is being degraded by urban and industrial development. In this perspective, the Ethiopian Government enacted the Environmental Protection Control Proclamation No. 300/2002 on. It is a powerful tool to realize implementation of the environmental objectives and goals incorporated in the Environmental Policy.

The Proclamation consists of a number of articles on different issues such as:

- Pollution control, management of hazardous wastes, chemicals and radioactive substances;
- Pollution control for municipal waste management;
- Environmental standards;
- Rights and duties of environmental inspectors and;
- Penalties.

Within this context, the Environmental Protection Agency issued provisional Standards for industrial pollution control and Guidelines for Ambient Environment Standards for Ethiopia. Both being periodically reviewed and updated in the light of additional information and knowledge.

1.4 Statement of the Problem

Waste Management is a serious concern in Addis Ababa. The only available waste disposal site is Koshe open landfill. It is old, not environment friendly and is in the process of close up. The new sanitary landfill to be built at Chebe Weregenu is a multimillion-dollar investment, which is in dire need to the expanding city and its dwellers. The Chebe Weregenu Sanitary landfill project feasibility studies were recently conducted. The project is now under the start up of design phase.

In the feasibility studies there are two major issues of concern. One concern is; the value of permeability of the clay cap and clay liner was below the standard requirement. The other concern is the soil profile of the residual soil at the site. The soil at the site contains 0-5 meters of

black cotton soil, therefore the recommendation was made to remove all black cotton soil by POYRY, 2011 and use Geo synthetic materials to improve the water tightness by GSE, 2010.

The above points, permeability value and the recommended mitigation measures are gaps of the feasibility studies of Chebe Weregenu sanitary land fill site.

This present research will study and fill the gap and further conduct geological and environmental appraisal of Chebe Weregenu sanitary land fill project, based on which it will forward recommendations to be considered in the design study phase.

1.5 Scope of the Research

The present research focused on the test and analysis of soil for clay cap and clay liner application based on eleven representative soil samples taken at a maximum depth of 4.5 meters. Other five soil samples were used for mineralogical analysis and two rock samples were taken for petrography analysis. In addition, four water samples and three soil samples for soil fertility test were taken for base line pollution reference for the operation phase of the landfill site.

1.6 Objective of the Research

1.6.1 General Objective of the Research

The general objective of the present research is to investigate geological and environmental context of the new Chebe Weregenu Sanitary Landfill Site. In addition, it was also intended to identify and fill gaps in the previously conducted feasibility studies and finally to draw a conclusion and forward recommendations.

1.6.2 The Specific Objective of the Research

- To identify the geologic, rock/soil/groundwater conditions that may affect the design, construction and operation phase of the landfill. To determine the physical and chemical characteristics of the soil that is going to be used for the Chebe Weregenu sanitary landfill cover and clay liner.

- To identify and asses the physical and chemical characteristics of water and soil to be used as a base line and reference point for any pollution that may occur during the operation phase of the sanitary landfill site.

- To identify and fill up gaps noted in two previously conducted feasibility studies on Chebe Weregenu sanitary landfill site.

1.7 Methodology of Research

The present research work was mainly conducted by generating primary data; however, secondary data was also utilized to meet out the objectives of the study. Primary data were generated by collecting rock, soil and water samples from the present study area, and tested in laboratory following standard specifications. The secondary data used during the present study were acquired from geological, hydrogeological, engineering geological maps and koshe open landfill soil fertility data. The following systematic research methodology was followed for the present study:

- Systematic literature review was undertaken to develop the conceptual framework for the research.
- Assessment of previous studies on the Chebe Weregenu Sanitary Landfill Project
- Establishing gaps in the feasibility studies done on Chebe Weregenu Landfill site
- Conducting research work with the following details:
  - Site investigation for surface and subsurface conditions
  - Rock, soil and water sample collection from site
  - Sample preparation
  - Rock, soil and water sample tests in the laboratory
  - Test report
  - Compliance analysis against the standards
  - Conclusion and recommendation

The research work started by assessing three different studies on the Chebe Weregenu Sanitary Landfill Project. These are:

(i) Prefeasibility study on preliminary Site Selection of New Sanitary Landfill for Addis Ababa City and Surrounding Towns conducted by New Landfill Site Selection Task Team in October 2009;

(ii) Feasibility study of Chebe Weregenu Sanitary Landfill Site for the city of Addis Ababa conducted by Geological Survey of Ethiopia, Geohazards Investigation Core Process in April 2010.

(iii) Federal Republic of Ethiopia, City of Addis Ababa, Addis Ababa Solid Waste Management Project, Phase II Development of the new sanitary landfill in Sendafa conducted by POYRY in February 2011.

Following the assessment of the studies, the researcher conducted literature review on different aspects of landfill system was carried out.

The detailed research work at site started with field investigation and collection of rock, soil and water samples from within the landfill site for clay lining application and from a nearby site where construction material is readily available for clay cap, cover application.

Two rock samples were collected, one from a site about 1.5km away from the landfill site which is intended to be used as a clay cap for the landfill application. It is a fresh basalt rock found at a depth of 1.2m. The other tuff sample was collected from the surface of the landfill site. These rock samples were used to conduct thin section analysis using petrographic microscope. The thin section analysis is used to classify the composition and characteristics of rocks.

Eleven representatives disturbed and eight undisturbed soil samples were collected from eight different test pits. Five test pits were dug at four corners of the landfill site, and one test pit dug at the center of the landfill site. The five test pits dug at a depth of 2 meters and one test pit dug at a depth of 4meters. In addition, two test pits were also dug at 1.5km far from the landfill site at a depth of1.2m and 4meters. All samples were collected by manual digging.

Disturbed soils samples, about 25 kg by weight, were collected from the site. These samples were prepared in the laboratory and the testing process started with air-drying. The dried samples were further quartered to get the required representative samples. The sample then passed

through crushing, grinding and sieving by different sieve sizes based upon different test parameter requirements.

Different soil tests were conducted from disturbed samples for clay liner and clay cap applications. These are: particle size grading(hydrometer), Atterberg Limit tests, shrinkage limit, free swell, specific gravity, standard and modified proctor test, porosity, permeability, unconfined compression strength, clay mineralogy and others. The particle size grading provides an excellent initial appraisal of the potential suitability of a soil for the construction of an impermeable liner. In addition it provides quantitative data on the range of sizes of particles and the amount of clay present. The Atterberg limit (liquid and plastic limits) provides the most useful way of identifying and classifying the fine-grained cohesive soils. The moisture content, compaction, permeability and others are engineering parameters of clay liner.

There are three different methods for collecting undisturbed soil samples. One is the core cutter method, the second is the block sample method (30x30cm or 40x40cm) and the third is the Shelby sampling tube method. Because of the situation at site, in this study, the core cutter method was used, and accordingly the undisturbed samples were collected using 10x12 cm core cutter sampler. Consolidation, swelling pressure, direct shear, unit weight, and moisture content tests were conducted on the undisturbed samples.

Because of the difficulty to collect the undisturbed soil sample from the site, disturbed samples were used to conduct unconfined compressive strength.

Five disturbed soil samples were used to conduct clay mineralogical test using XRD (X- ray diffraction).

For environmental appraisal purpose four water samples and three disturbed soil samples were collected from the project site and physical and chemical analysis were conducted in the laboratory. From the four water samples, three were spring waters and the other one was ground water sample. One groundwater and two spring water samples were collected from adjacent site to the landfill area, and one spring water was collected from the landfill site. In addition, secondary data of recent soil quality test results of Koshe open landfill sitewas also utilized, for comparison purpose, as Koshe open landfill site is the only available open landfill in Addis

Ababa, Ethiopia. The Horn of Africa Regional Environment Center and Network conducted the test at Water Works Design and Supervision Enterprise Laboratory.

During the research study various equipment and tools were used for field investigation and in the laboratory. For the field work; GPS, Digital Camera, Cone Penetrometer, Geological Hammer, Lenses, Core Cutter, Shelby, Shovel, Pickaxe, Sample Bag, Log book and labeling marker were used. For the laboratory work, various laboratory equipments for soil and water analysis were used.

Most test results were compared against standard requirements for the construction and operation phase of the sanitary landfill site. Finally, conclusions were drawn and recommendations are forwarded.

1.8 Significance of the Research

The Chebe landfill project is active and it is under design stage. The prefeasibility and feasibility phases were already completed. Currently it is under the starting phase of the design study .The output of the present research project work can be an additional reference to the design study works to be conducted by the Sanitary Landfill Design Consultant.

The different stakeholders; the Addis Ababa City Administration, Environmental Protection Authority, the general public and the Government at Federal and Regional level are beneficiaries of the successful project which depends on proper design, construction work and operation of the closed landfill.

- Addis Ababa City Administration as service provider owns an effectively operating closed landfill system available to the public.

- EPA will benefit from the creation of an environment friendly system.
- The general public will benefit from clean and green environment protected from soil, water and air pollution. Public mind set will be changed from considering waste as something unimportant to a high utility material. Therefore, the situation will lead to the public to sort out waste at house level.

- Government can replicate the successful completion of the new sanitary landfill at Chebe Weregenu to other sub cities in Addis and to other regional cities out of Addis.

1.9 Limitations of the present research

The timing of this research study and that of the project design study of the landfill site unfortunately did not match, which could have been an opportunity to get drill based sample data which enables to get deep subsurface bed rock conditions and generate primary data. As a result the research data is only limited to a maximum depth of 4.5 meters.

From environmental perspective the present research has dealt only with soil and water quality. Air quality was not done due to the unavailability of reliable air quality measurement device.

1.10 Structure of the Thesis

The present research is conducted by identifying previous studies at Chebe Weregenu Sanitary Landfill site and review literature on different aspects related to sanitary landfill suitability. Soil and water samples were collected from the landfill site for geotechnical, environmental and mineralogical tests, conducted in Water Works Design and Supervision Enterprise Laboratory and Geological Survey of Ethiopia Laboratory. This research also includes conclusions and recommendations based on the result and standard requirements. The present research is organized into five chapters and the structure of thesis is as follows:

Chapter one comprises the introduction, which include the background of the study, landfill review, clay liner and clay cap for sanitary landfill, standard ranges of coefficient of permeability, statement of the problem, scope of the research, objective of the study, methodology, significance of the research and limitation of the present research.

Chapter two presents an over view of the study area. It includes the geology, engineering geology and hydrogeology of the study area.

Chapter three presents samples and laboratory tests and also includes results, discussion and interpretation.

Chapter four presents a review of previous feasibility studies and it also includes gaps, gap analysis and gap filling.

Chapter five presents the overall conclusion made and recommendations given based on the present research.

CHAPTER– 2 AN OVERVIEW OF THE STUDY AREA

2.1 Location

The new sanitary land fill site is located in the Sendafa area, at Chebe Weregenu. (Fig.2.1, Table 2.1).

The study area can be accessed through two directions; one route is, through Ayat road, and other along Addis Ababa-Dessie road. It is 37.2 Km northeast of Addis, out of which from city center to Legetafo it is 20 Km, and from Legetafo to Legedadi Dam is 12.2 Km and from Legedadi dam to Chebe Wergenu site is 5Km which is a gravel road, that needs proper road construction. However, all the other roads are made of Asphalt. Along the Ayat road, the site is around 26 km from the center of Addis Ababa.

The site is located at downstream of Legedadi Dam, which provides the water supply to Addis Ababa city and is found entirely on an area of water shed free from surface drainage.

Table 2.1 Geographic coordinates of the Chebe Weregenu Landfill site (UTM-WGS 84)

Site (corner points)	Location
Chebe Weregenu-1	491612 E: 0999500N
Chebe Weregenu-2	492294E: 0999500N
Chebe Weregenu-3	492484E: 0997490N
Chebe Weregenu-4	491573E:0997494N

2.2 The proposed Chebe landfill site and the service provision potential

As shown in Fig. 2.2 range of different service zones were identified. The Landfill site can gives service reasonably almost to 50% of Addis Ababa residents and the nearby Towns within the range of 20 km radius. On the other hand, for the waste generated from each built up area in the extreme Northwest and Southwest of Addis Ababa (specifically in Akaki-Kality, Nifas silk-Lafto and Kolfe-Keranyo sub cities) the service provider will travel long distance for the round trip.

2.3 Topography and Climate of the Site

Topography

Table 2.2 Summary of Chebe Weregenu site condition

Site Name	Location of the project area	Landfill Area (hectare)	Elevation (m)	Land Use
Chebe Weregenu	491,573-492,484m E and 997,494-999,500m N *	136.6 *	2452 to 2476 m	Farm land; Teff, wheat, lentil,

(*Source: Addis Ababa City Administration Project office*)

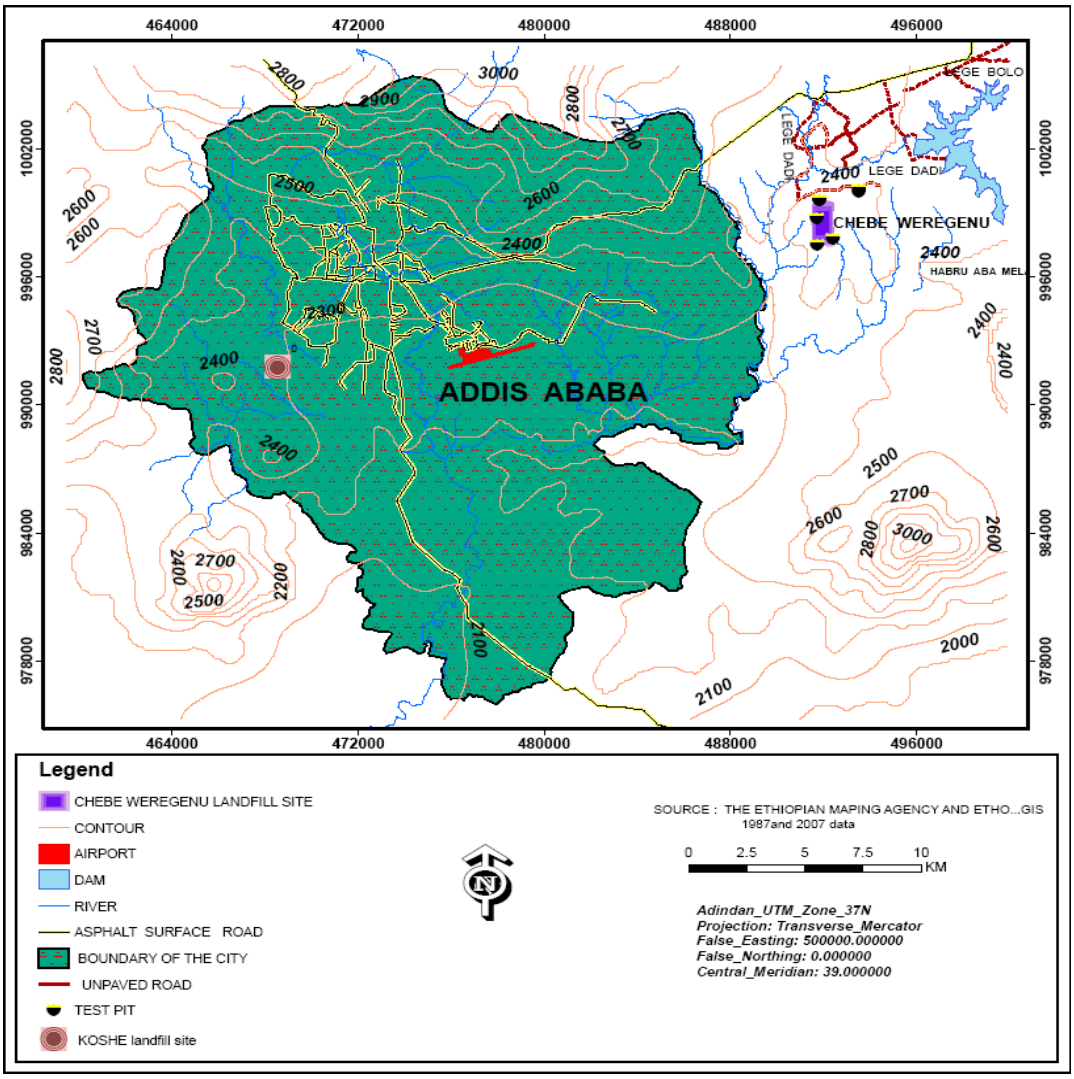

Fig.2.1 Chebe Weregenu Sanitary Landfill Project site location

Climate

There are two major seasonal patterns in the region. The major rainy period is from June to September; whereas October to May is the dry period.

Temperatures

Maximum and minimum temperature data of 21 years from 1991-2011 was collected from National Meteorology Agency, Bole Station. Table 2.3 shows the maximum and minimum monthly temperature data.

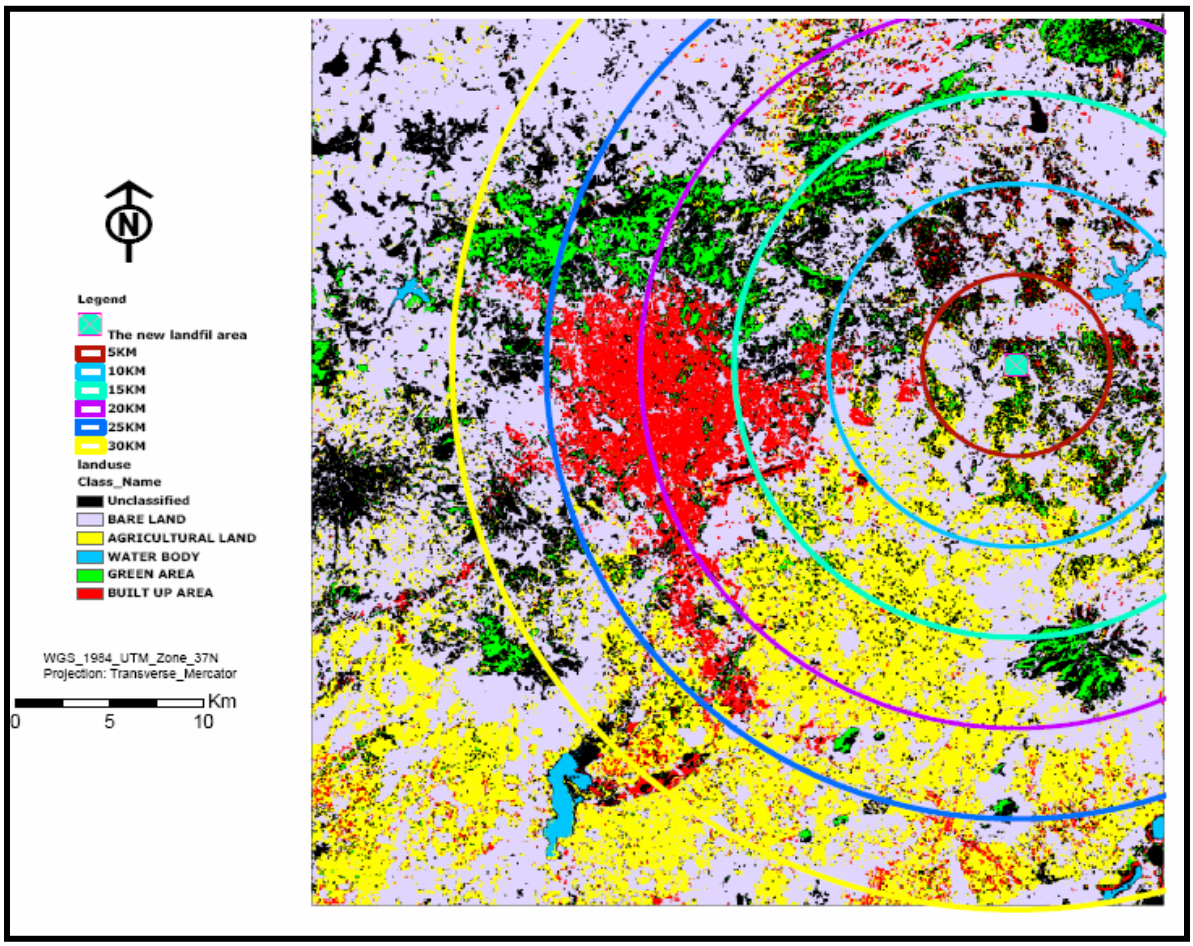

Fig 2.2 Chebe landfill site location and its service provision potential (*Netsanet Mengistie, 2010*)

Table 2.3 Max and Min Monthly Temperature (^{o}C)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
Max	24.1	25.2	25.5	25.0	25.4	23.6	21.2	21.0	22.0	23.1	23.2	23.4	23.5
Min	9.2	10.0	11.5	12.3	12.4	11.6	11.3	11.7	11.3	10.2	8.6	7.9	10.67
Rain Season													
Dry Season													

Rainfall

Rainfall data for 32 years was collected from the National Meteorological Agency. One from Sendafa meteorological station and the other from Addis Ababa Bole stations from 1976 to 2010. Summary of the mean rainfall (mm/month) data is given in the Table 2.4 and 2.5.

Table 2.4: Summary of mean rainfall data of Sendafa Station, Year 1976-2007

Month	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
Rainfall	20.29	27.53	53.73	75.49	54.61	98.82	328.71	307.46	91.43	23.17	4.71	5.06	1091.01

Table2.5: Summary of mean rainfall data of Addis Ababa Station, Year 1979-2010

Month	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
Rainfall	16.2	31.6	65.9	84.2	73.4	116.1	229.8	238.0	126.5	29.7	4.5	6.5	1023.4

From the rainfall data of the stations high rainy seasons are observed in July and August.

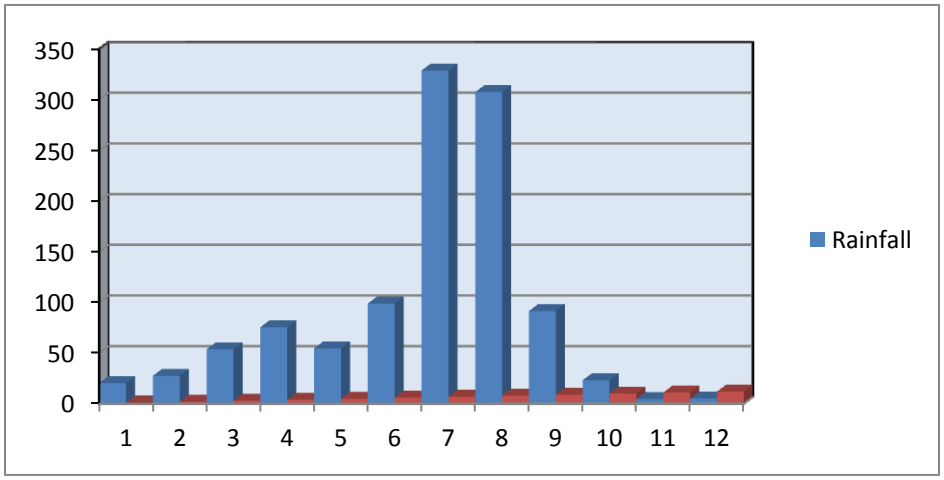

Fig.2.3 Mean Annual Rainfall Chart of Sendafa Station (in mm)

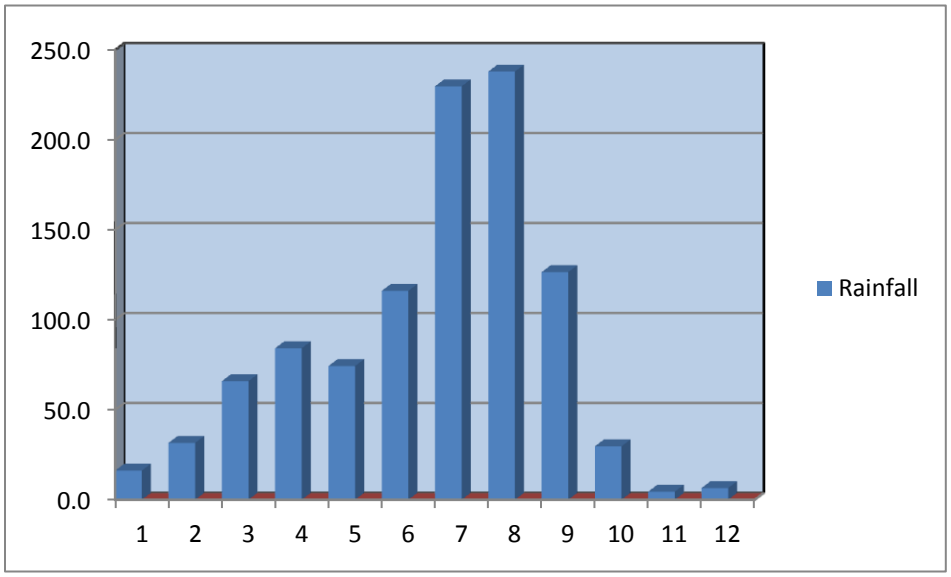

Fig.2.4 Mean Annual Rainfall Chart of Addis Ababa Station

The charts (Fig. 2.3 and 2.4) clearly show that the area has maximum rainfall in July and August. And the minimum rainfall is recorded in November and December.

2.4 Geology

According to the Ethiopian Geological Survey Feasibility study of Chebe Weregenu Sanitary Landfill Project Site report (GSE, 2010), the area is found in a volcanic terrain composed of tertiary basalts and pyroclastic rocks. The geologic formations from the youngest, to the oldest in the project area and its immediate surroundings are as follows (Fig.2.5-2.7):

- ☞ Tertiary basalts (lower part)
- ☞ Pyroclastic rocks (middle part)
- ☞ Quaternary soil (top most part)

2.4.1 Tertiary basalts (Tb)

The Tertiary basalt is exposed a little bit outside the map boundary. This basalt is exposed in the northwestern tip of the study area at Gewasa-Yera locality and in the Valley of Akaki River. The

basalt is dark grey when fresh and brown when it is weathered. It shows aphanitic texture and is mainly massive. The top most part is horizontally layered and grades to massive variety down wards. Its composition is dominantly of mafic minerals but scarce amount of olivine and scattered pyroxene and plagioclase also occur. At places, scoria flow is intercalated within the basalt. The scoria is reddish, weathered and contains rock fragments of scoria and basalt.

Petrographic study of basalt sample show cryptocrystalline groundmass (23%), crystallites of plagioclase (20%), opaque (25%), sanidine (2%), plagioclase (3%), glass (15%), olivine (7%) and pyroxene (5%). The texture is fluidal (flow) and at places glass is altered to palagonite. Many crystals occur as glassy and remain ultrafine grained. There are scattered olivine, rare pyroxene and rare crystals of plagioclase as phenocrysts. The pyroxenes include orthopyroxenes and clinopyroxenes (GSE, 2010).

2.4.2 Pyroclastic rocks (Pyx)

This unit is exposed in all parts of the study area. It forms flat topography, gentle slope, moderate slopes and also cliffs. The cliffs are observed to the west side of the map area, whereAkaki River drains. The pyroclasts show slight Easterly tilt. This implies the pyroclasts were deposited on subdued or tilted or inclined topography. The pyroclastic deposits include tuffs and ignimbrites of various types. Different successions of pyroclasts are logged in the valley of Akaki (Fig. 2.5). Unconformities are recognized within the stratigraphic sections at different elevations.

The tuff includes lapilli tuff, lithic tuff and massive type of tuff. The color of the tuff varies according to composition and stratigraphic position and hence, white, light grey, light yellow and light brown types exist (Fig.2.7). The lithic tuff shows stratification of deposition at its bottom part. Above the lithic tuff there is massive, softer and fractured and weathered tuff, whereas below the lithic tuff there is whitish fine and harder tuff with rare rock fragments. Below this tuff there is highly vesicular tuff.

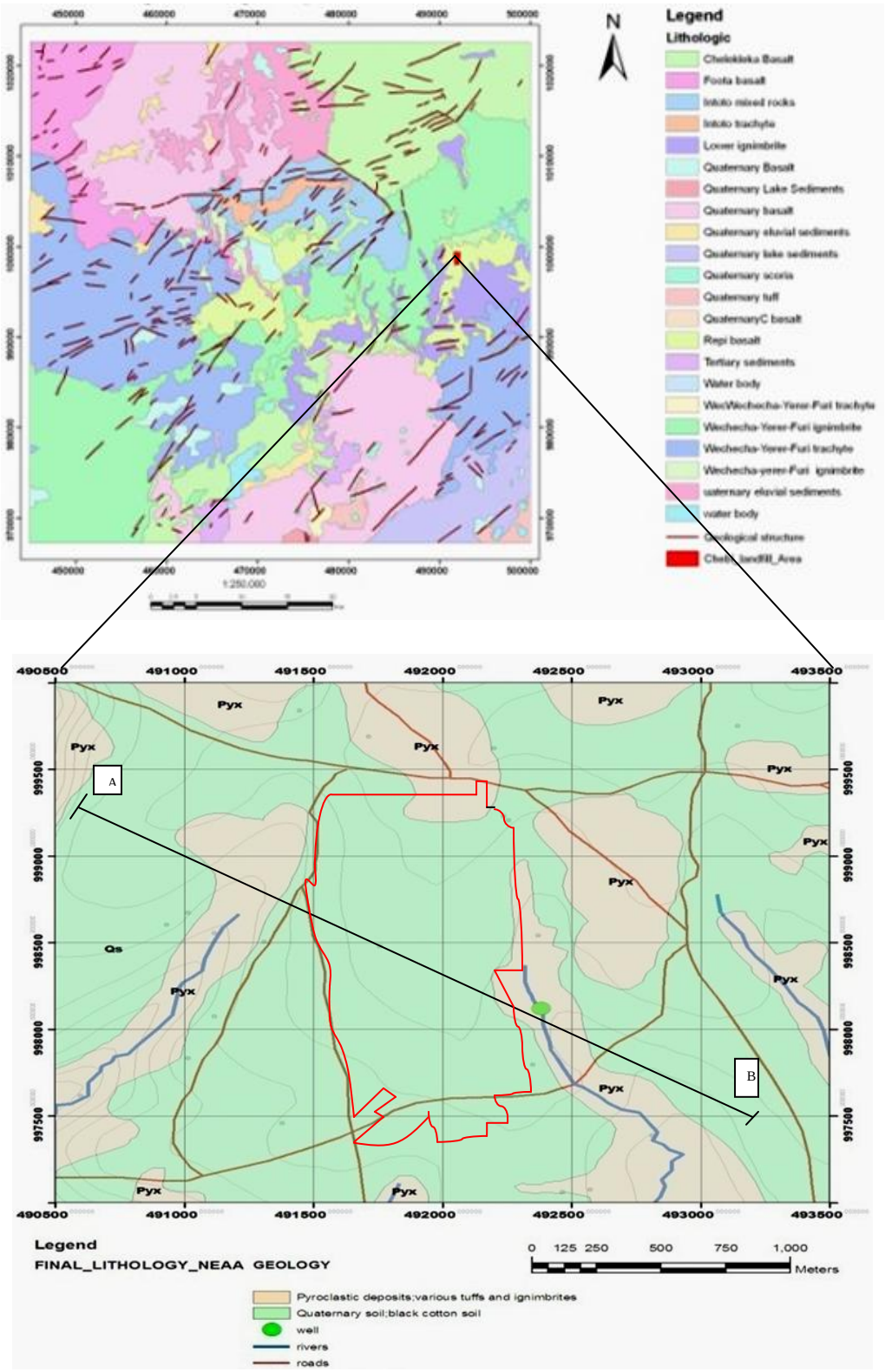

Fig.2.5 Detail geological map (1:5,000 scale) of the Chebe-Weregenu proposed landfill site (map inset – geological map of NE Addis Ababa sub-sheet) (GSE, 2010).

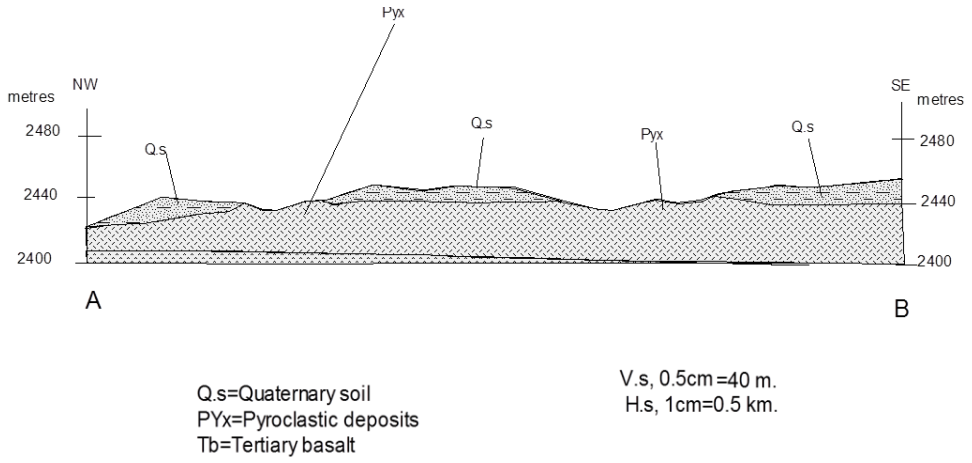

Fig. 2.6 Geological cross section along line A-B.

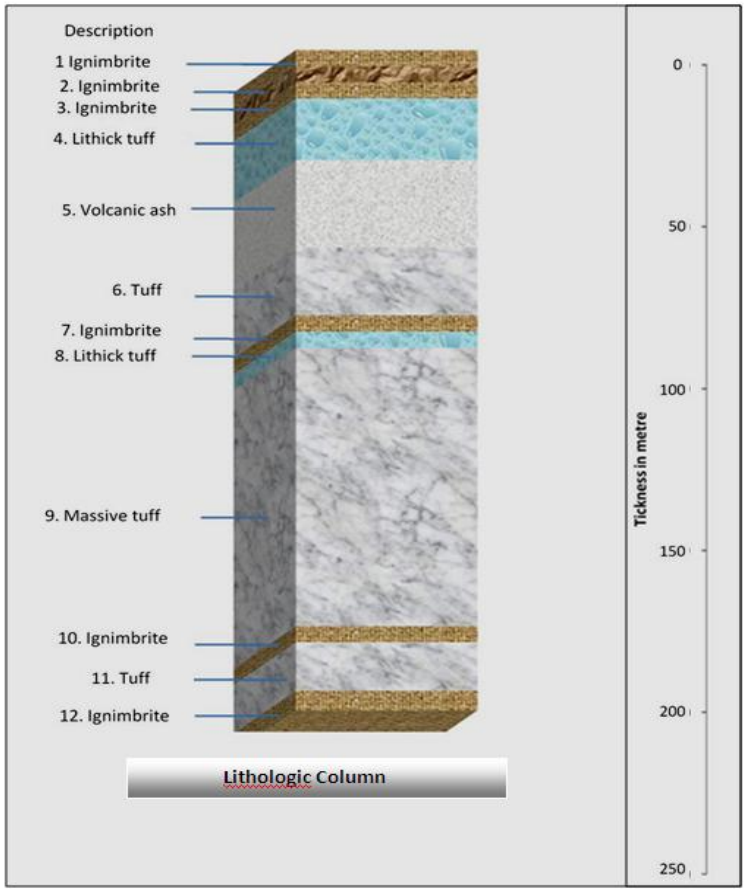

Fig. 2.7 Lithostratigarphy of Chebe-Weregenu area (modified after GSE, 2010)

Rock fragments of tuff, obsidian, weathered pumice and scoria in the range of 1cm to 0.5m in diameter are common within the tuffs. At places wood fossils are recognized within the tuffs. The top part of the pyroclast is mainly tuff but is intercalated with minor ignimbrite (GSE, 2010).

The lithic tuff shows stratification of deposition at its bottom part. Above the lithic tuff there is a massive, softer and fractured and weathered tuff. Below the lithic tuff there is whitish fine and harder tuff with rare rock fragments. And below this tuff there is vesicular tuff (Fig.2.7). There is also a N20E trending lineament or fracture which crosses the tuff. It also shows some caves on it. From petrographic study the tuff is light grey to white, slightly weathered, softer and lighter rock. Rock fragment is rare or absent. Its major composition is glass or mostly volcanic ash. Sanidine is rare (GSE, 2010).

Lower Ignimbrite

The lower ignimbrite lies unconformably (which is marked by baked soil) below the whitish fine-grained tuff and above the basaltic unit. It forms a gentle slope and flat topography. The lower ignimbrite is light to dark grey in color. It is medium to coarse grained hard and compact. It contains fiammes of trachyte, weathered pumice (which is yellow in color) and obsidian. It is composed of dominant amount of quartz, sanidine, rock fragments of volcanic ash and others rocks. At places it is fresh, massive with no fractures (GSE, 2010).

Upper Ignimbrite

The upper ignimbrite lies unconformably above the whitish tuff, which is harder and fine-grained and in most places it is covered by clay soil. It forms flat topography. It is exposed around the confluence of Akaki and Legedadi rivers. This ignimbrite is somewhat different from other pyroclast in that it passes to the wider geographic areas, while other underlying pyroclasts don't continue, especially to the North or Northeast or Northwest, but continues to South or Southeast (GSE, 2010).

It is grey, medium to coarse grained, hard containing high amount of lenticular shape fiammes of pitchstone, obsidian and trachyte with maximum length of up to 5cm. It is composed of quartz and rock fragments of pitchstone, obsidian, trachyte and pumice. Rock fragments dominate it and at places its composition is dominated by quartz. At places the top most ignimbrite is observed

on a flat topography. It is light grey, fine to medium and also medium to coarse grained and fresh containing sanidine and quartz at gentle slope. At places it is highly weathered. There is intercalation of lithic tuff within the ignimbrite (GSE, 2010).

Petrographic study reveals ignimbrite containing 40% glass shards, 12%rock fragments, 36% glass, 2% opaque minerals and 10% anorthoclase and sanidine. It shows eutaxitic texture (parallel arrangement of glass shards).The major rock fragments are trachytic obsidian and the minor rock fragments are pumice. The glass shards are prismatic to folded skeletal fragments of glass with various shapes and they are oriented sub-parallel (GSE, 2010).

2.4.3 Quaternary soil (Q.s)

The Quaternary soil covers most part of the study area. It is black cotton soil, massive & rests on the ignimbrite. At places it has a maximum thickness of more than 2m. It is black cotton soil of the plateau. It shows multi-directional deep-rooted desiccation cracks. It is cultivated with Wheat and Teff (GSE, 2010).

2.4.4 Structure

There are 325NW, 320NW, 30NE and N20E trending lineaments or fractures which crosses the tuff (GSE, 2010).During field investigation, there was no visible micro fracture observed in the area.

2.5 Engineering Geology

The engineering geological map was prepared at a scale of 1:5000 by Geological Survey of Ethiopia in the feasibility study of Chebe Weregenu Sanitary Landfill Project Site (GSE, 2010). It includes classification of soils and rocks according to their geotechnical properties. Soils are classified according to their genesis as residual. Rocks are classified according to their rock mass strength values, degree of weathering and joint spacing.

Residual soil unit

Residual soil is an in-situ developed soil from the underlying parent rock by mechanical and chemical decomposition (GSE, 2010). Fig.2.8 shows the engineering geological map of the study area at1:5,000.

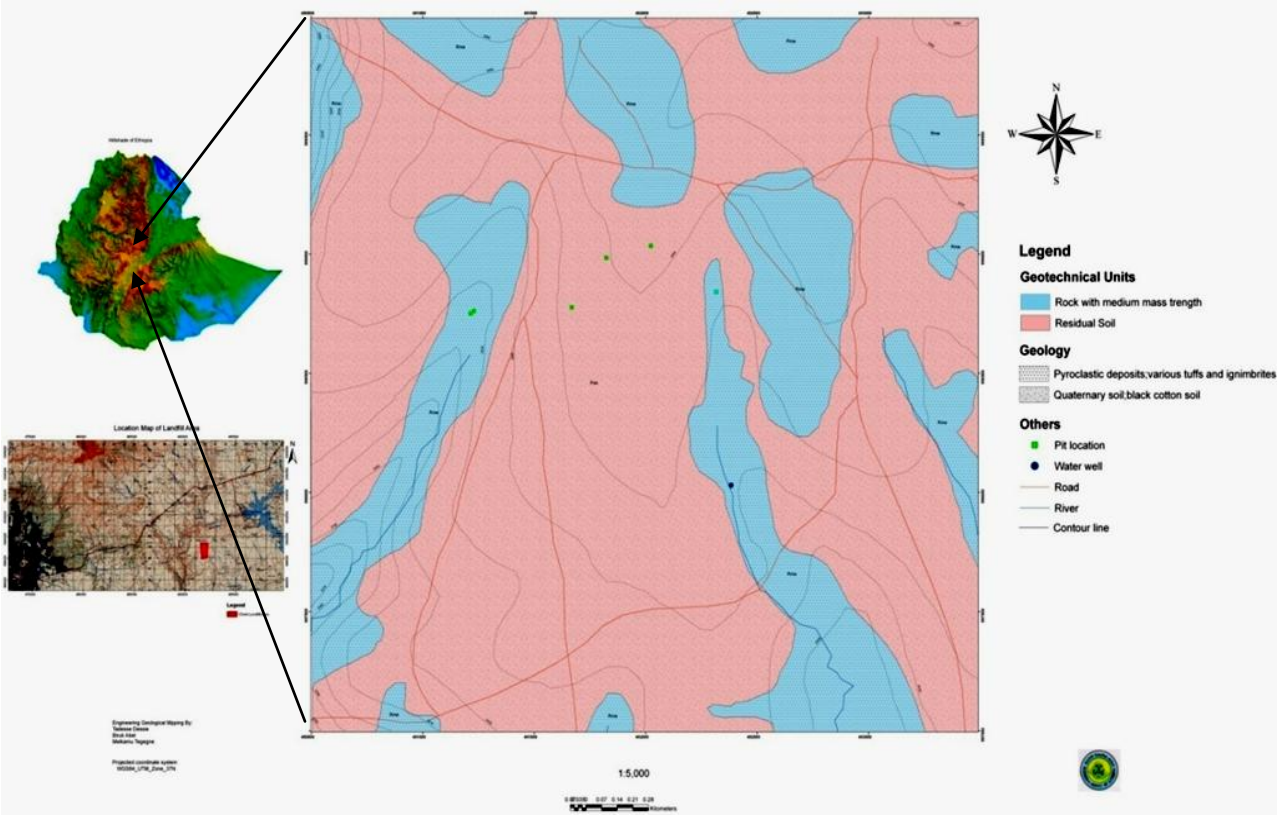

Fig.2.8 Engineering geological map of the Chebe-Weregenu landfill site (*Source: GSE, 2010*)

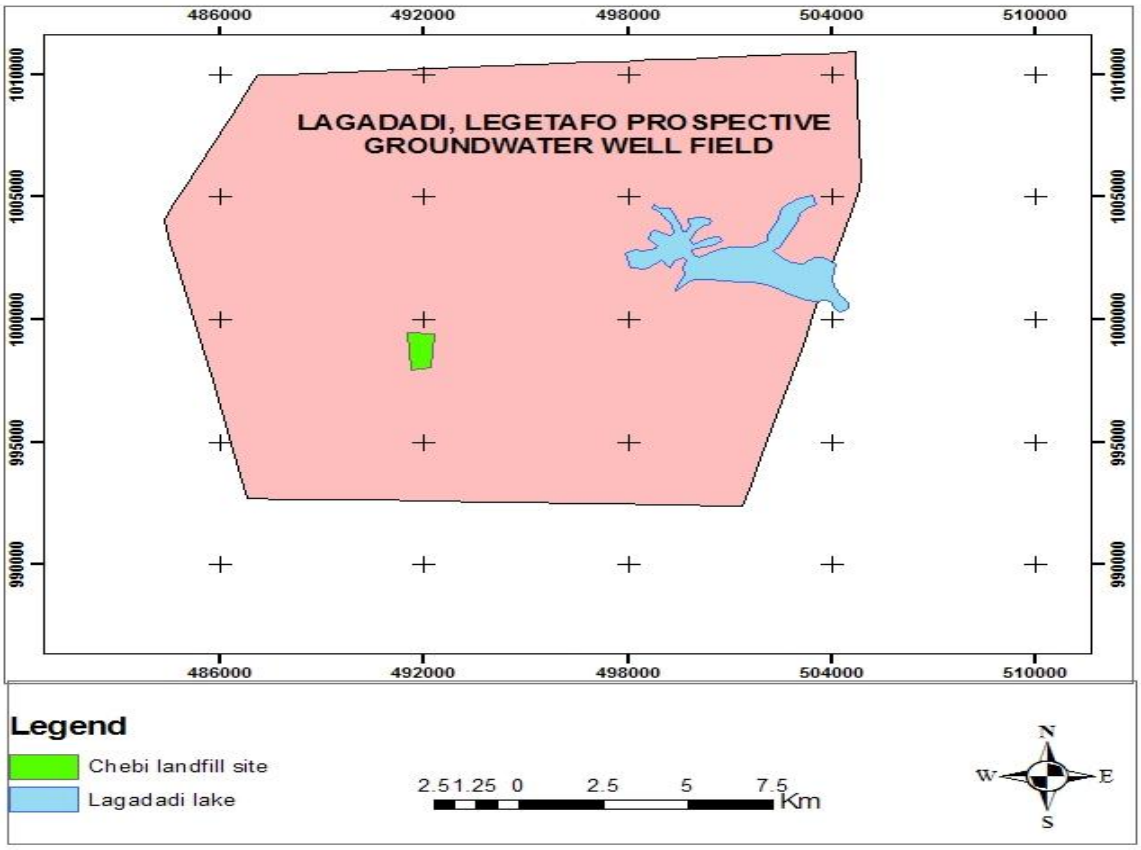

Fig.2.9 Chebe Weregenu Sanitary landfill site and the prospective well field (source: GSE, 2010)

Rock with medium mass strength (Ignimbrite)

According to the Ethiopian Geological Survey feasibility study, beneath the residual soil, there is Ignimbrite, and as observed in the field it is slightly weathered, moderately jointed, with two joint sets. It has vertical and horizontal joint sets. The vertical joint spacing is 50 - 76 cm where as the horizontal joint spacing is 30 - 44 cm. Joints are filled with overlying clay soil. The ignimbrite has medium mass strength (Rme).

Construction Raw Materials for Clay Cap application

An investigation for a quarry site for construction raw material to be used as cap was conducted about 1.5 km from the landfill site. The area investigated is 150,000m^2. In the vicinity of the landfill site over 750,000 m^3 brown clay soil is available for construction material (GSE, 2010).

2.6 Hydrogeology

The Chebe Weregenu Sanitary Landfill Site is found on the plateau top. Streams are drained towards Southeast and Southwest starting from the project area (GSE, 2010). The slope is moderate in the North, South and West directions whereas gentle towards the East.

The maximum elevation is 2470m on the top of the plateau and the minimum is 2340m at the valley in the southwest. The mean annual precipitation and temperature are 1186 and 16.20c respectively (GSE, 2010).The Chebe Landfill site is found within the Lagadadi-Lagatefo well field site (Fig. 2.9).

CHAPTER 3 – SAMPLES, TESTS, RESULTS, DISCUSSIONS AND INTERPRETATIONS

3.1 samples and laboratory tests

3.1.1 Sampling

Soil samples, rock samples and water samples were collected from the landfill Site and from the adjacent areas.

Soil Samples

Eleven representative disturbed and undisturbed soil samples were collected from Chebe Weregenu sanitary landfill Site on November 04, 2011 and February 18, 2012 from the coordinates given below.

Table 3.1 Soil Sample Collection Points

Test Pit Number	Depth (m)	Geographic Coordinate (UTM)	Date Sampled
TP-1	0.0-1.3	492453E:0999498N	Nov 4,2012
	1.3-2.0	"	"
TP-2	1.2-2.0	491843E:0999589N	"
TP-3	0.0-2.0	491899E:0998562N	"
TP-4	0.0-2.0	492460E:0997510N	"
TP-5	0.0-1.2	491800E:0997398N	"
	1.2-2.0	"	"
TP-6	0.0-1.2	493507E:1000070N	"
TP-7	0.0-4.0	493519E:1000111N	Feb 02,2012
TP-8	1.87-3.17	491691E:0998769N	Feb 18,2012
	3.17-4.12	"	"

Plate 1- Different test pit excavations at Chebe landfill site

Rock Samples

Two rock samples were collected, one from a location about 1.5km away from the landfill site which is intended to be used as a clay cap for the landfill application. It is a fresh olivine basalt found at a depth of 1.2m. Another sample, an andesitic tuff, was collected from the surface of the landfill site. These rock samples were used to conduct petrographic analysis.

Table 3.2 Rock Sample Collection Points

Test Pit Number	Depth (m)	Geographic Coordinate (UTM)	Date Sampled
TP-6	1.20	493507E:1000070N	Nov 4,2012
SER	Surface	-	

Plate 2: Location of proposed construction material site

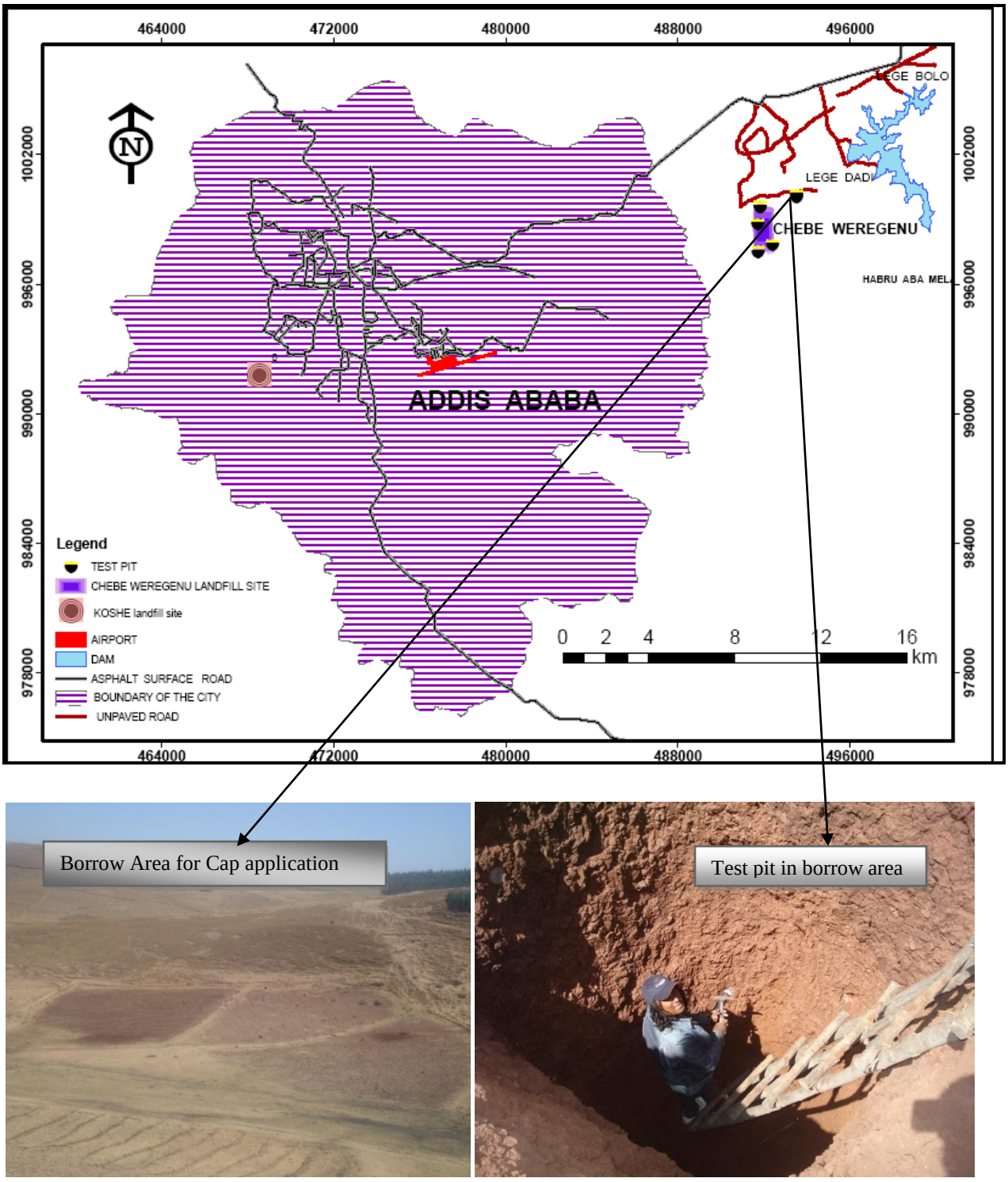

Fig.3.1.The location of construction raw material for the Chebe Weregenu sanitary landfill (left the borrow area and right the test pit excavated at 4.0 meter).

Soil Samples for Mineralogy Test

From the eleven soil samples, five representative soil samples were analyzed for clay mineralogy using XRD, at Geological Survey of Ethiopia Laboratory.

Table 3.3 Soil Sample Collection Point for Clay Mineralogy

Test Pit Number	Depth (m)	Geographic Coordinate (UTM)	Date Sampled
TP-1	0.0-1.3	493507E:1000070N	Nov 4,2012
TP-2	1.2-2.0	493507E:1000070N	"
TP-3	0.0-2.0	493507E:1000070N	"
TP-5	1.2-2.0	493507E:1000070N	"
TP-6	0.0-1.20	493507E:1000070N	"

Soil Samples for Fertility

Three representative samples collected from the Chebe Sanitary Landfill Site for beatifying the site after operational phase from the following coordinates.

Table 3.4 Soil Sample Collection Point for Soil Fertility

Test Pit Number	Depth (m)	Geographic Coordinate (UTM)	Date Sampled
TP-1	0.0-1.3	493507E:1000070N	Nov 4,2012
TP-3	0.0-2.0	493507E:1000070N	"
TP-6	0.0-1.20	493507E:1000070N	"

Water Samples

Four water samples were collected from the nearby areas of the landfill site. One was ground water sample which was collected outside the landfill site. The second sample was collected from Bekene spring which is found in Akaki Kele Kebele, close to the landfill site, whereas the remaining samples were collected from kawa spring and Nebe spring, outside the landfill site.

Table 3.5 Water Sample Collection Points

Test Pit Number	Geographic Coordinate (UTM)	Date Sampled
Kawa Spring	493525E:1000354N	Feb 18,2012
Nebe Spring	493017E:1000497N	"
Ground Water	493020E:1000513N	12/03/2010
Bekene Spring	490570E:0997563N	12/03/2010

Plate3: Water Sample collection from Chebe Weregenu Sanitary Landfill site

3.1.2 Laboratory Tests

Soil Mechanics Laboratory Tests

Table 3.6 Summary of exploration and tests performed

Type of exploration (test)	Quantity	Remarks
Test pit excavation to a maximum depth of 4.5 meters	2	1 within the landfill site and the other 1.5km far from the landfill site, for landfill cap application.
Test pit excavation to a maximum depth of 2 meters	6	
Undisturbed soil sampling	8	10x12 cm core cutter sampling device
Disturbed soil sampling	11	Maximum of 25 kg representative samples
Laboratory tests performed		
Grain Size Analysis (hydrometer + wet sieve)	11	(10 hydrometer and 1 sieve analysis)
Atterberg Limit	10	Conducted from disturbed
Linear Shrinkage	8	Conducted from disturbed
Specific Gravity	11	Conducted from disturbed
Free Swell	7	Conducted from disturbed
Porosity	6	Conducted from undisturbed samples
Natural Moisture Content	9	"
Unit Weight	7	"
Dispersion (by Pinhole Method)	6	Conducted from disturbed
Compaction	6	Five standard and 1 modified.
Consolidation	8	Conducted from Undisturbed samples.
Permeability	9	Conducted from disturbed samples.
Shear Strength Direct Shear	6	Conducted 5 from undisturbed samples & 1 from disturbed sample.
- Unconfined Comprehensive Strength(UCS) for soil	6	Conducted from disturbed samples.
In situ Test - Pocket Penetrometer	6	
Swelling Pressure	1	

Plate 4: Some of laboratory test instruments used during the research study

Soil Fertility Test

Physical and chemical characteristics of soil test were conducted in Water Works Design and Supervision Enterprise Laboratory. This was mainly for two reasons. One is to assess possibility of improving the aesthetics of the Sanitary Landfill site after the top cover of each portion of the landfill and the other is to use the data as a base line data.

Table 3.7 Summary of tests performed at WWDSE Soil Fertility Laboratory

Laboratory tests performed	Sample Type	Quantity	Date Sampled	Date Tested
PH	Disturbed	3	Nov 4, 2012	Feb 29,2012
EC		3		
Gypsum		3		
Exc. Bases Na,K,Ca,Mg		3		
CEC		3		
OC		3		
N		3		
Available Phosphorous		3		
Available Potasium		3		
CaCO3		3		
ESP %		3		
Gypsum		3		
Soluble Salts		3		
Micro Nutrients; Cu, Fe, Mn, Zn		3		
Boron		3		

Surface cracks formed during drying of swelling clays, Feb, 2012

Barely plantation observed on field investigation, November 04, 2011

Plate 5: Soil Fertility of Chebe Weregenu Sanitary Landfill Site

Water Quality Tests

Water quality test was conducted from environmental perspective, in order to establish a reference point for the operation phase of the sanitary landfill system.

Table 3.8 Summary of tests performed at WWDSE Water Quality Laboratory

Laboratory tests performed	Sample Type	Quantity	Date Sampled	Date Tested Conducted
PH	Water	4	Feb 02, 2012	Feb 13, 2012
Turbidity		4		
Color		4		
Total Solid		4		
Total Dissolved Solid		4		
EC		4		
N		4		
Av.P		4		
Av.K		4		
CaCo3		4		
FC		4		
Soluble Salts		4		
Total Hardness, Ca& Mg		4		
Potassium & Sodium		4		
Iron		4		
Manganese		4		
Chloride		4		
Sulphate		4		
Nitrate		4		
Alkalinity, CO3 & HCO3		4		
Fluoride		4		
Phosphate		4		
Ammonia		4		
Aluminium		1		
Zinc		1		
Copper		1		
Chromium		1		
Silica		1		
Molibidium		1		
Lead		1		
Nickel		1		
Organic Carbon		1		

Rock Tests

Table 3.9 Summary of Rock tests performed at Geological Survey of Ethiopia Laboratory

Laboratory tests performed	Sample Type	Quantity	Date Sampled	Date Tested
Thin Section Analysis	Rock	2	Nov 4, 2012	27/12/2011

Soil, Mineralogical Tests

Table 3.10 Summary Mineralogy of tests performed at Geological Survey Laboratory

Laboratory tests performed	Sample Type	Quantity	Date Sampled	Date Tested
Clay Mineralogy(X-RD)	Disturbed Soil	5	Nov 4, 2012	03/02/2012

3.2 Laboratory Test Results, Discussions and Interpretations

Introduction

In this chapter all laboratory test results are discussed. In addition, the Chebe Weregenu Sanitary Landfill Site is appraised from mineralogical, geotechnical and environmental aspects based on laboratory test results. Finally test results were compared against standard requirements and interpreted accordingly.

3.2.1 Laboratory Test Results

The following are summary of laboratory test results of soil, water and rock samples from Chebe Weregenu sanitary landfill site. (For details please refer annex)

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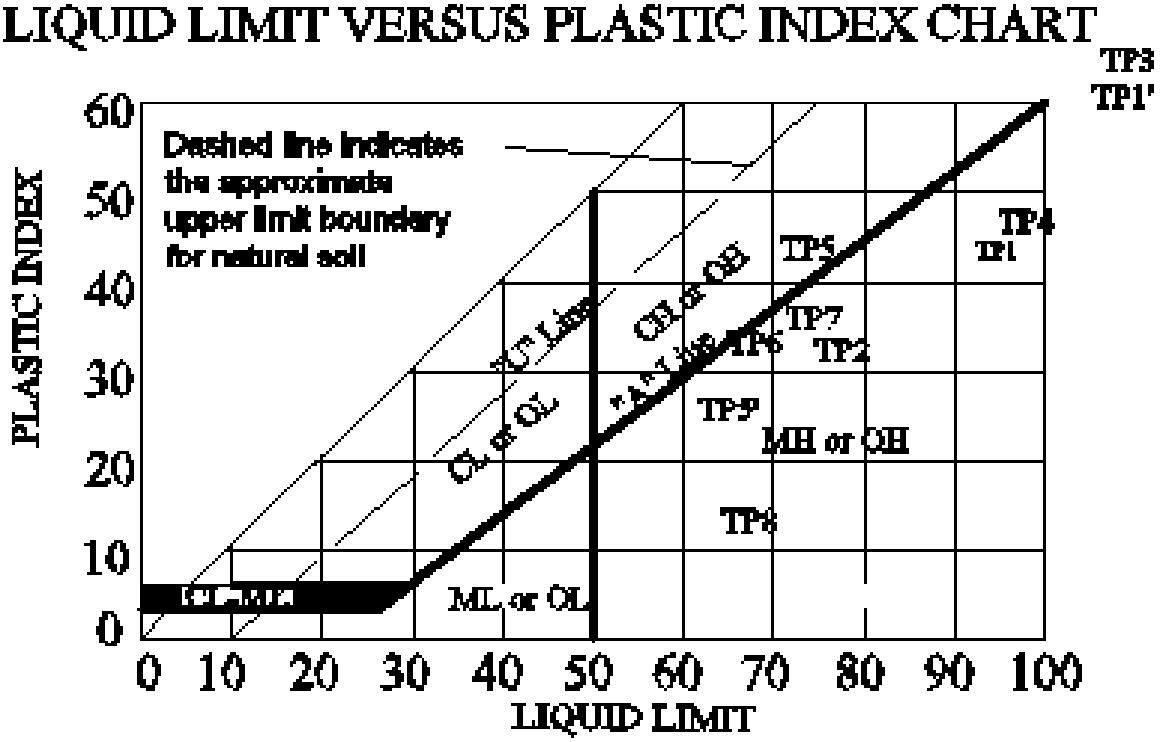
Table 3.11 Summaries of Chebe Weregenu Sanitary Landfill Project Site Soil Mechanics Laboratory Test Results, November 11, 2011

Parameters	TP-1 (0.0-1.3)m	TP-1 (1.3-2.0)m	TP-2 (1.2-2.0)m	TP-3 (0.0-2.0)m	TP-4 (0.0-2.0)m	TP-5 (0.0-1.2)m	TP-5 (1.2-2.0)m	TP-6 (0.0-1.2)m
Atterberg Limit								
Liquid limit %	91.70	105.28	78.30	106.30	95.32	75.10	62.63	65.62
Plastic Limit %	45.55	42.31	44.50	41.98	45.71	34.01	39.21	34.59
Plasticity Index %	46.15	62.97	33.80	64.32	49.61	41.09	23.42	31.03
Linear Shrinkage Limit (%)	21.57	23.86	16.79	21.82	22.54	21.14	11.5	15.29
Specific Gravity	2.71	2.40	2.40	2.75	2.61	2.33	2.52	2.72
Free Swell (%)	120.0	150.0	89.0	155.0	147.5	144.0	-	85.0
Porosity (%)	-	52	54	53	54	-	56	59
Grain Size Analysis								
Clay %	57.85	70.05	50.08	94.70	77.35	55.50	19.25	29.50
Silt %	37.97	27.05	38.88	4.80	20.75	40.44	42.59	42.60
Sand %	4.18	2.90	11.04	0.50	1.90	4.06	38.16	10.95
Gravel %	-	-	-	-	-	-	-	16.95
Natural Moisture Content (%)	-	37.72	51.93	36.34	43.99	37.87	54.84	31.35
Unit Weight (gm/cc)	-	1.68	1.46	1.76	1.64	-	1.58	1.64
Dispersion (by Pinhole Method)	ND2	-	ND3	ND1	ND1	-	ND1	ND1
Compaction Test								
MDD gm/cc	1.164	1.084	1.070	1.154	-	-	1.082	1.292
OMC %	40.25	46.60	44.50	41.54	-	-	47.00	34.00
		0.200	0.439	0.245	0.265	-	0.140	0.185
Permeability (cm/sec)	$9.07 X10^{-8}$	$3.496 X10^{-8}$	$3.30X10^{-8}$	$2.839X10^{-8}$	$1.085X10^{-8}$	-	$1.897X10^{-7}$	$1.257X10^{-6}$
Direct Shear								
C((Kpa)	-	71.00	56.66	-	-	-	62.30	61.66
Ø (^{0})	-	13.22	15.10	-	-	-	17.44	17.74
Unconfined Compression Strength (Kpa)	-	387.21	505.56	588.61	-	-	391.76	355.71
Swelling Pressure (%)	-	415.76	-	-	-	-	-	-

Summaries of Chebe Soil Laboratory Test Results, November 11, 2011, Cont'd….

Parameters	TP-7 (3.30-4.0)m	TP-8 (1.87-3.17)m	TP-8 (3.17-4.50)m
Grain Size Analysis			
Clay %	63.85	11.75	5.50
Silt %	32.79	50.99	47.46
Sand %	3.36	37.26	47.04
Gravel %	-	-	-
Atterberg Limit			
Liquid limit %	76.63	69.00	-
Plastic Limit %	38.70	55.42	-
Plasticity Index %	37.93	13.58	-
Specific Gravity	2.73	2.61	2.59
Water Absorption (%)	-	59.64	59.24
Natural Moisture Content (%)	40.31	-	63.33
Unit Weight (gm/cc)	-	-	1.35
Compaction Test			
MDD gm/cc	1.255	-	-
OMC %	35.50	-	-
Oedeometer Consolidation Cc	0.285	-	0.510
Permeability (cm/sec)	$6.99 X10^{-8}$	-	$7.76 X10^{-7}$
Direct Shear			
C((Kpa)	48.33	-	114.0
¬ (^{0})	14.30	-	13.76
Unconfined Compression Strength (Kpa)	457.63	-	-



SOIL DATA						
SAMPLE NO	DEPTH (M)	NATURAL MOISTURE CONTENT (%)	LIQUID LIMIT (%)	PLASTIC LIMIT (%)	PLASTICITY INDEX (%)	USCS
TP1	0.0-1.3	-	91.70	45.55	46.15	OH
TP1'	1.3-2.0	87.72	105.28	42.31	62.97	OH
TP2	1.2-2.0	51.93	78.30	44.50	33.80	OH
TP3	0.0-2.0	36.34	106.30	41.98	64.32	OH
TP4	0.0-2.0	43.99	95.32	45.71	49.61	OH
TP5	0.0-1.2	37.87	75.1	34.01	41.09	CH
TP9	1.2-2.0	54.84	62.63	39.21	23.42	OH
TP6	0.0-1.2	31.35	65.62	34.59	31.03	OH
TP7	3.5-4.0	40.31	76.63	38.70	37.93	OH
TP8	1.87-3.17	-	69.00	55.42	13.58	OH
TP9	3.17-4.5	63.30	-	-	-	

Fig. 3.2 Plastic Index versus Liquid Limit Chart

Table 3.12 Summary of Clay mineralogical test results

Test Pit No.	Depth (m)	Identified Minerals	Identified Minerals (%)	Remarks
TP-1	0.0-1.30	Muscovite	73.2	
		Dickite	26.8	-
TP-2	1.20-2.0	Muscovite	-	The dominant part of the sample is non crystalline (amorphous)
Tp-3	0.0-2.0	Quartz	81.6	
		Dickite	18.4	-
TP-5	1.20-2.0	Magnetite	12.4	
		Muscovite	64.4	
		Kaolinite	23.2	-
TP-6*	0.0-1.20	Albite	63.9	
		Hematite	13.0	
		Quartz	13.9	
		Dickite	9.1	-

*Remark: The % proportions of identified minerals do not add up 100. This might be human error during reporting.

Table 3.13 Summary of rock Petrographic analysis

Test Pit No.	Depth (m)	Rock Name	Mineral	Modal (%)	Texture
TP-6	1.20	Olivine Basalt	Plagioclase Pyroxene Opaque Olivine Volcanic glass Calcite Biotite	36 34 10 8 8 3 1	Lath Anhedral Fine-anhedral Euhedral - Anhedral Platy
SER	Surface	Andesitic Tuff	Microlite Plagioclase Pyroxene Rock fragment Opaque Volcanic glass	40 20 20 10 10	Microlitic Anhedral - Fine-anhedral -

3.2.2. Discussion and Interpretation

(i) Geotechnics Engineering parameters of clay liner

Classification of Soil, Liquid Limit and Coefficient of Permeability

Test results, standard requirements and compliance analysis are given here under.

Table 3.14: Laboratory test results of soil sample classification and Coefficient of Permeability

Parameters	TP-1 (0.0-1.3m)	TP-1 (1.3-2m)	TP-2 (1.2-2m)	TP-3 (0.0-2m)	TP-4 (0.0-2m)
Clay content (%)	57.85	70.05	50.08	94.70	77.35
Fines clay & silt content)%	95.82	97.10	88.96	99.50	98.12
Liquid Limit (%)	91.70	105.28	78.30	106.30	95.32
Plasticity index (%)	46.15	62.97	33.80	64.32	49.61
Coefficient of Permeability K (cm/sec)	$9.07X10^{-8}$	$3.496X10^{-8}$	$3.30X10^{-8}$	$2.839X10^{-8}$	$1.085X10^{-8}$

Laboratory test result of soil classification and coefficient of permeability, cont'd….

Parameters	TP-5 (0.0-1.2m)	TP-5 (1.2-2m)	TP-6 (0.0-1.2m)	TP-7 (3.5-4m)	TP-8 (1.87-3.2m)	TP-8 (3.17-4m)
Clay content (%)	51.50	19.25	29.50	63.85	11.75	5.50
Fines clay & silt content)%	95.94	61.84	72.10	96.64	62.74	52.96
Liquid Limit (%)	75.10	62.63	65.62	76.63	69.0	-
Plasticity index (%)	41.09	23.42	31.03	37.93	13.58	-
Coefficient of Permeability K (cm/sec)	-	$1.897\ X10^{-7}$	$1.257\ X10^{-6}$	$6.99\ X10^{-8}$	-	$7.76\ X10^{-7}$

Table 3.15: Standard requirements for Compacted Clay Liner

Minimum Clay Content %	10%
Minimum fines (clay & silt)content %	>30%
Liquid Limit %	<90 %
Plasticity Index %	>10% and <65%
Coefficient of permeability K (m/sec)	1X10-9 m/sec or less
Maximum particle size (mm)	75mm

Source : (http://www.igsl.ie/wp-content/uploads/clay_liners_for_landfill_projects.pdf)

Table 3.16 Compliance analysis table

Parameters	Test Pit No.	Depth (m)	Compliance with the Standard Requirements	Remarks
Liquid Limit (LL)	TP-1	0.0-1.3	Yes	
	TP-2	1.2-2.0	Yes	
	TP-5	0.0-1.2	Yes	
	TP-5	1.2-2.0	Yes	
	TP-6	0.0-1.2	Yes	
	TP-7	3.5-4.0	Yes	
	TP-8	1.87-3.17	Yes	
	TP-1	1.3-2.0	No	
	TP-3	0.0-2.0	No	
	TP-4	0.0-2.0	No	
Coefficient of Permeability	All nine test pits, please refer table 5.8	Please refer table 5.8	Yes	

- ☞ The permeability test result of the Chebe Weregenu Sanitary Landfill Site for the cap and the liner material are all incompliance with the standard requirements given in table 3.19 above.

Natural Moisture content

Table 3.17: Natural Moisture Content of soil sample laboratory test data

Parameters	TP-1 (0.0-1.30m)	TP-1 (1.3-2.0m)	TP-2 (1.2-2.0m)	TP-3 (0.0-2.0m)	TP-4 (0.0-2.0m)
Natural Moisture Content (%)	-	37.72	51.93	36.34	43.99

Natural Moisture Content of soil sample laboratory test data, contd…

Parameters	TP-5 (0.0-1.20m)	TP-5 (1.2-2.0m)	TP-6 (0.0-1.20m)	TP-7 (4.0m)	TP-8 (4.5m)
Natural Moisture Content (%)	37.87	54.84	31.35	40.31	63.33

The moisture content test results of samples TP-2 (1.20-2.0m), TP-5(1.2-2.0m) are very high and the moisture content of TP-8(4.5m) is also very high compared to the other eight samples. This may be due to the type of materials; because all three samples are found from highly weathered, lightweight yellowish to grayish tuff materials. It has the possibility of absorbing water through pores.

Activity of Clays

Table 3.18: Laboratory test results of Activity of clays

Parameters	TP-1 (0.0-1.30m)	TP-1 (1.3-2.0m)	TP-2 (1.20-2.0m)	TP-3 (0.0-2.0m)	TP-4 (0.0-2.0m)
Plasticity index (%)	46.15	62.97	33.80	64.32	49.61
Percent finer than 2 microns	57.85	70.05	50.08	94.70	77.35
Activity %	0.80	0.90	0.67	0.68	0.64

Laboratory test results of Activity of clays cont'd…

Parameters	TP-5 (0.0-1.20m)	TP-5 (1.2-2.0m)	TP-6 (0.0-1.20m)	TP-7 (3.5-4.0m)	TP-8 (1.87-3.17m)
Plasticity index (%)	41.09	23.42	31.03	37.93	13.58
Percent finer than 2 microns	51.50	19.25	29.50	63.85	11.75
Activity %	0.80	1.21	1.05	0.59	1.16

Table 3.19 Soil classification according to activity of clays

A	Soil type
< 0.75	Inactive
0.75-1.40	Normal
> 1.40	Active

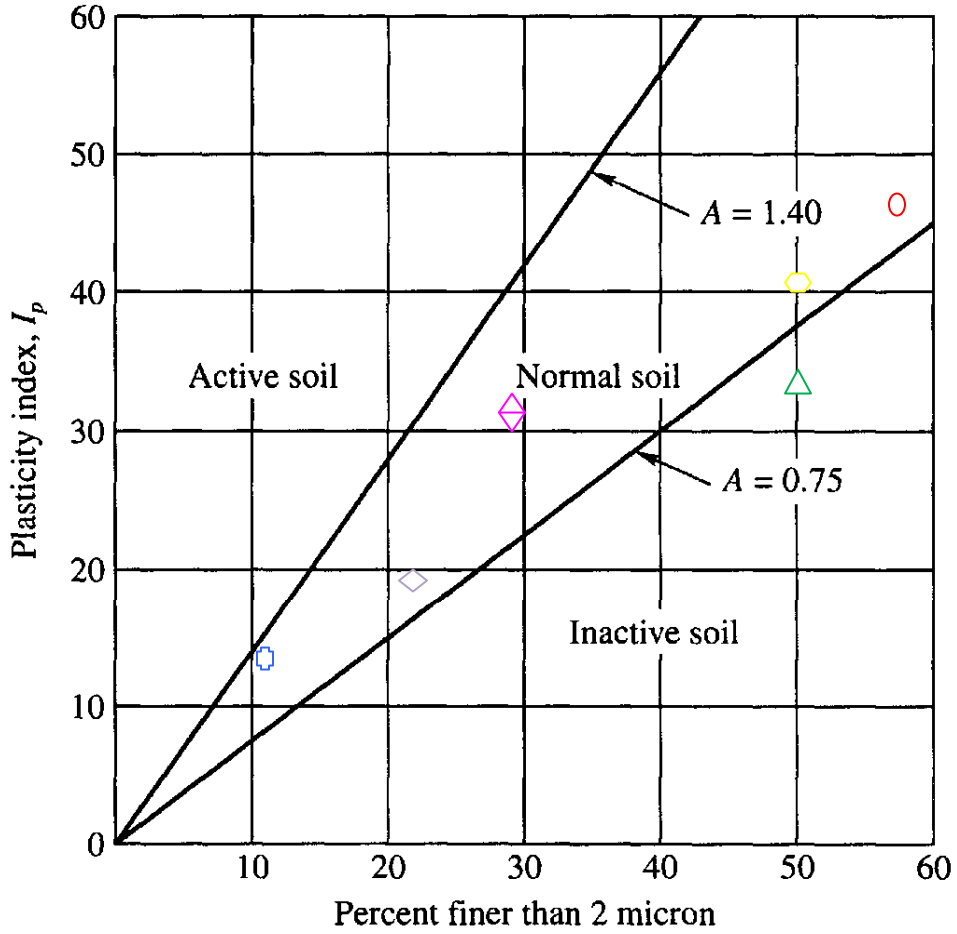


Fig.3.3 Soil classification chart (Skempton, 1953).

☞ Based on the soil classification chart (Skempton, 1953) indicated on figure 3.3 and activity classification table 3.23, all the soil test results fall in normal and inactive soil groups. This shows that the soil is not the type that swells.

Porosity

Table 3.20: Porosity laboratory test data

Parameters	TP-1 (0.0-1.30m)	TP-1 (2.0m)	TP-2 (2.0m)	TP-3 (2.0m)	TP-4 (2.0m)
Porosity (%)	-	52	54	53	54

Porosity laboratory test data , cont'd…

Parameters	TP-5 (0.0-1.2m)	TP-5 (2.0m)	TP-6 (1.2m)	TP-7 (4.0m)	TP-8 (4.5m)
Porosity (%)	-	56	59	-	-

Table 3.21: Standard requirements of porosity range

Well sorted sand or gravel	25-50%
Sand and gravel, mixed	20-35%
Glacial till	10-20%
Silt	35-50%
Clay	33-60%

Source: C.W. FETTER, JR University of Wisconsin-Oshkosh, Applied Hydrogeology p-64

- ☞ The porosity test results of Chebe Weregenu site is from 52% up to 59%. These results comply with the standard requirements of porosity which is 40-70%.

Oedometer Consolidation

Table 3.22: Results of Volume Compressibility (Mv), Coefficient of Consolidation (CV) and Cc

Pressure kN/m^2	TP-1 (2.0m)			TP-2 (2.0m)			TP-3 (2.0m)		
	Coefficient								
	Mv (m^2/MN)	Cv (m^2/year)	Cc	Mv (m2/MN)	Cv (m^2/year)	Cc	Mv (m^2/MN)	Cv (m^2/year)	Cc
50	0.000	0.000	0.200	0.000	0.000	0.439	0.000	0.000	0.245
100	0.000	0.000		0.232	1.445		0.000	0.000	
200	0.000	0.000		0.182	4.403		0.000	0.000	
400	0.077	1.639		0.163	1.984		0.079	1.217	
800	0.065	0.803		0.177	1.562		0.073	0.847	
1600	0.048	0.607		0.119	0.348		0.052	0.192	

Results of Volume Compressibility (Mv), Coefficient of Consolidation (CV) and Cc, cont'd...

Pressure kN/m^2	TP-4 (2.0m)			TP-5 (2.0m)			TP-6 (1.20m)		
	Coefficient								
	Mv (m^2/MN)	Cv (m^2/year)	Cc	Mv (m^2/MN)	Cv (m^2/year)	Cc	Mv (m^2/MN)	Cv (m^2/year)	Cc
50	0.000	0.000		0.252	1.067		0.251	3.153	
100	0.229	3.941		0.250	2.271		0.249	2.481	
200	0.225	1.544		0.247	5.802		0.243	1.065	
400	0.137	0.525	0.265	0.083	1.410	0.140	0.178	1.709	0.185
800	0.100	0.321		0.063	3.165		0.102	0.819	
1600	0.066	0.086		0.048	0.955		0.057	0.507	

Results of Volume Compressibility (Mv), Coefficient of Consolidation (CV) and Cc cont'd…

Pressure kN/m^2	TP-7(4.0m)			TP-8 (4.10m)					
	Coefficient								
	Mv (m^2/MN)	Cv (m^2/year)	Cc	Mv (m2/MN)	Cv (m^2/year)	Cc			
50	0.000	0.000		0.523	1.626		-	-	
100	0.245	0.703		0.516	1.248		-	-	
200	0.242	2.505		0.505	2.916		-	-	
400	0.130	2.977	0.285	0.249	2.246	0.510	-	-	-
800	0.104	0.696		0.134	0.921		-	-	
1600	0.104	0.692		0.118	0.587		-	-	

Table 3.23: Oedometer Consolidation Laboratory test results

Parameters	TP-1 (2.0m)	TP-2 (2.0m)	TP-3 (2.0m)	TP-4 (2.0m)	TP-5 (2.0m)
Oedometer Consolidation (CC)	0.200	0.439	0.245	0.265	0.140

Oedometer Consolidation Laboratory test results cont'd…

Parameters	TP-6 (1.20m)	TP-7 (4.0m)	TP-8 (4.10m)
Oedometer Consolidation (CC)	0.185	-	0.510

Standard ranges of values of Coefficient of Consolidation and Compression Index.

Table 3.24: Standard range of Coefficient of consolidation

Soil type	Plasticity Index range	Coefficient of consolidation Cv (m^2/year) undisturbed	remolded	Compression Index Cc
Clays-montmorillonite				Up to 2.6
High plasticity	Greater than 25	0.1-1.0	About 25-50% of undisturbed values	
Medium plasticity	25-5	1-10		0.8-0.2
Low plasticity	15 or less	10-100		
Silts		Above 100		

Source: *British Standard, Manual of Soil Laboratory Testing volume2 P683, ELE*

- The consolidation test results of the Chebe Weregenu Sanitary Landfill site is given in Table 3.27. As per values of coefficient of consolidation and compression index given in Table 3.28, the soil type falls within the high plasticity range. This is also true of the classification test results. However, the (Cv) of samples TP-2(2.0m), TP-5(2.0m), TP-6(1.20m) and TP-8(4.10m) are out of the range which are more than $1m^2$/year against 25-50% of 0.1-$1m^2$/year. The soil type also falls in the medium plasticity range. However on the classification test results these sample found high plasticity. On the other hand the compression index (Cc) is found within the range.

(ii) Mineralogy

Thin section for rock samples

Table 3.25 Clay mineralogical test results

Test Pit No.	Depth (m)	Identified Minerals	Identified Minerals (%)	Remarks
TP-1	0.0-1.30	Muscovite	73.2	
		Dickite	26.8	-
Tp-3	0.0-2.0	Quartz	81.6	
		Dickite	18.4	-

- ☞ According to the test result of XRD given above, the mineral identification of TP-1(0.0-1.30m) was found to be muscovite 73.2% and duckite26.8%. However, the soil appears dark black, dry, firm to stiff, highly plastic expansive (black cotton) soil. The laboratory test results also show a highly plastic soil.
- ☞ The mineral identification of TP-3(0-2.0m) shows quartz 81.6% and dickite 18.4%. The soil description during field investigation was light grayish, wet soft and highly to extremely plastic expansive clay. The laboratory test result also shows that the soil has high plasticity and low permeability. In addition the in situ unconfined compresive strength value measured in the field shows an average of 375Kpa, indicating a soil has with high strength. Therefore, the laboratory result 81.6 % of quartz is difficult to accept.

Identification of clay minerals using Casagrande's PI-LL Chart

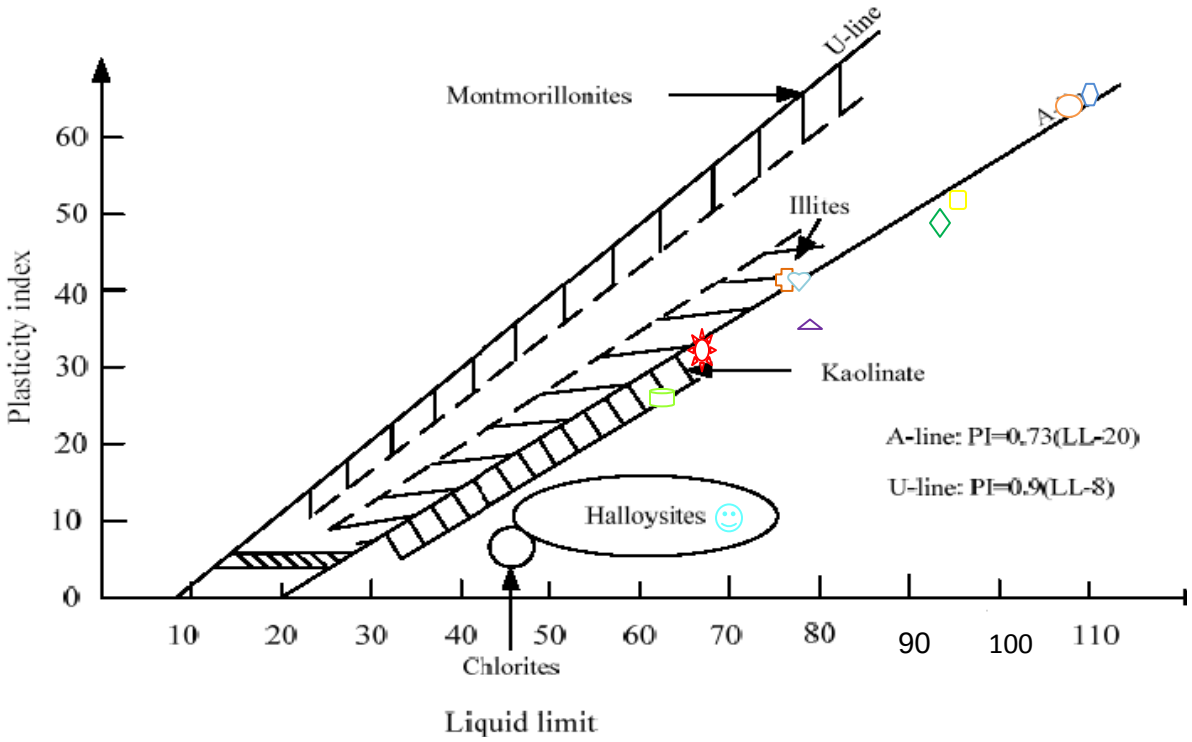


Fig.3.4 Plot of clay minerals on Casagrande's chart (Chleborad, 2005).

Table 3.26 Soil sample LL-PI laboratory test data

ChebeWeregenu Sanitary Landfill Site Soil Data					
Symbol	Test Pit No.	Depth(m)	LL %	PI %	Clay Mineral Group
◇	TP-1	0.0-1.30	91.70	46.15	Kaolinate
○	TP-1	1.30-2.0	105.28	62.97	Illite group
△	TP-2	1.20-2.0	78.30	33.80	Kaolinate
⬯	TP-3	0.0-2.00	106.30	64.32	Illite group
□	TP-4	0.0-2.00	95.32	49.61	Kaolinate
✚	TP-5	0.0-1.20	75.10	41.09	Illite group
⬭	TP-5	1.20-2.0	62.63	23.42	Kaolinate
✸	TP-6	0.0-1.20	65.62	31.03	Marginal between Illite and Kaolinate
♡	TP-7	3.50-4.0	76.63	37.93	Marginal between Illite and Kaolinate
☺	TP-8	1.87-3.13	69.00	13.58	Halloysites

☞ The laboratory soil test results of Chebe Weregenu Sanitary Landfill Site, which was presented above were plotted on a Casagrande LL-PI Chart in figure 3.4 in order to identify the clay mineral types. Accordingly, the clay mineral group respective ranges were given in the table and figure above. Details of the clay mineral group are given in table 3.30 above.

(iii) Environmental aspect

Water Analysis

The water quality laboratory test results of Chebe Weregenu Sanitary Landfill Site are given in table 3.12 and 3.13.The hydrochemistry data for one groundwater and three spring water samples in the landfill area and water analyses plotted on a piper diagram are given below. Cation percentages in mg/l plotted on the left triangle, and anion percentages in mg/l plotted on the right triangle.

Table 3.27 Hydrochemistry data

Sample ID	Source	Na			K			Ca			Mg			HCO3-			Cl-			SO4-			PH
		mg/l	meq/l	%	mg/l	meq/l	%	mg/l	meq/l	%	mg/l	meq/l	%	mg/l	meq/l	%	mg/l	meq/l	%	mg/l	meq/l	%	
A	Ground water	13.5	0.587	15.17	2.50	0.064	1.65	53.20	2.65	68.49	6.90	0.568	14.68	230.6	3.78	99.21	1.00	0.028	0.740	0.090	0.002	0.05	7.50
B	Kawa Spring	12.0	0.522	12.46	1.90	0.048	1.14	56	2.79	66.57	10.08	0.83	19.80	220.21	3.61	92.00	10.92	0.31	7.90	0.19	0.002	0.051	7.19
C	Bekene Spring	13.5	0.587	21.18	7.10	0.181	6.53	38.00	1.89	68.21	1.38	0.113	4.080	148.6	2.436	98.78	1.00	0.282	1.143	0.09	0.076	0.08	6.84
D	Nebe Spring	20.0	1.54	32.22	4.70	0.120	2.51	56	2.79	58.36	8.16	0.33	6.90	236.44	3.87	92.41	10.92	0.31	7.40	0.76	0.0079	0.19	7.17

Total Sum of Cation Concentration in meq/l		% of each Cation		
Sample ID	SUM of Cation	Na+K	Ca	Mg
A	3.869	16.82	68.49	14.68
B	4.190	13.60	66.57	19.80
C	2.771	27.71	68.21	4.080
D	4.780	34.73	58.36	6.90

Total Sum of Anion Concentration in meq/l		% of each Anion		
Sample ID	SUM of Anion	HCO3	Cl	SO4
A	3.810	99.21	0.74	0.050
B	3.922	92.00	7.90	0.051
C	2.466	98.78	1.14	0.080
D	4.188	92.41	7.40	0.190

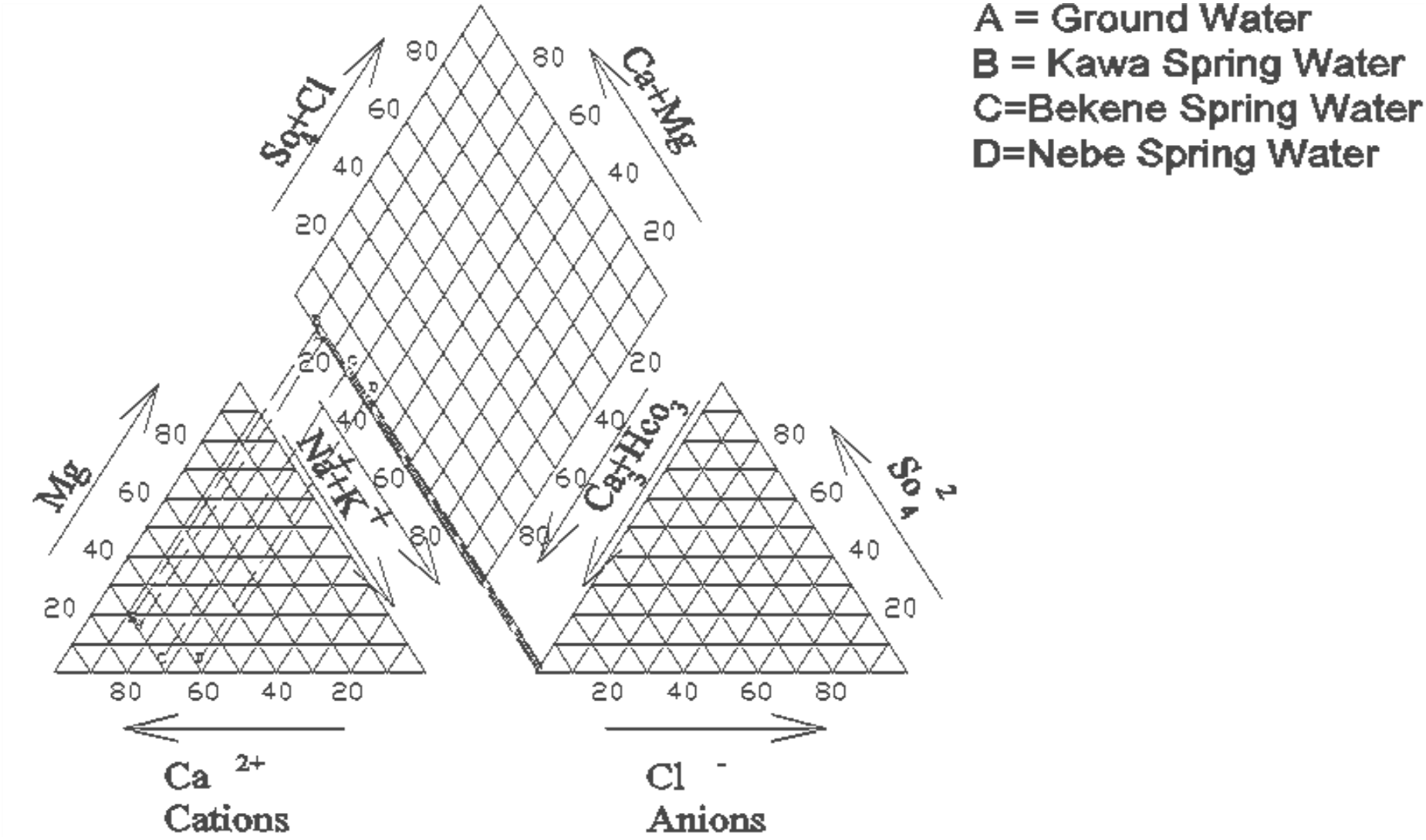


Figure 3.5: Water analysis of four samples plotted on a piper diagram

Groundwater sample, Nebe spring and Bekene spring water sample have shown Ca-Na/HCO3 water type, where as Kawa spring show Ca-Mg/HCO3 type (see figure 3.5).

☞ The water sample test results are within the WHO Standard which is fit for drinking purpose. The data is thus advised to be kept as a base line reference data for any variation that can be recorded regularly in the course of the operational life of the Chebe Weregenu Sanitary Landfill Site.

Soil Fertility

The soil fertility physical and chemical test analysis of Chebe Weregenu Sanitary Landfill site was given on table 3.14 and 3.15. The following textural classification chart was plotted in order to identify soil textures.

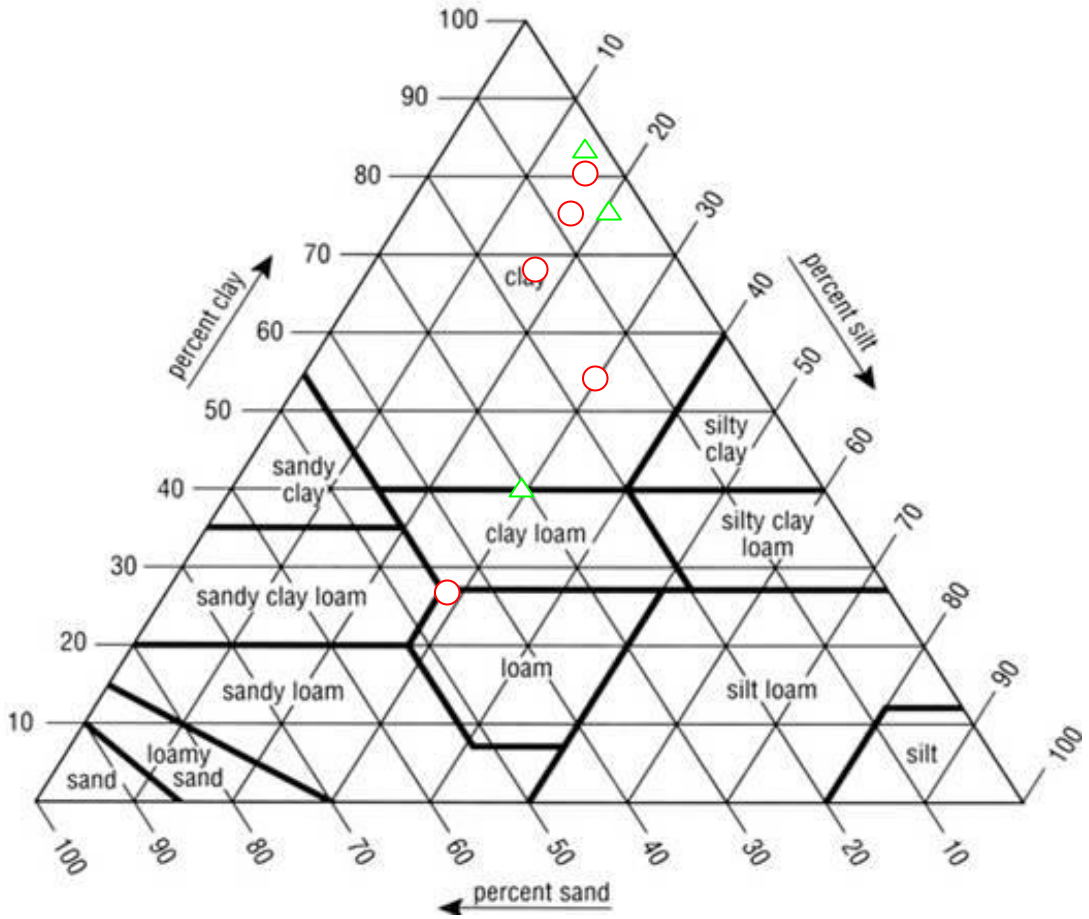


Figure 3.6 Soil Textural Triangle Classification Chart
Source: http://soils.usda.gov/technical/manual/print_version/complete.html

The green triangle in the textural triangle chart shows the result of soil texture presented in annex 2.Whereas the red circle shows the soil texture test result presented in annex 2.1, which was conducted by the researcher during undergraduate studies in 2010.

☞ Based on the soil fertility classification test results, the Chebe Weregenu Sanitary Landfill Site soil texture result was classified in clay category except TP-4(1.28-1.78m), which falls in clay loam category. In general the overall textural classes are clay.

Koshe Open Landfill Soil Fertility Data

Secondary data on physical and chemical characteristics of soil from Koshe open landfill site was collected from WWDSE Laboratory. The client was Horn of Africa Regional Environmental Center and Network. The sample was collected on October, 2011. This secondary data was used to compare and to look into possible worst-case pollution scenario for the new Chebe Weregenu Sanitary Landfill Site.

Table 3.28 Micronutrient test results of Koshe Open Landfill (Source: WWDSE Laboratory).

Sample No.										
Depth (m)	1	5	10	15	20	25	30	35	40	45
Cu(mg/kg soil)	0.36	3.72	6.73	3.74	6.49	6.23	3.49	2.53	3.64	4.68
Fe (mg/kg soil)	72.53	30.40	26.18	60.81	39.20	30.7	35.25	46.35	46.40	46.30
Mn (mg/kg soil)	84.73	80.93	74.95	45.72	69.64	72.40	105.83	92.87	92.50	92.00
Zn (mg/kg soil)	155.3	156.5	154.7	155.7	154.4	156.0	155.10	54.49	54.51	54.50
Boron	6.33	2.62	4.49	10.38	13.28	9.57	12.07	5.67	5.72	5.67

Table 3.29 Micronutrient test results of Chebe Weregenu Sanitary Landfill Project

Sample No.	**TP-1**	**TP-3**	**TP-6**
Depth (m)	0.0-1.3	0.0-2.0	0.0-1.2
Cu(mg/kg soil)	1.62	1.15	0.79
Fe (mg/kg soil)	15.16	30.77	6.85
Mn (mg/kg soil)	10.13	7.50	0.26
Zn (mg/kg soil)	4.30	1.52	2.47
Boron	0.30	0.06	0.33

The Koshe open landfill site has serving for the last 45 years and is still operational. The soil micronutrients at Koshe conducted up to 45 meters deep by Horn of Africa registered high value as indicated in table 3.32. This may be due to the possibility of leachate migration through the soil. On the other hand the soil micronutrient for the new Sanitary landfill project site at Chebe Weregenu conducted up to two meters deep by the researcher registered very low value as indicated in table 3.33.

☞ The comparison of the two tables 3.32 and 3.33 demonstrate extreme pollution scenarios. This may happen on the new sanitary landfill if it is not properly designed, or constructed during the project phase or poorly managed during operation.

As indicated in the Environmental Law of Ethiopia, all persons have the right to clean and healthy environment. However, the data of Koshe clearly demonstrates the high pollution and the negative impact on the society. The Chebe Weregenu sanitary landfill project can learn from Koshe and use the extreme scenarios and in particular the base line data to ensure clean and healthy environment during the project and operational life of the sanitary landfill.

CHAPTER – 4 A REVIEW OF FEASIBILITY STUDIES, GAP, GAP ANALYSIS AND GAP FILLING

4.1 A review of previous feasibility studies

Introduction

In the present research two feasibility study documents on Chebe Sanitary Landfill project are presented. These are feasibility studies conducted by Geological Survey of Ethiopia (GSE, 2010) and by POYRY, 2011. The feasibility studies were reviewed and some gaps on the studies were identified.

4.1.1 Review of Feasibility study by Geological Survey of Ethiopia April, 2010

The main objective of this study was to carry out the feasibility study for Chebe Weregenu Site to achieve the following specific targets.

- To map lithologic boundaries within the landfill site and subsurface structural features;
- To delineate aquifer beds and determine depth to ground water table, flow directions of the ground water and permeability of the top part of the geologic sections;
- Explore construction raw material in nearby localities.

In the field investigation the above mentioned study was conducted from geological, engineering geological, hydrogeological and geophysical point of view.

From geological point of view, a geologic map of the project area was made which shows Tertiary basalt, pyroclastic rocks and Quaternary soil.

From engineering geology point of view, the engineering geology map of the site was done. Different laboratory soil tests were conducted using three undisturbed soil samples and five disturbed soil samples from five test pits, each having a depth of Five meters. The Chebe Weregenu sanitary land fill site is entirely covered by residual soil mainly black cotton soil. The permeability value of the residual soil covering the landfill site ranges from $1.164x10^{-4}$ to

$2.329x10^{-4}$, which indicates the soil is semi-pervious. The liquid limit value of the residual soil varies from 57 to 100%, which indicates the soil has high plasticity.

From hydrogeology point of view, permeability classifications were conducted, water quality analysis and anticipated impact on the environment was conducted. The findings indicate that the water is fit for drinking purpose. With respect to the impact on the environment, the residual soil and the pyroclastic deposits (tuff and ignimbrites) are permeable and can transmit leachate and bacteria to the nearby boreholes and springs.

From geophysical point of view, the study applied electrical resistivity and magnetic method for the surface and subsurface. The finding indicated that the groundwater table at the site is estimated to be as deep as 60 meters. This suggests that the probability of interaction of waste disposal with groundwater is relatively less, which also means the groundwater could be safe from pollution.

Finally concluded that the Chebe Weregenu site is fit for sanitary landfill application based on:

- Site flatness, presence of no crossing stream and no significant geological structures (faults, major joints and structures).
- From the analysis of resistivity sounding data interpretation, the local geology underlying the area is represented by three geo-electric layers with distinct resistivity values: the upper part shows 1-7meters thick black cotton soil with a low resistivity of 6 to 15Ω-m, the intermediate layer shows 25meters thick weathered tuff with a resistivity values of 24-34 Ω-m and the bottom layer which is weathered ignimbrite with a resistivity of 55-102 Ω-m.
- From the hydro-geological point of view, the lithologic units in the area are found to be low to moderately permeable.
- From test pit excavation and geophysical investigation the thickness of the residual soil in the area is 1 to 7m, which indicates that there is sufficient thickness of soil to protect leakages of leachate underground. The residual soil is generally impervious.

- Brown clay deposit with an average thickness of 30 meters at a distance of about 1.5 km northeast of the landfill site. It has an estimated reserve of 750,000 m^3 with a permeability value of $1.97x10^{-4}$ cm/sec which is indicated as semi-pervious.

The recommendations made from the above mentioned study are;

- It is proposed that compaction of the residual soil should be made. Besides, proper implementation of artificial synthetic membrane lining and dyking during construction to improve the water tightness of the surface (cap) material is also proposed.
- It is also recommended to regularly monitor the groundwater chemistry and use the present hydrochemistry data as the base line.

4.1.2 Review of Feasibility Study by POYRY October, 2011

The objective of this study was to provide a comprehensive overview of the constraints surrounding the development of a new sanitary landfill in Sendafa. This study also identifies and defines potential adverse effects to human health and to the environment caused by the construction and operation of a new landfill, and recommends adequate measures to avoid or mitigate these effects.

The study used secondary data from GSE, 2010, regarding physical characteristics like geological, hydro geological, hydrological and water provision.

The above mentioned study discusses natural environment, anthropogenic environment, airport management and bird aircraft strike, legal provisions and permitting requirements and social aspects.

Finally, the above mentioned study concluded following physical characteristics;

Extensive technical investigations were carried out over the area, including electrical resistivity sounding, boreholes and test pit excavations. Results show three geo-electric layers with distinct responses. The top layer is made of residual soil, has a permeability ranging from $1.164x10^{-4}$ to $2.329x10^{-4}$ cm/sec, which indicates the soil is semi-pervious and does not provide adequate hydrogeological protection. The underlying formation consists of a thick layer of welded ignimbrites that are completely impervious and confine the lower basalt aquifer found relatively

deep (60 meters below surface) with a head of 50 to 100 meters. In this perspective, the contamination of the main aquifer by surface water or leachate is impossible. However, attention must be paid to the surface aquifers often used by local communities for agricultural purposes or as water holes for cattle. Thus, flooding and geotechnical instability are not considered as a high risk.

- No major geological structures (faults, major joints and fractures) are detected within and in the immediate surroundings of the landfill site.
- Hydrogeologically, the area around the landfill is not seen as suitable for well field development.
- The aquifer is entirely confined.

Therefore, finally it was concluded that the area is adequate for the development of a landfill".

4.1.3 Strength and Gaps of the Feasibility studies

An assessment was made on the feasibility studies of Chebe Weregenu Sanitary landfill site. Accordingly, the strength and the gaps of the respective studies are given below.

(i) Feasibility study by Geological Survey of Ethiopia

Strength of the study

The field investigation was done in four major areas: geology, engineering geology, hydrogeology and in geophysics. In addition, geological, engineering geological and hydrogeological maps were made. Soil and water samples were taken and analyzed. Further borrow area was investigated for construction raw material. Surface and subsurface conditions of the area were also assessed. Finally conclude that Chebe Weregenu sanitary landfill site is feasible for sanitary landfill application.

Gaps of the study

From engineering geological point of view, as stated by GSE, 2010 the Chebe Weregenu sanitary landfill site is entirely covered by residual soil mainly black cotton soil. Test pits excavated within the area revealed that the top 1-5 meters is underlain by black cotton soil. Below the black cotton soil there is tuff, which is silty clay size in composition. The total thickness of black cotton soil and tuff is 7 meter. The liquid limit value of the residual soil varies from 57 to 100%, which indicates the soil has high plasticity.

In addition GSE (2010) indicated that the permeability value of this black cotton soil changes from $1.16x10^{-4}$ cm/sec to $2.32x10^{-4}$ cm/sec, which indicates the soil is semi-permeable. In order to improve the water tightness of the residual soil proper compaction is necessary during construction of the landfill. The thickness of the residual soil (1-7 meters) is sufficient to protect leakage of leachates underground. From geophysical investigation result the groundwater level is inferred to be over 100 meters deep. This means risk of groundwater pollution is minimum.

Moreover the liquid limit value of cs1 and cs2 samples (construction raw materials to be used as a cap) from the brown clay soil have values of 57-87%. This value indicates the soil is of high plasticity and compressibility, which could be due to rainy season during the field work. From general practice, brown clay is ideal used as blanket material.

"The permeability test result of sample ctp1 (cb1) is $1.97x10^{-4}$cm/sec. The soil suggested to be used as construction material is slightly permeable."

From hydrogeology point of view, under anticipated landfill impacts on the environment (GSE, 2010) stated that,

The residual soil and the pyroclastic deposits (tuff and ignimbrites) are permeable and can transmit leachate and bacteria to the nearby boreholes and springs.

(GSE, 2010) indicated that,

The thickness of the residual soil according to the results of test pit excavation and geophysical investigation is 1 to 7m, which means there is sufficient thickness of soil to protect leakages of leachates underground. The residual soil is mainly silty clay soil which is generally impervious.

In addition, the permeability of the brown clay soil is $1.97x10^{-4}$cm/sec which indicates it is semi-pervious. From general practice, brown clay soil is water tight.

(GSE, 2010) accordingly recommended that;

Proper implementation of artificial synthetic membrane lining and dyking are recommended during construction in order to improve the water tightness of the surface (cap) material.

The following are the summary of the gaps.

Based on standard requirement for clay cap and clay liner application, the permeability value is given from $1x10^{-7}$cm/sec or less. But what was given by GSE was $1.164x10^{-4}$ to $2.329x10^{-4}$. These values of permeability do not meet the requirement for sanitary landfill site application.

The value given on plasticity is 57 to 100 %, which is high plasticity. On the other hand the permeability value given was$1.164x10^{-4}$ to $2.329x10^{-4}$which is semi pervious. As per British standard Manual of Soil Laboratory Testing, clays of high plasticity are likely to have a lower permeability, which is a contradiction.

The residual soil 1-5meters is black cotton soil as given by GSE study. Black cotton soil is a highly plastic material and impermeable on the other hand GSE also stated that the residual soil is permeable and transmit leachate. This is a contradiction.

The liquid limit value of the construction cap is value of 57-87% which indicates that the soil is highly plastic and compressible. On the other hand the permeability value is slightly

permeable. These two statements are contradictory. Moreover the study recommended artificial synthetic membrane lining. This is contradictory.

(ii) Feasibility Study by POYRY February, 2011

Strength of the study

This study has looked in to the Airport Management and Bird-Aircraft Strike Hazard (BHSH). The standard requirement of a landfill being 13km away from the airport and the need to avoid any bird strike is well discussed. Landfills often attract birds, and when located near airports, it results in Bird-Aircraft Strike Hazard (BASH). Collisions with birds are a severe threat to the safety of the aviation industry. The study assessed the nature of the risk and proposed adequate preventive measures, which is necessary.

Gaps of the study

From the geological survey feasibility study reports for which this study referred regarding physical characteristics concerns stated that, 0-5meters black cotton soil and from 5-7meter found tuff and the total 0-7meters were concluded that it is a residual soil. The test report stated that the residual soil in the landfill area is highly plastic. On the other hand the permeability result given was $1.164x10^{-4}$ to $2.329x10^{-4}$cm/sec. Naturally a black cotton soil has high plasticity and has low permeability, which has a permeability result of less than 10^{-7}cm/sec based on British standard. As can be seen the permeability value and the plasticity values are contradictory. The POYRY study might have retested and clarified the contradiction.

Further on the residual soil recommended that, black cotton soil forming the top layer is not suitable for any structural work. Therefore, soil will be cleared and stockpiled for reuse as temporary and final cover.

The POYRY feasibility study accepted the physical characteristics of residual soil from the feasibility study conducted by GSE in 2010 as final. It did not put any effort to check the GSE study. On the whole, the POYRY feasibility study did not substantiate the feasibility of the site, for sanitary landfill application both from the geotechnical and environmental aspects based on

primary data. Given the gaps of GSE study indicated above, POYRY's adoption of GSE feasibility study also demonstrated a gap.

4.2 Feasibility studies gap, gap analysis and gap filling

Introduction

In this chapter the gaps filled by the present research study on the gap identified in the feasibility studies conducted by Geological Survey of Ethiopia and another study conducted by POYRY is presented in the following table.

Table 4.1Standard requirements, Gaps of Geological Survey and Gap filling by the present research

S.N.	Described by Geological Survey of Ethiopia	Current Site Investigation	Standard Requirements for landfill application as per given in table 5.9	Gap/Variation	Gap Filling
1.	Chebe landfill Liner permeability value ranges from $1.16x10^{-4}$ cm/sec to $2.32x10^{-4}$ cm/sec.	Chebe landfill Liner permeability value ranges from $7.76X10^{-7}$ cm/sec to $1.085X10^{-8}$ cm/sec. (please refer table 3.18)	The standard permeability requirement for sanitary landfill Liner is $\leq 1X10^{-7}$cm/sec.	The permeability value given by the Geological survey is below standard requirement	The permeability value given by the researcher meets the standard requirement
2.	Chebe landfill Cap permeability value $1.97x10^{-4}$cm/sec.	Chebe landfill Cap permeability value ranges from $1.257X10^{-6}$ cm/sec to $6.99X10^{-8}$ cm/sec. (Please refer table 3.18)	The standard permeability requirement for sanitary landfill Cap is $\leq 1X10^{-7}$cm/sec.	The permeability value given by the Geological survey is below standard requirement	The average value of the permeability of the two pits about 10mts apart each other an average value of $4.12X10^{-7}$cm/sec.

Table 4.2 Standard requirements, Gaps of Geological Survey and Gap filling by the present research

S.N.	Site investigation by Geological Survey, the National Consultant	Current Site Investigation	Standard Requirements for landfill application as per British Standard given in Figure 1.2	Gap Filling	Remarks
1.	Artificial synthetic membrane lining and dyking are recommended during construction in order to improve the water tightness of the cap material.	The existing average soil permeability value, $4.12X10^{-7}$ cm/sec does not allow leakage	The permeability classification lies impermeable and the drainage characteristic lies practically impervious.	By applying a proper compaction the available cap material is suitable and may not allow leakage into the landfill. The synthetic membrane may be very expensive and redundant given the permeability value.	Synthetic materials allow less leakage but are difficult to protect from damage, whereas clay liners are not easily damaged. Hence clay is preferred as a liner in such landfills.

Table 4.3 Site investigation, Gap by Geological Survey and Gap filling by the present research

S.N.	Site investigation by Geological Survey, the National Consultant	Current Site Investigation	Gap/Variation	Gap Filling	Remarks
1.	As per the test pit excavation of the Chebe landfill site, the top 1-5meters is entirely covered by Black Cotton Soil.	Six test pits were excavated within the landfill site. The soil profiles show; black cotton and tuff materials. For details please refer photos given below and soil description given on annex-5	Based on actual site condition from excavated test pits the soil profile is not uniform.	Based on excavated test pits, confirmed that there are not only black cotton soil 1-5m.But different soil profiles, black cotton and tuff materials with different colors within a test pit.	_

Table 4.4 Sit investigation, Gap by POYRY and Gap filling by the present research

S.N.	Site investigation by POYRY, the International Consultant	Current Site Investigation	Gap/Variation	Gap Filling	Remarks
1.	No site investigation was conducted by POYRY at all. Referred Geological Survey Study and accepted 1-5meters black cotton soil.	Six different test pits were excavated within the landfill site. The soil profiles show; black cotton and tuff materials. For details please refer photos given below in plate 6 and soil description given on annex -5	Based on actual site condition from excavated test pits the soil profile is not uniform. POYRY didn't do any site investigation to check and prove the GSE study.	Based on excavated test pits, confirmed that there are not only black cotton soil 1-5m. But different soil profiles, black cotton and tuff materials with different colors within a test pit.	Feasibility study of a high investment project should be based on a proper site investigation, test and techno economic analysis
2.	The top black cotton soil is not suitable for any structural work and hence recommended clearing all black cotton soil and stockpiled for reuse as temporary and final cover.	1-5 meters is not at all black cotton soil based on pit excavation.(Please refer photos)	Cutting and removing 1-5 meters depth of black cotton soil with an area of 136.6 hectare might be very expensive.	The tuff material can be reinforced by applying proper compaction.	Feasibility study of a high investment project should be based on a proper site investigation, test and techno economic analysis.
3.	No site investigation was conducted by POYRY regarding air, water and soil as a base line for future reference on the environmental aspects.	Conducted site investigation and collected soil and water samples from Chebe landfill site and conducted laboratory tests from environmental point of view.	POYRY did not do site investigation.	Established base line data on soil and water From environmental point of view.	Feasibility study of a high investment project should be based on a proper site investigation, test and techno economic analysis

Plate 6: Different test pits at site

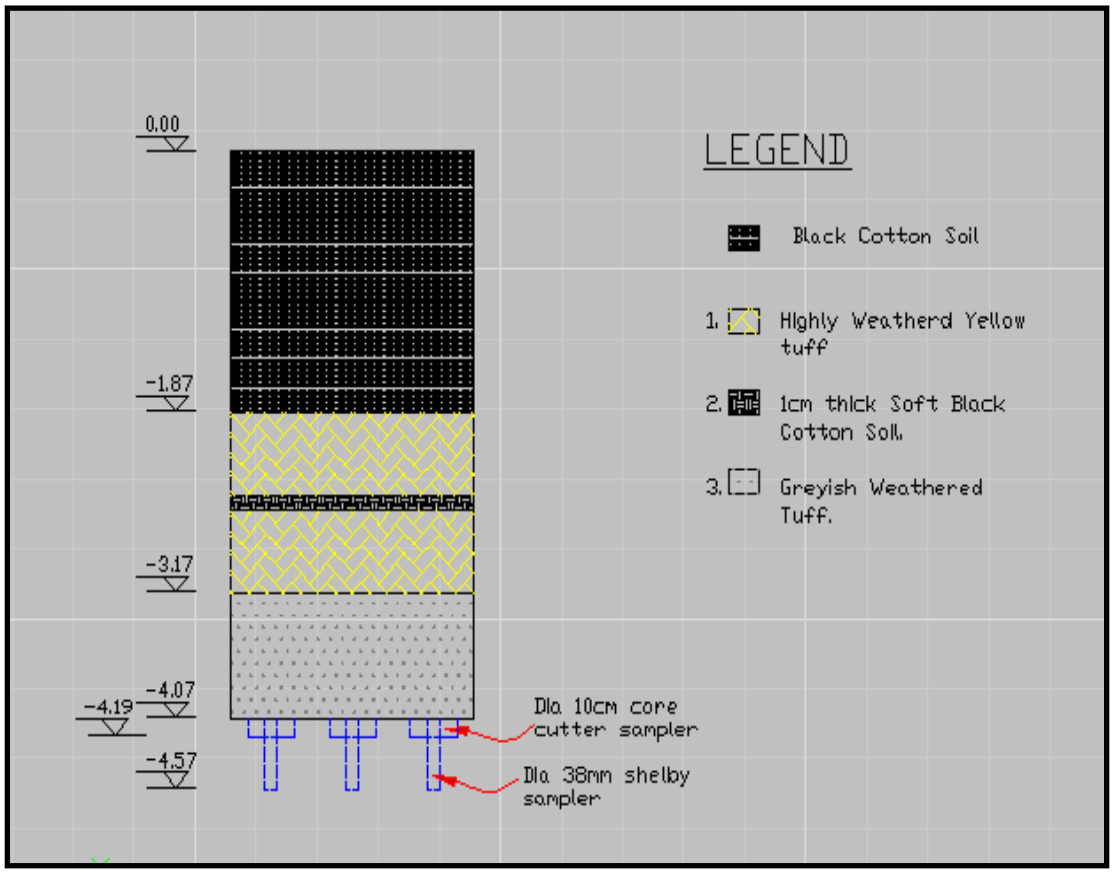


Fig.4.1Test Pit No. 8 profile from 0 - 4.5m

CHAPTER – 5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

- From hydrogeological perspective, the lithologic units in the landfill site are found to be very low permeability which is an average of $1x10^{-8}$cm/sec. This value meets the standard requirement for sanitary landfill application, < $1x10^{-7}$cm/sec. Based on the geophysical data, the groundwater table in the site is estimated to below 60 meters. The very low permeability and the deep groundwater table indicate that the possibility of pollution of groundwater is minimal.

- Permeability is the main gap in the feasibility studies which is a very basic parameter for the selection criteria of the Chebe Weregenu sanitary landfill site when clay liner and clay cap are considered. The correct permeability of the site, which was determined in this study, meets the standard requirement and as a result filled the gap noted in the feasibility studies

- When analysed from a geotechnical investigation perspective, the laboratory soil test results of Chebe Weregenu sanitary landfill site; minimum clay content, minimum fines, plasticity Index, coefficient of permeability, and maximum particle sizes comply with the requirements for compacted Clay Liner. The liquid limit value of the seven tests out of the ten test pits also comply with the landfill standard requirement. However, two test pit results do not comply with the standard requirements.

- In addition in this research study further geotechnical parameters which are very basic for foundation structure like strength test, consolidation test, porosity, shrinkage limit, compaction test, unit weight, specific gravity, natural moisture content, water absorption, swelling and free swell are checked against British standard. Based on the standard requirements most of them comply with the standard. However some of the plasticity, water absorption and moisture content test results are high, some of the shear strength value also very low. These parameters require further retest during design phase by taking more samples at different depths.

- From environmental point of view, the water quality analysis test result of Chebe Weregenu Sanitary Landfill Site, which is fit for drinking water based on WHO standard can be used as a reference point for future variance analysis during the operation phase of the landfill site. Koshe current soil data can also be used as a worst-case scenario for future pollution measurement and monitoring.

- From the physical and chemical characteristics of the clay cap cover, the landfill can be beautified and be used for recreational purpose upon completion of the landfill.

- The Chebe Weregenu landfill site can serve economically those residents of Addis Ababa and surrounding towns with in the radius of 20km. For those residents far away the site may not be economically feasible. It may require further selection of additional sites based on prefeasibility and feasibility studies.

5.2 Recommendations

As the Chebe Weregenu Sanitary Landfill project is just at the start up of the design phase, it is highly recommended that;

- Those sanitary landfill requirements found fit in this research to be further checked and reconfirmed based on more representatives and with drill based samples.
- Those parameters found out of the range of the standard requirement to be checked again with more samples and borehole data. If the same no conformance to standard requirements exists, take mitigation measures by generating alternative design solutions and select that best fit technical and economical requirements.
- Use different laboratories for testing to avoid or minimize man made errors.
- A design review should be conducted at every stage of the work involving an independent and qualified consultant or a team of multidisciplinary professionals with geologist, engineering geologist, environmentalist and others related to the landfill project.
- Investigate regularly the water quality from locations adjacent to the landfill site and establish variance in the operation life of the landfill to determine leachate contamination into the ground water.
- Use the fertility of the clay cover (landfill cover) to beautify the sanitary landfill with shallow root plants after completion.
- Look into the study of an additional sanitary landfill site for those residents of Addis Ababa 20 kilometers away from Chebe Weregenu.

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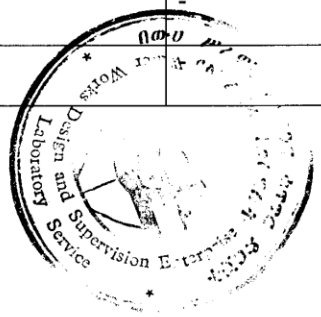
Annex 1: Standard Procedures and Summary of Test Results for Soil Mechanics

This report presents Summery of laboratory test results of soils taken from Chebe Weregenu Sanitary Landfill Site. The test results are Grain Size Analysis, Atterberg Limit, Shrinkage Limit, Specific Gravity, Free Swell, Porosity, Natural Moisture Content, Unit Weight, Dispersion, Proctor, Consolidation, Permeability, Direct Shear, Unconfined Compression Strength and Swelling Pressure.

The soil tests are carried out following the appropriate sample preparation and testing procedures. The following are the standard procedures followed to carry out the analysis.

1.1 Standard Procedures

	Type of Test	Standard
1.	Grain Size Analysis-Hydrometer & Wet Sieve	BS Test 7(B) & 7(D)
2.	Atterberg Limit	BS Test 2(A) & 2(B)
3.	Shrinkage Limit	BS Test 5
4.	Specific Gravity	BS 1377:1967 Test 6(B)
5.	Free Swell	Gibb' & Holtz (1956) s
6.	Porosity	-
7.	Natural Moisture Content	BS Test 1(A)
8.	Unit Weight	-
9.	Dispersion	Sherard et al (1976)
10.	Proctor Test	BS 1377:1975,Test 12 & 13
11.	Oedometer Consolidation	BS 1377:1975,Test 17
12.	Permeability	ASTM D2434
13.	Direct Shear	-
14.	Unconfined Compression Strength	-
15.	Swelling Pressure	



Annex 1.1 Atterberg Limit Graphs of Chebe

በውሃ ሥራዎች ዲዛይንና ቁጥጥር ድርጅት
የሳቦራቶሪ ክገልግሎት ንዑስ የሥራሂደት

Water Works Design and Supervision Enterprise Laboratory service Sub Process

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Soil & Material Testing Section

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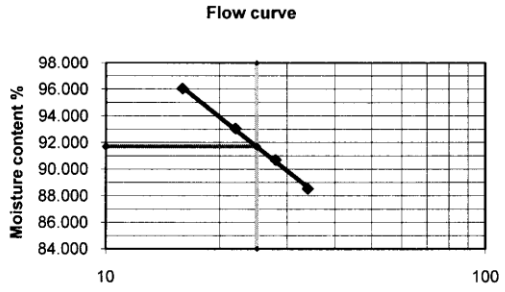
Project : Geological & Environmental Appraisal for Chebe Weregenu Sanitary Landfill Site
Client : Netsanet Mengistie,AAU
Sample type : Disturbed
Test Pit No. TP-1
Test type : Atterberg Limit
Depth (m): 0.0-1.30
Date : 25/11/2011
Location: 491845E:0999586N, 2481m
Purpose : Clay Liner Application

LIQUID AND PLASTIC LIMIT
DETERMINATIONS
DATA AND COMPUTATION SHEET

Type of test	LL	LL	LL	LL
Conteiner No.	15	19	15	13
No. of Blows	34	28	22	16
Wt.of sample + Tare wet	37.150	26.780	26.560	28.010
Wt.of sample + Tare dry	27.360	21.810	21.600	22.420
Wt.of water	9.790	4.970	4.960	5.590
Tare	16.300	16.330	16.270	16.600
wt.of dry soil	11.060	5.480	5.330	5.820
Water content %	88.517	90.693	93.058	96.048

Type of test	PL	PL	
Conteiner No.	11	10	
Wt.of sample + Tare wet	27.270	27.400	
Wt.of sample + Tare dry	23.870	23.990	
Wt.of water	3.400	3.410	
Tare	16.390	16.520	
wt.of dry soil	7.480	7.470	
Water content %	45.455	45.649	45.552



L.Limit	91.70%
P.limit	45.55%
P.Index	46.15%

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Soil & Material Testing Section

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Addis Ababa
Ethiopia

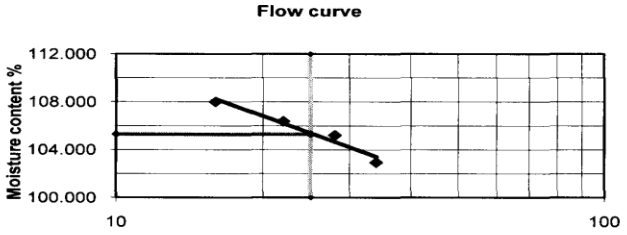
Project : Geological & Environmental Appraisal for Chebe Weregenu Sanitary Landfill Site
Client : Netsanet Mengistie,AAU
Test Pit No. TP-1
Depth (m): 1.30 2.0
Location: 491845E:0999586N, 2481m

Sample type : Disturbed
Test type : Atterberg Limit
Date : 28/11/2011
Purpose : Clay Liner Application

LIQUID AND PLASTIC LIMIT
DETERMINATIONS
DATA AND COMPUTATION SHEET

Type of test	LL	LL	LL	LL
Conteiner No.	1	4	6	17
No. of Blows	34	28	22	16
Wt.of sample + Tare wet	34.240	35.360	36.860	34.610
Wt.of sample + Tare dry	25.160	25.860	26.350	25.440
Wt.of water	9.080	9.500	10.510	9.170
Tare	16.340	16.830	16.470	16.950
wt.of dry soil	8.820	9.030	9.880	8.490
Water content %	102.948	105.205	106.377	108.009

Type of test	PL	PL	
Conteiner No.	5	6	
Wt.of sample + Tare wet	29.340	29.350	
Wt.of sample + Tare dry	25.420	25.570	
Wt.of water	3.920	3.780	
Tare	16.310	16.480	
wt.of dry soil	9.110	9.090	
Water content %	43.030	41.584	42.307



L.Limit	105.28%
P.limit	42.31%
P.Index	62.97%

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Ethiopia

Project : Geological & Environmental Appraisal for Chebe Weregenu Sanitary Landfill Site
Client : Netsanet Mengistie,AAU
Test Pit No. TP-2
Depth (m): 1.20-2.0
Location: 491843E:0999589N, 2467m

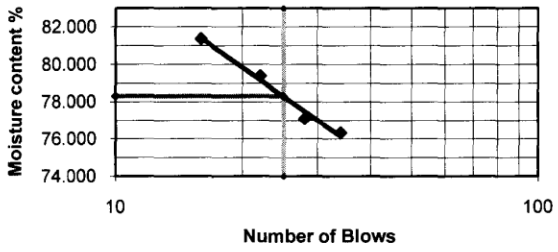
Sample type : Disturbed
Test type : Atterberg Limit
Date : 25/11/2011
Purpose : Clay Liner Application

LIQUID AND PLASTIC LIMIT
DETERMINATIONS
DATA AND COMPUTATION SHEET

Type of test	LL	LL	LL	LL
Conteiner No.	15	8	57	18
No. of Blows	34	28	22	16
Wt.of sample + Tare wet	37.530	35.500	36.660	36.960
Wt.of sample + Tare dry	28.530	27.120	27.760	27.880
Wt.of water	9.000	8.380	8.900	9.080
Tare	16.740	16.250	16.550	16.720
wt.of dry soil	11.790	10.870	11.210	11.160
Water content %	76.336	77.093	79.393	81.362

Type of test	PL	PL	
Conteiner No.	7	8	
Wt.of sample + Tare wet	30.200	30.600	
Wt.of sample + Tare dry	25.950	26.150	
Wt.of water	4.250	4.450	
Tare	16.410	16.140	
wt.of dry soil	9.540	10.010	
Water content %	44.549	44.456	44.502

Flow curve



L.Limit	78.30%
P.limit	44.50%
P.Index	33.80%

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Ethiopia

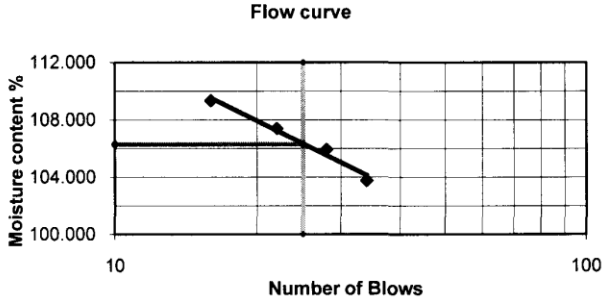
Project : Chebe Sanitary Landfill Site
Client : Netsanet Mengistie,AAU
Test Pit No. TP-3
Depth (m): 0.0-2.0
Location: 491899E:0998562N, 2476m

Sample No. _
Sample type : Disturbed
Test type : Atterberg Limit
Date : 18/11/2011
Purpose : Clay Liner Application

LIQUID AND PLASTIC LIMIT
DETERMINATIONS
DATA AND COMPUTATION SHEET

Type of test	LL	LL	LL	LL
Conteiner No.	70	98	3'	60
No. of Blows	34	28	22	16
Wt.of sample + Tare wet	25.660	29.520	28.340	28.980
Wt.of sample + Tare dry	20.990	22.750	22.260	22.200
Wt.of water	4.670	6.770	6.080	6.780
Tare	16.490	16.360	16.600	16.000
wt.of dry soil	4.500	6.390	5.660	6.200
Water content %	103.778	105.947	107.420	109.355

Type of test	PL	PL	
Conteiner No.	11	15	
Wt.of sample + Tare wet	29.050	28.380	
Wt.of sample + Tare dry	25.310	24.770	
Wt.of water	3.740	3.610	
Tare	16.390	16.180	
wt.of dry soil	8.920	8.590	
Water content %	41.928	42.026	41.977



L.Limit	106.30%
P.limit	41.98%
P.Index	64.32%

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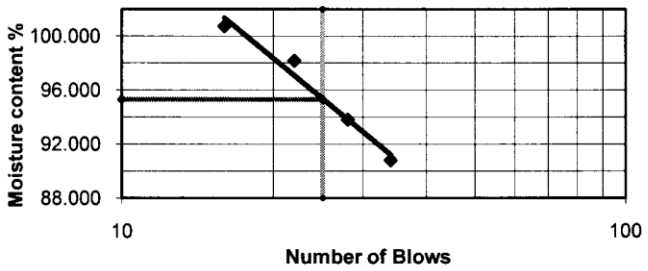
Project : Geological & Environmental Appraisal for Chebe Weregenu Sanitary Landfill Site
Client : Netsanet Mengistie,AAU Sample type : Disturbed
Test Pit No. TP-4 Test type : Atterberg Limit
Depth (m): 0.0-2.0 Date : 18/11/2011
Location : 492460E:0997510N, 2452m Purpose : Clay Liner Application

LIQUID AND PLASTIC LIMIT
DETERMINATIONS
DATA AND COMPUTATION SHEET

Type of test	LL	LL	LL	LL
Conteiner No.	82	V	21	10
No. of Blows	34	28	22	16
Wt.of sample + Tare wet	33.240	25.710	26.450	24.990
Wt.of sample + Tare dry	25.150	21.160	21.540	20.860
Wt.of water	8.090	4.550	4.910	4.130
Tare	16.240	16.310	16.540	16.760
wt.of dry soil	8.910	4.850	5.000	4.100
Water content %	90.797	93.814	98.200	100.732

Type of test	PL	PL	
Conteiner No.	M4	25	
Wt.of sample + Tare wet	30.640	28.960	
Wt.of sample + Tare dry	26.330	24.990	
Wt.of water	4.310	3.970	
Tare	16.960	16.250	
wt.of dry soil	9.370	8.740	
Water content %	45.998	45.423	45.711

Flow curve



L.Limit	95.32%
P.limit	45.71%
P.Index	49.61%

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Ethiopia

Project : Geological & Environmental Appraisal for Chebe Weregenu Sanitary Landfill Site
Client : Netsanet Mengistie,AAU
Test Pit No. TP-5
Depth (m): 0.0-1.20
Location :491800E:0997398N, 2454m

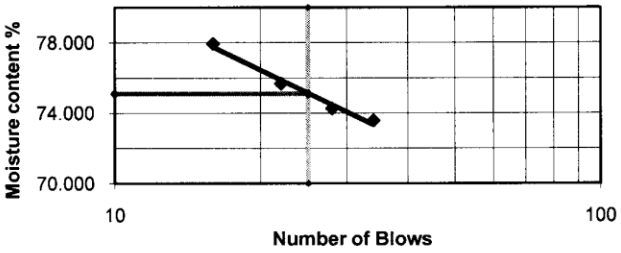
Sample type : Disturbed
Test type : Atterberg Limit
Date : 25/11/2011
Purpose : Clay Liner Application

LIQUID AND PLASTIC LIMIT
DETERMINATIONS
DATA AND COMPUTATION SHEET

Type of test	LL	LL	LL	LL
Conteiner No.	99	N	D	14
No. of Blows	34	28	22	16
Wt.of sample + Tare wet	37.730	36.050	34.640	36.290
Wt.of sample + Tare dry	28.730	27.800	26.740	27.490
Wt.of water	9.000	8.250	7.900	8.800
Tare	16.500	16.690	16.300	16.200
wt.of dry soil	12.230	11.110	10.440	11.290
Water content %	73.590	74.257	75.670	77.945

Type of test	PL	PL	
Conteiner No.	3	4	
Wt.of sample + Tare wet	26.940	28.330	
Wt.of sample + Tare dry	24.220	25.450	
Wt.of water	2.720	2.880	
Tare	16.350	16.840	
wt.of dry soil	7.870	8.610	
Water content %	34.562	33.449	34.006

Flow curve



L.Limit	75.10%
P.limit	34.01%
P.Index	41.09%

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Addis Ababa
Ethiopia

Project : Geological & Environmental Appraisal for Chebe Weregenu Sanitary Landfill Site
Client : Netsanet Mengistie,AAU
Test Pit No. TP-5
Depth (m): 1.20-2.0
Location :491800E:0997398N, 2454m

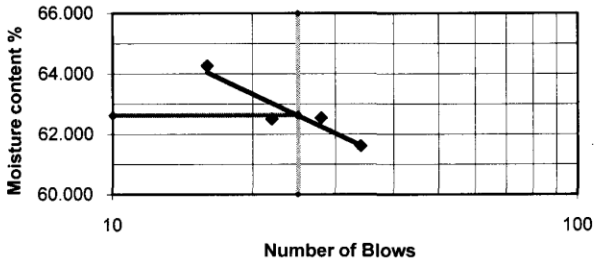
Sample type : Disturbed
Test type : Atterberg Limit
Date : 18/11/2011
Purpose : Clay Liner Application

LIQUID AND PLASTIC LIMIT
DETERMINATIONS
DATA AND COMPUTATION SHEET

Type of test	LL	LL	LL	LL
Conteiner No.	F1	18	67	16
No. of Blows	34	28	22	16
Wt.of sample + Tare wet	33.240	34.290	34.280	37.110
Wt.of sample + Tare dry	26.820	27.460	27.410	29.070
Wt.of water	6.420	6.830	6.870	8.040
Tare	16.400	16.540	16.420	16.560
wt.of dry soil	10.420	10.920	10.990	12.510
Water content %	61.612	62.546	62.511	64.269

Type of test	PL	PL	
Conteiner No.	17	H	
Wt.of sample + Tare wet	27.890	27.370	
Wt.of sample + Tare dry	24.620	24.320	
Wt.of water	3.270	3.050	
Tare	16.270	16.550	
wt.of dry soil	8.350	7.770	
Water content %	39.162	39.254	39.208

Flow curve



L.Limit	62.63%
P.limit	39.21%
P.Index	23.42%

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Ethiopia

Project : Geological & Environmental Appraisal for Chebe Weregenu Sanitary Landfill Site
Client : Netsanet Mengistie,AAU
Test Pit No. TP-6
Depth (m): 0.0-1.20
Location: 493507E: 1000070N, 2450m

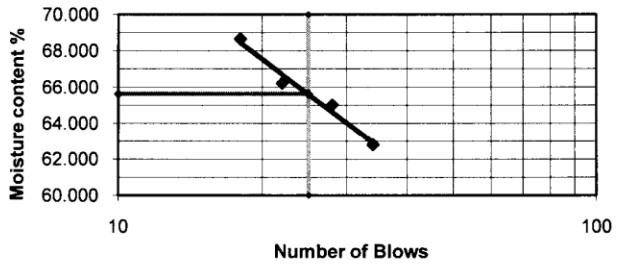
Sample type : Disturbed
Test type : Atterberg Limit
Date : 25/11/2011
Purpose : Clay Cap Application

LIQUID AND PLASTIC LIMIT
DETERMINATIONS
DATA AND COMPUTATION SHEET

Type of test	LL	LL	LL	LL
Conteiner No.	13	19	2	85
No. of Blows	34	28	22	18
Wt.of sample + Tare wet	27.020	29.300	31.400	29.200
Wt.of sample + Tare dry	22.950	24.300	25.580	23.940
Wt.of water	4.070	5.000	5.820	5.260
Tare	16.470	16.610	16.790	16.280
wt.of dry soil	6.480	7.690	8.790	7.660
Water content %	62.809	65.020	66.212	68.668

Type of test	PL	PL	
Conteiner No.	1	2	
Wt.of sample + Tare wet	30.480	31.100	
Wt.of sample + Tare dry	26.890	27.250	
Wt.of water	3.590	3.850	
Tare	16.340	16.300	
wt.of dry soil	10.550	10.950	
Water content %	34.028	35.160	34.594

Flow curve



L.Limit	65.62%
P.limit	34.59%
P.Index	31.03%

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Project : Geological & Environmental Appraisal for Chebe Weregenu Sanitary Landfill Site
Client : Netsanet Mengistie,AAU
Test Pit No. TP-7
Depth (m): 4.00
Location: 493519E:1000111N, 2440m

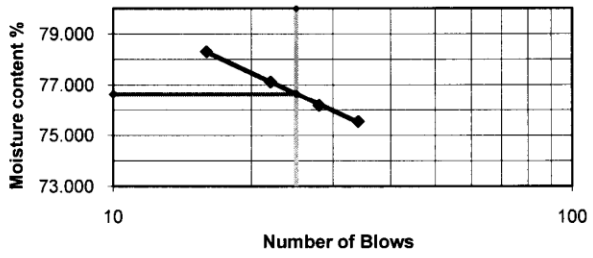
Sample type : Disturbed
Test type : Atterberg Limit
Date : 28/11/2011
Purpose : Clay Liner Application

LIQUID AND PLASTIC LIMIT
DETERMINATIONS
DATA AND COMPUTATION SHEET

Type of test	LL	LL	LL	LL
Conteiner No.	392	323	316	131
No. of Blows	34	28	22	16
Wt.of sample + Tare wet	38.610	37.330	35.810	39.270
Wt.of sample + Tare dry	28.480	27.540	26.710	28.510
Wt.of water	10.130	9.790	9.100	10.760
Tare	15.070	14.690	14.910	14.770
wt.of dry soil	13.410	12.850	11.800	13.740
Water content %	75.541	76.187	77.119	78.311

Type of test	PL	PL	
Conteiner No.	320	28	
Wt.of sample + Tare wet	27.930	27.210	
Wt.of sample + Tare dry	24.190	23.830	
Wt.of water	3.740	3.380	
Tare	14.610	15.020	
wt.of dry soil	9.580	8.810	
Water content %	39.040	38.365	38.703

Flow curve



L.Limit	76.63%
P.limit	38.70%
P.Index	37.93%

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Ethiopia

Project : Geological & Environmental Appraisal for Chebe Weregenu Sanitary Landfill Site
Client : Netsanet Mengistie,AAU
Test Pit No. TP-8
Depth (m): 1.87-3.17
Location: 491691E:0998769N, 2462m

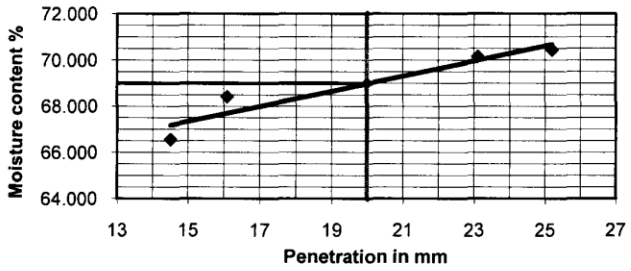
Sample type : Disturbed
Test type : Atterberg Limit
Date : 28/11/2011
Purpose : Clay Liner Application

LIQUID AND PLASTIC LIMIT
DETERMINATIONS
DATA AND COMPUTATION SHEET

Type of test	LL	LL	LL	LL
Conteiner No.	40	74	149	138
No. of Blows	14.5	16.1	23.1	25.2
Wt.of sample + Tare wet	29.180	33.660	31.030	32.610
Wt.of sample + Tare dry	23.450	25.820	24.380	25.180
Wt.of water	5.730	7.840	6.650	7.430
Tare	14.840	14.360	14.900	14.630
wt.of dry soil	8.610	11.460	9.480	10.550
Water content %	66.551	68.412	70.148	70.427

Type of test	PL	PL	
Conteiner No.	364	356	
Wt.of sample + Tare wet	31.140	27.630	
Wt.of sample + Tare dry	25.470	23.120	
Wt.of water	5.670	4.510	
Tare	14.880	15.200	
wt.of dry soil	10.590	7.920	
Water content %	53.541	56.944	55.243

Flow curve



L.Limit	69.00%
P.limit	55.42%
P.Index	13.58%

Tested by
Checked by
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ANNEX-1.2 Hydrometer Graphs

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Water Works Design and Supervision Enterprise
Laboratory service Sub Process

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Soil & Material Testing Section

Project : Geological and Environmental Appraisal for the New Chebe Weregenu Sanitary Landfill Site
Client : Netsanet Mengistie, AAU — Sam. Type : Disturbed
Location : 491845E:0999586N, 2481m — Test Type : Hydrometer
T.Pit. No. TP-1 — Date : 18/11/2011
Depth(m) : 0.0-1.30

Total mass of sample, g 50

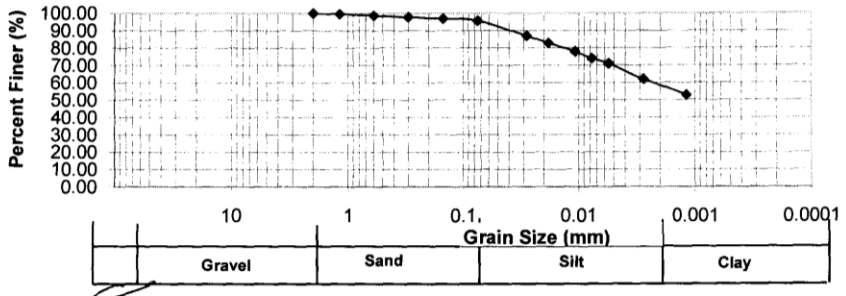
Sieve No	*Sieve Opening(mm)*	*Mass of Sieve(g)*	*Mass of sieve + Ret .soil(g)*	*Mass of Ret. soil (g)*	*Percentage Retained*	*Cumulative % Retained*	*Percentage Passing*
No 10	*2.000*	*551.100*	*551.100*	*0.000*	*0.000*	*0.000*	*100.000*
No 16	*1.180*	*538.900*	*539.110*	*0.210*	*0.420*	*0.420*	*99.580*
No 30	*0.600*	*516.700*	*517.140*	*0.440*	*0.880*	*1.300*	*98.700*
No 50	*0.300*	*488.200*	*488.620*	*0.420*	*0.840*	*2.140*	*97.860*
No 100	*0.150*	*481.900*	*482.370*	*0.470*	*0.940*	*3.080*	*96.920*
No 200	*0.075*	*459.200*	*459.750*	*0.550*	*1.100*	*4.180*	*95.820*
pan		*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*

Hydrometer Analysis

Specific Gravity 2.71 — 21.0

Elapsed Time (min)	*Actual Hydrometer Reading*	*Tenprature deg.c*	*Corrected Hydrometer Reading*	*Effective Depth (cm)*	*Coefficient K*	*Grain Size (mm)*	*Percentage Finer Combined*
2	*50.0000*	*21.0*	*43.5000*	*9.10*	*0.01328*	*0.0283*	*87.00*
5	*48.0000*	*21.0*	*41.5000*	*9.50*	*0.01328*	*0.0183*	*83.00*
15	*45.5000*	*21.0*	*39.0000*	*9.90*	*0.01328*	*0.0108*	*78.00*
30	*43.5000*	*21.0*	*37.0000*	*10.20*	*0.01328*	*0.0077*	*74.00*
60	*42.0000*	*21.0*	*35.5000*	*10.50*	*0.01328*	*0.0056*	*71.00*
250	*37.5000*	*22.5*	*31.0000*	*11.20*	*0.01312*	*0.0028*	*62.00*
1440	*32.500*	*22.0*	*26.5000*	*11.90*	*0.01297*	*0.0012*	*53.00*

Grain Size Distribution Curve,BS



Tested by :

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Water Works Design and Supervision Enterprise Laboratory service Sub Process

Soil & Material Testing Section

Project : Geological and Environmental Appraisal for the New Chebe Weregenu Sanitary Landfill Site

Client : Netsanet Mengistie, AAU — Sam. Type : Disturbed

Location : 491845E:0999586N, 2481m — Test Type : Hydrometer

T.Pit. No. TP-1 — Date : 23/11/2011

Depth(m) : 1.30-2.0

Total mass of sample, g 50

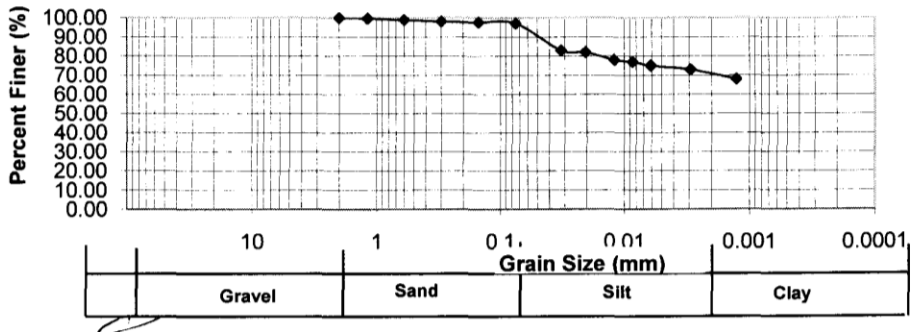
Sieve No	*Sieve Opening(mm)*	*Mass of Sieve(g)*	*Mass of sieve Ret .soil(g)*	*Mass of Ret. soil (g)*	*Percentage Retained*	*Cumulative % Retained*	*Percentage Passing*
No 10	*2.000*	*551.100*	*551.100*	*0.000*	*0.000*	*0.000*	*100.000*
No 16	*1.180*	*538.900*	*539.040*	*0.140*	*0.280*	*0.280*	*99.720*
No 30	*0.600*	*516.700*	*517.100*	*0.400*	*0.800*	*1.080*	*98.920*
No 50	*0.300*	*488.200*	*488.550*	*0.350*	*0.700*	*1.780*	*98.220*
No 100	*0.150*	*481.900*	*482.130*	*0.230*	*0.460*	*2.240*	*97.760*
No 200	*0.075*	*459.200*	*459.530*	*0.330*	*0.660*	*2.900*	*97.100*
pan		*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*

Hydrometer Analysis

Specific Gravit 2.40 — 20.0

Elapsed Time (min)	*Actual Hydrometer Reading*	*Tenprature deg.c*	*Corrected Hydrometer Reading*	*Effective Depth (cm)*	*Coefficient K*	*Grain Size (mm)*	*Percentage Finer Combined*
2	*48.0000*	*20.0*	*41.5000*	*9.50*	*0.014832*	*0.0323*	*83.00*
5	*47.5000*	*20.0*	*41.0000*	*9.60*	*0.014832*	*0.0206*	*82.00*
15	*45.5000*	*20.0*	*39.0000*	*9.90*	*0.014832*	*0.0120*	*78.00*
30	*45.0000*	*20.0*	*38.5000*	*10.00*	*0.014832*	*0.0086*	*77.00*
60	*44.0000*	*20.0*	*37.5000*	*10.10*	*0.014832*	*0.0061*	*75.00*
250	*43.0000*	*22.0*	*36.5000*	*10.30*	*0.014491*	*0.0029*	*73.00*
1440	*40.000*	*19.0*	*34.0000*	*10.70*	*0.014832*	*0.0013*	*68.00*

Grain Size Distribution Curve,BS



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Water Works Design and Supervision Enterprise
Laboratory service Sub Process

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Soil & Material Testing Section

Project : Geological and Environmental Appraisal for the New Chebe Weregenu Sanitary Landfill Site

Client : Netsanet Mengistie, AAU — Sam. Type : Disturbed

Location : 491843E:0999589N, 2467m — Test Type : Hydrometer

T.Pit. No. TP-2 — Date : 23/11/2011

Depth(m) : 1.20-2.0

Total mass of sample, g 50

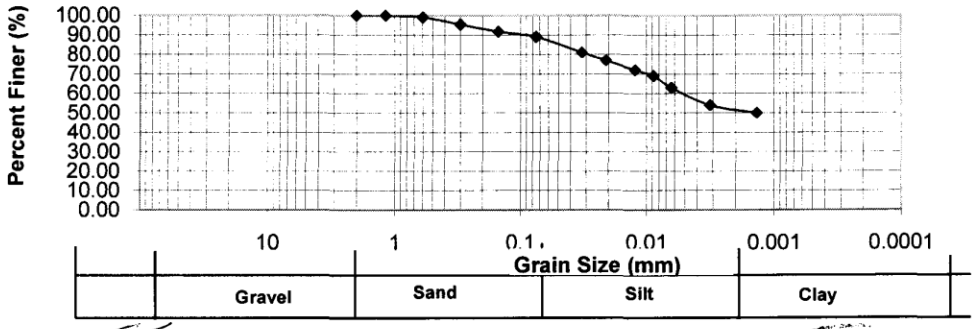
Sieve No	*Sieve Opening(mm)*	*Mass of Sieve(g)*	*Mass of sieve + Ret .soil(g)*	*Mass of Ret. soil (g)*	*Percentage Retained*	*Cumulative % Retained*	*Percentage Passing*
No 10	*2.000*	*551.100*	*551.100*	*0.000*	*0.000*	*0.000*	*100.000*
No 16	*1.180*	*538.900*	*538.930*	*0.030*	*0.060*	*0.060*	*99.940*
No 30	*0.600*	*516.700*	*517.170*	*0.470*	*0.940*	*1.000*	*99.000*
No 50	*0.300*	*488.200*	*490.060*	*1.860*	*3.720*	*4.720*	*95.280*
No 100	*0.150*	*481.900*	*483.700*	*1.800*	*3.600*	*8.320*	*91.680*
No 200	*0.075*	*459.200*	*460.560*	*1.360*	*2.720*	*11.040*	*88.960*
pan		*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*

Hydrometer Analysis

Specific Gravi 2.40 — *20.0*

Elapsed Time (min)	*Actual Hydrometer Reading*	*Tenprature deg.c*	*Corrected Hydrometer Reading*	*Effective Depth (cm)*	*Coefficient K*	*Grain Size (mm)*	*Percentage Finer Combined*
2	*47.0000*	*20.0*	*40.5000*	*9.60*	*0.014832*	*0.0325*	*81.00*
5	*45.0000*	*20.0*	*38.5000*	*10.00*	*0.014832*	*0.0210*	*77.00*
15	*42.5000*	*20.0*	*36.0000*	*10.40*	*0.014832*	*0.0124*	*72.00*
30	*41.0000*	*20.0*	*34.5000*	*10.60*	*0.014832*	*0.0088*	*69.00*
60	*38.0000*	*20.0*	*31.5000*	*11.10*	*0.014832*	*0.0064*	*63.00*
250	*33.5000*	*22.0*	*27.0000*	*11.90*	*0.014491*	*0.0032*	*54.00*
1440	*31.000*	*19.0*	*25.0000*	*12.20*	*0.014832*	*0.0014*	*50.00*

Grain Size Distribution Curve,BS



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Water Works Design and Supervision Enterprise Laboratory service Sub Process

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Project : Geological and Environmental Appraisal for the New Chebe Weregenu Sanitary Landfill Site

Client : Netsanet Mengistie, AAU — Sam. Type : Disturbed

Location : 491899E:0998562N, 2476m — Test Type : Hydrometer

T.Pit. No. TP-3 — Date : 19/11/2011

Depth(m) : 0.0-2.0

Total mass of sample, g 50

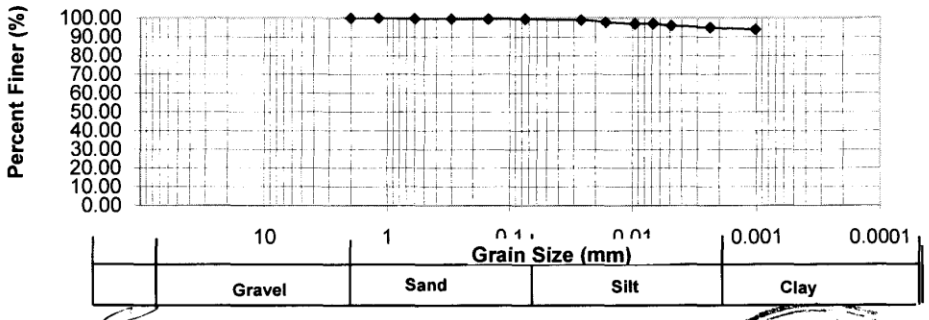
Sieve No	*Sieve Opening(mm)*	*Mass of Sieve(g)*	*Mass of sieve Ret .soil(g)*	*Mass of Ret. soil (g)*	*Percentage Retained*	*Cumulative % Retained*	*Percentage Passing*
No 10	*2.000*	*551.100*	*551.100*	*0.000*	*0.000*	*0.000*	*100.000*
No 16	*1.180*	*538.900*	*538.900*	*0.000*	*0.000*	*0.000*	*100.000*
No 30	*0.600*	*516.700*	*516.750*	*0.050*	*0.100*	*0.100*	*99.900*
No 50	*0.300*	*488.200*	*488.270*	*0.070*	*0.140*	*0.240*	*99.760*
No 100	*0.150*	*481.900*	*481.990*	*0.090*	*0.180*	*0.420*	*99.580*
No 200	*0.075*	*459.200*	*459.240*	*0.040*	*0.080*	*0.500*	*99.500*
pan		*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*

Hydrometer Analysis

Specific Gravity 2.75 — *20.0*

Elapsed Time (min)	*Actual Hydrometer Reading*	*Tenprature deg.c*	*Corrected Hydrometer Reading*	*Effective Depth (cm)*	*Coefficient K*	*Grain Size (mm)*	*Percentage Finer Combined*
2	*56.0000*	*20.0*	*49.5000*	*7.80*	*0.01325*	*0.0262*	*99.00*
5	*55.5000*	*20.0*	*49.0000*	*7.80*	*0.01325*	*0.0165*	*98.00*
15	*55.0000*	*20.0*	*48.5000*	*7.90*	*0.01325*	*0.0096*	*97.00*
30	*55.0000*	*20.0*	*48.5000*	*8.00*	*0.01325*	*0.0068*	*97.00*
60	*54.5000*	*20.0*	*48.0000*	*8.10*	*0.01325*	*0.0049*	*96.00*
250	*54.0000*	*21.0*	*47.5000*	*8.20*	*0.01309*	*0.0024*	*95.00*
1440	*53.500*	*19.0*	*47.0000*	*8.30*	*0.01342*	*0.0010*	*94.00*

Grain Size Distribution Curve,BS



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Water Works Design and Supervision Enterprise Laboratory service Sub Process

Soil & Material Testing Section

Project : Geological and Environmental Appraisal for the New Chebe Weregenu Sanitary Landfill Site

Clinent : Netsanet Mengistie, AAU Sam. Type : Disturbed

Location : 492460E:0997510N, 2452m Test Type : Hydrometer

T.Pit. No. TP-4 Date : 19/11/2011

Depth(m) : 0.0-2.0

Total mass of sample, g 50

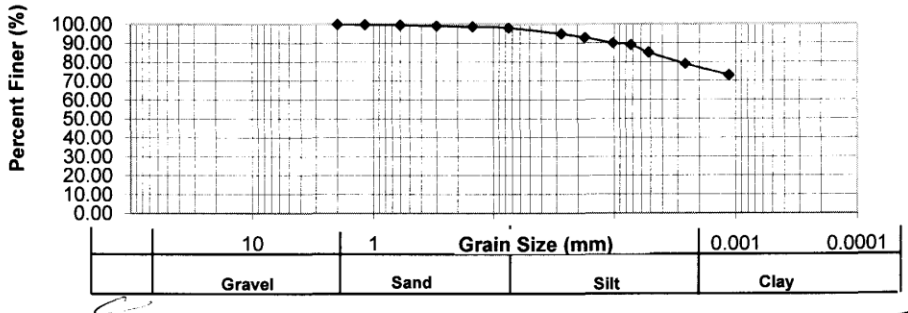
Sieve No	*Sieve Opening(mm)*	*Mass of Sieve(g)*	*Mass of sieve Ret .soil(g)*	*Mass of Ret. soil (g)*	*Percentage Retained*	*Cumulative % Retained*	*Percentage Passing*
No 10	*2.000*	*551.100*	*551.100*	*0.000*	*0.000*	*0.000*	*100.000*
No 16	*1.180*	*538.900*	*538.950*	*0.050*	*0.100*	*0.100*	*99.900*
No 30	*0.600*	*516.700*	*516.870*	*0.170*	*0.340*	*0.440*	*99.560*
No 50	*0.300*	*488.200*	*488.370*	*0.170*	*0.340*	*0.780*	*99.220*
No 100	*0.150*	*481.900*	*482.150*	*0.250*	*0.500*	*1.280*	*98.720*
No 200	*0.075*	*459.200*	*459.510*	*0.310*	*0.620*	*1.900*	*98.100*
pan		*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*

Hydrometer Analysis

Specific Gravity 2.61 *20.0*

Elapsed Time (min)	*Actual Hydrometer Reading*	*Tenprature deg.c*	*Corrected Hydrometer Reading*	*Effective Depth (cm)*	*Coefficient K*	*Grain Size (mm)*	*Percentage Finer Combined*
2	*54.0000*	*20.0*	*47.5000*	*8.50*	*0.01325*	*0.0273*	*95.00*
5	*53.0000*	*20.0*	*46.5000*	*8.70*	*0.01325*	*0.0175*	*93.00*
15	*51.5000*	*20.0*	*45.0000*	*8.90*	*0.01325*	*0.0102*	*90.00*
30	*51.0000*	*20.0*	*44.5000*	*9.00*	*0.01325*	*0.0073*	*89.00*
60	*49.0000*	*20.0*	*42.5000*	*9.30*	*0.01325*	*0.0052*	*85.00*
250	*46.0000*	*21.0*	*39.5000*	*9.80*	*0.01309*	*0.0026*	*79.00*
1440	*43.000*	*19.0*	*36.5000*	*10.30*	*0.01342*	*0.0011*	*73.00*

Grain Size Distribution Curve,BS



Tested by :

Checked by :

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Water Works Design and Supervision Enterprise Laboratory service Sub Process

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Project : Geological and Environmental Appraisal for the New Chebe Weregenu Sanitary Landfill Site

Clinent : Netsanet Mengistie, AAU — Sam. Type : Disturbed

Location : 491800E:0997398N, 2454m — Test Type : Hydrometer

T.Pit. No. TP-5 — Date : 19/11/2011

Depth(m) : 0.0-1.20

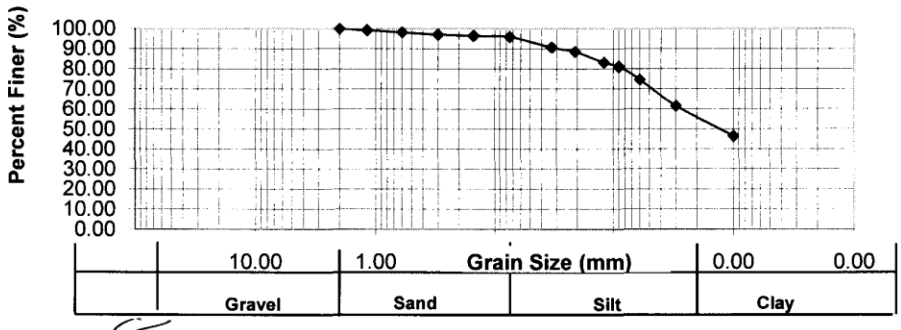
Sieve No	Sieve Opening(mm)	Mass of Sieve(g)	Mass of sieve Ret .soil(g)	Mass of Ret. soil (g)	Percentage Retained	Cumulative % Retained	Percentage Passing
No 10	2.000	551.100	551.100	0.000	0.000	0.000	100.000
No 16	1.180	538.900	539.090	0.190	0.380	0.380	99.620
No 30	0.600	516.700	517.400	0.700	1.400	1.780	98.220
No 50	0.300	488.200	488.770	0.570	1.140	2.920	97.080
No 100	0.150	481.900	482.190	0.290	0.580	3.500	96.500
No 200	0.075	459.200	459.480	0.280	0.560	4.060	95.940
pan		0.000	0.000	0.000	0.000	0.000	0.000

Hydrometer Analysis

Specific Gravi 2.33 — 20.0

Elapsed Time (min)	Actual Hydrometer Reading	Tenprature deg.c	Corrected Hydrometer Reading	Effective Depth (cm)	Coefficient K	Grain Size (mm)	Percentage Finer Combined
2	48.5000	20.0	42.0000	9.40	0.01523	0.0330	90.78
5	47.5000	20.0	41.0000	9.60	0.01523	0.0211	88.61
15	45.0000	20.0	38.5000	10.00	0.01523	0.0124	83.21
30	44.0000	20.0	37.5000	10.10	0.01523	0.0088	81.05
60	41.0000	20.0	34.5000	10.60	0.01523	0.0064	74.57
250	35.0000	22.0	28.5000	11.60	0.014863	0.0032	61.60
1440	28.000	19.0	21.5000	12.80	0.01543	0.0015	46.47

Grain Size Distribution Curve,BS



Tested by : _____

Checked by : _____

Approved by : _____

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Water Works Design and Supervision Enterprise Laboratory service Sub Process

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Soil & Material Testing Section

Project : Geological and Environmental Appraisal for the New Chebe Weregenu Sanitary Landfill Site

Clinent : Netsanet Mengistie, AAU

Sam. Type : Disturbed

Location : 491800E:0997398N, 2454m

Test Type : Hydrometer

T.Pit. No. TP-5

Date : 18/11/2011

Depth(m) : 1.20-2.00

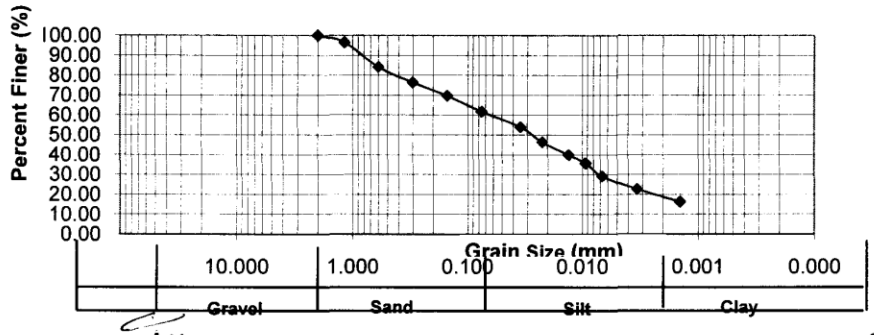
Sieve No	*Sieve Opening(mm)*	*Mass of Sieve(g)*	*Mass of sieve + Ret .soil(g)*	*Mass of Ret. soil (g)*	*Percentage Retained*	*Cumulative % Retained*	*Percentage Passing*
No 10	*2.000*	*551.100*	*551.100*	*0.000*	*0.000*	*0.000*	*100.000*
No 16	*1.180*	*538.900*	*540.660*	*1.760*	*3.520*	*3.520*	*96.480*
No 30	*0.600*	*516.700*	*522.840*	*6.140*	*12.280*	*15.800*	*84.200*
No 50	*0.300*	*488.200*	*492.130*	*3.930*	*7.860*	*23.660*	*76.340*
No 100	*0.150*	*481.900*	*485.180*	*3.280*	*6.560*	*30.220*	*69.780*
No 200	*0.075*	*459.200*	*463.170*	*3.970*	*7.940*	*38.160*	*61.840*
pan		*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*

Hydrometer Analysis

Specific Gravi *2.52* *21.0*

Elapsed Time (min)	*Actual Hydrometer Reading*	*Tenprature deg.c*	*Corrected Hydrometer Reading*	*Effective Depth (cm)*	*Coefficient K*	*Grain Size (mm)*	*Percentage Finer Combined*
2	*31.5000*	*21.0*	*25.0000*	*12.20*	*0.01391*	*0.0344*	*54.03*
5	*28.0000*	*21.0*	*21.5000*	*12.80*	*0.01391*	*0.0223*	*46.47*
15	*25.0000*	*21.0*	*18.5000*	*13.20*	*0.01391*	*0.0130*	*39.98*
30	*23.0000*	*21.0*	*16.5000*	*13.60*	*0.01391*	*0.0094*	*35.66*
60	*20.0000*	*21.0*	*13.5000*	*14.10*	*0.01391*	*0.0067*	*29.18*
250	*17.0000*	*22.5*	*10.5000*	*14.60*	*0.01391*	*0.0034*	*22.69*
1440	*14.000*	*22.0*	*7.5000*	*15.10*	*0.01391*	*0.0014*	*16.21*

Grain Size Distribution Curve,BS



Tested by :

Checked by :

Approved by :

Water Works Design and Supervision Enterprise Laboratory service

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Water Works Design and Supervision Enterprise
Laboratory service Sub Process

የአፈር ምህንድስና ክፍል | **Soil & Material Testing Section**

Project : Geological & Environmental Appraisal for Chebe Weregenu Sanitary Landfill Site
Client : Netsanet Mengistie, AAU — Sam. Type : Disturbed
Location : 493507E: 1000070N, 2450m — Test Type : Hydrometer
T.Pit. No.: TP-6 — Date :23/11/2011
Depth(m) : 0.0-1.20

Total mass of sample, g 50

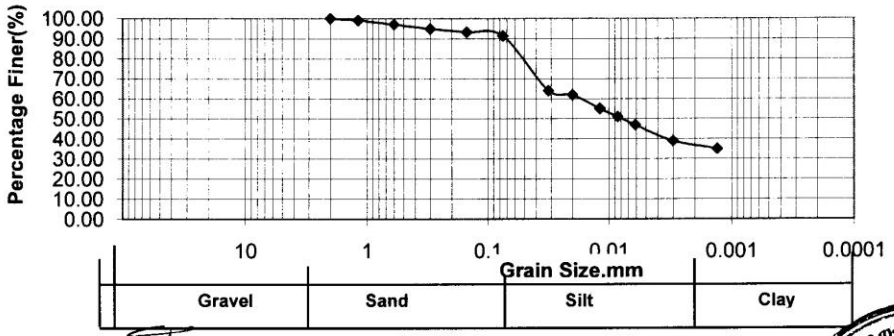
Sieve No	Sieve Opening(mm)	Mass of Sieve(g)	Mass of sieve + Ret .soil(g)	Mass of Ret. soil (g)	Percentage Retained	Cumulative % Retained	Percentage Passing
No 10	2	551.1	551.1	0.00	0.000	0.0	100.0
No 16	1.18	538.9	539.6	0.49	0.980	1.0	99.0
No 30	0.6	516.7	517.1	1.01	2.020	3.0	97.0
No 50	0.3	488.2	488.4	1.07	2.140	5.1	94.9
No 100	0.15	481.9	482.2	0.86	1.720	6.9	93.1
No 200	0.075	459.2	459.6	0.92	1.840	8.7	91.3
pan		0.0	0.0	0.0	0.000	0.0	0.0

Hydrometer Analysis

Specific Gravity of 2.72 — *Test Temperature, deg.c* 20

Elapsed Time (min)	Actual Hydrometer Reading	Tenprature deg.c	Corrected Hydrometer Reading	Effective Depth (cm)	Coefficient K	Grain Size (mm)	Percentage Finer Combined
2	38.5000	20.0	32.0000	11.10	0.01344	0.0317	64.00
5	37.5000	20.0	31.0000	11.20	0.01344	0.0201	62.00
15	34.0000	20.0	27.5000	11.80	0.01344	0.0119	55.00
30	32.0000	20.0	25.5000	12.00	0.01344	0.0085	51.00
60	30.0000	20.0	23.5000	12.40	0.01344	0.0061	47.00
250	26.0000	22.0	19.5000	13.10	0.01312	0.0030	39.00
1440	23.5000	19.0	17.5000	13.40	0.01361	0.0013	35.00

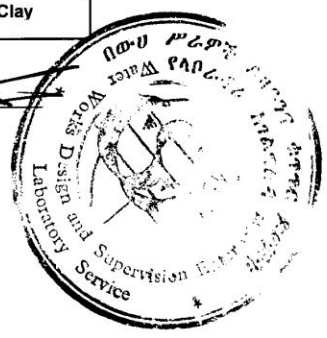
Grain Size Distribution Curve,BS



Tested by : _____

Checked by : _____

Approved by : _____



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Water Works Design and Supervision Enterprise Laboratory service Sub Process

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Soil & Material Testing Section

ject: Geological & Environmental Appraisal for Chebe Weregenu Sanitary Landfill Site

Client : Netsanet Mengistie, AAU — Sam. Type : Disturbed

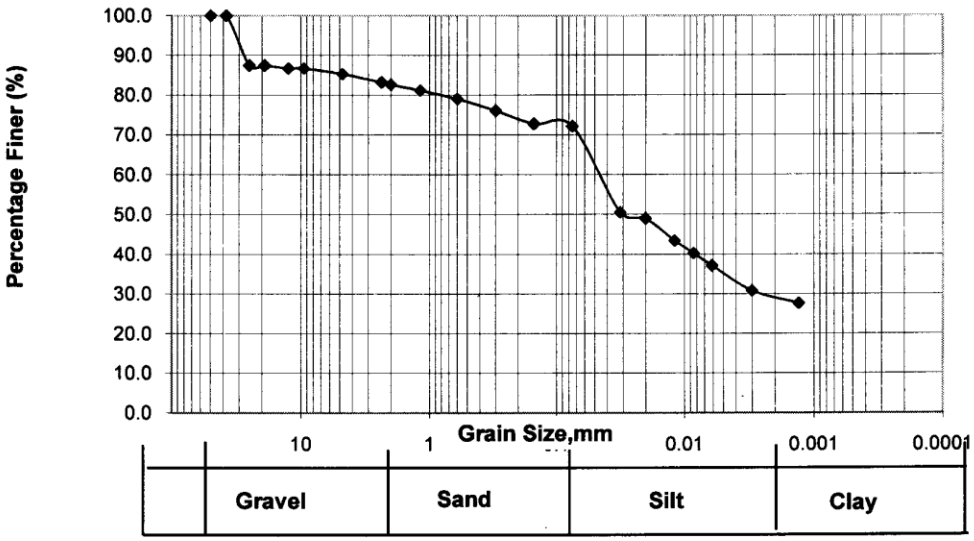
Location : 493507E: 1000070N, 2450m — Test Type :Wet Sieve +Hydrometer

T.Pit. No. TP-6 — Date :23/11/2011

Depth(m) : 0.0-1.20

Combined Graph

Grain Size Distribution Curve,BS



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Water Works Design and Supervision Enterprise Laboratory service Sub Process

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Soil & Material Testing Section

Project : Geological and Environmental Appraisal for the New Chebe Weregenu Sanitary Landfill Site

Clinent : Netsanet Mengistie, AAU — Sam. Type : Disturbed

Location : 493519E:1000111N, 2440m — Test Type : Hydrometer

T.Pit. No. TP-7 — Date : 18/02/2012

Depth(m) : 4.00

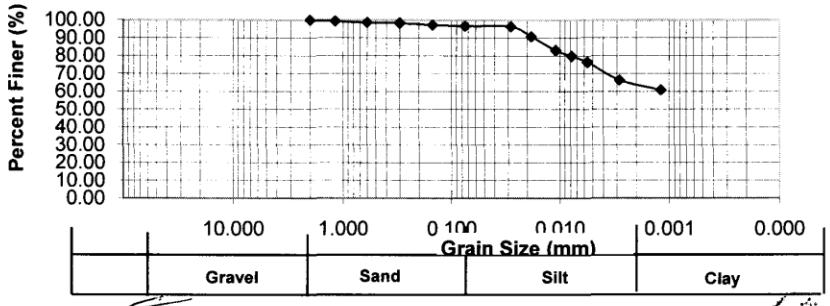
Sieve No	*Sieve Opening(mm)*	*Mass of Sieve(g)*	*Mass of sieve Ret .soil(g)*	*Mass of Ret. soil (g)*	*Percentage Retained*	*Cumulative % Retained*	*Percentage Passing*
No 10	*2.000*	*551.100*	*551.100*	*0.000*	*0.000*	*0.000*	*100.000*
No 16	*1.180*	*538.900*	*539.210*	*0.310*	*0.620*	*0.620*	*99.380*
No 30	*0.600*	*516.700*	*517.050*	*0.350*	*0.700*	*1.320*	*98.680*
No 50	*0.300*	*488.200*	*488.400*	*0.200*	*0.400*	*1.720*	*98.280*
No 100	*0.150*	*481.900*	*482.400*	*0.500*	*1.000*	*2.720*	*97.280*
No 200	*0.075*	*459.200*	*459.520*	*0.320*	*0.640*	*3.360*	*96.640*
pan		*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*

Hydrometer Analysis

Specific Grav *2.73* *21.0*

Elapsed Time (min)	*Actual Hydrometer Reading*	*Tenprature deg.c*	*Corrected Hydrometer Reading*	*Effective Depth (cm)*	*Coefficient K*	*Grain Size (mm)*	*Percentage Finer Combined*
2	*50.0000*	*20.5*	*43.5000*	*9.10*	*0.01328*	*0.0283*	*96.38*
5	*47.5000*	*20.5*	*41.0000*	*9.60*	*0.01328*	*0.0184*	*90.84*
15	*44.0000*	*20.5*	*37.5000*	*10.10*	*0.01328*	*0.0109*	*83.09*
30	*42.5000*	*20.5*	*36.0000*	*10.40*	*0.01328*	*0.0078*	*79.76*
60	*41.0000*	*20.5*	*34.5000*	*10.60*	*0.01328*	*0.0056*	*76.44*
250	*36.5000*	*20.5*	*30.0000*	*11.40*	*0.01328*	*0.0028*	*66.47*
1440	*34.000*	*21.5*	*27.5000*	*11.80*	*0.01312*	*0.0012*	*60.93*

Grain Size Distribution Curve,BS



Tested by :

Checked by :

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Water Works Design and Supervision Enterprise Laboratory service Sub Process

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Soil & Material Testing Section

Project : Geological and Environmental Appraisal for the New Chebe Weregenu Sanitary Landfill Site

Clinent : Netsanet Mengistie, AAU

Sam. Type : Disturbed

Location : 491691E:0998769N, 2462m

Test Type : Hydrometer

T.Pit. No. TP-8

Date : 02/03/2012

Depth(m) : 1.87-3.17

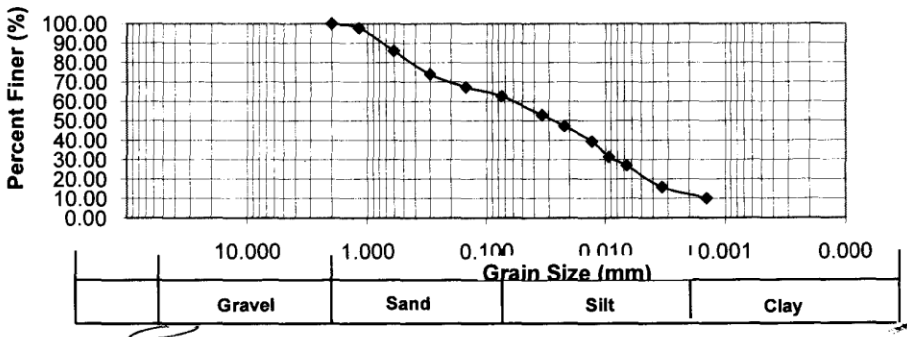
Sieve No	Sieve Opening(mm)	Mass of Sieve(g)	Mass of sieve + Ret .soil(g)	Mass of Ret. soil (g)	Percentage Retained	Cumulative % Retained	Percentage Passing
No 10	2.000	551.100	551.100	0.000	0.000	0.000	100.000
No 16	1.180	538.900	539.980	1.080	2.160	2.160	97.840
No 30	0.600	516.700	522.590	5.890	11.780	13.940	86.060
No 50	0.300	488.200	494.220	6.020	12.040	25.980	74.020
No 100	0.150	481.900	485.220	3.320	6.640	32.620	67.380
No 200	0.075	459.200	461.520	2.320	4.640	37.260	62.740
pan		0.000	0.000	0.000	0.000	0.000	0.000

Hydrometer Analysis

Specific Gravi 2.61 21.0

Elapsed Time (min)	Actual Hydrometer Reading	Tenprature deg.c	Corrected Hydrometer Reading	Effective Depth (cm)	Coefficient K	Grain Size (mm)	Percentage Finer Combined
2	30.0000	20.5	23.5000	12.40	0.01369	0.0341	52.94
5	27.5000	20.5	21.0000	12.90	0.01369	0.0220	47.31
15	24.0000	20.5	17.5000	13.40	0.01369	0.0129	39.42
30	20.5000	20.5	14.0000	14.00	0.01369	0.0094	31.54
60	18.5000	22.5	12.0000	14.30	0.01353	0.0066	27.03
250	13.5000	22.5	7.0000	15.20	0.01353	0.0033	15.77
1440	11.000	20.5	4.5000	15.50	0.01369	0.0014	10.14

Grain Size Distribution Curve,BS



Tested by :

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Water Works Design and Supervision Enterprise Laboratory service Sub Process

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Soil & Material Testing Section

Project : Geological and Environmental Appraisal for the New Chebe Weregenu Sanitary Landfill Site

Clinent : Netsanet Mengistie, AAU

Location : 491691E:0998769N, 2462m

T.Pit. No. TP-8

Depth(m) : 3.17-4.50

Sam. Type : Disturbed

Test Type : Hydrometer

Date : 10/03/2012

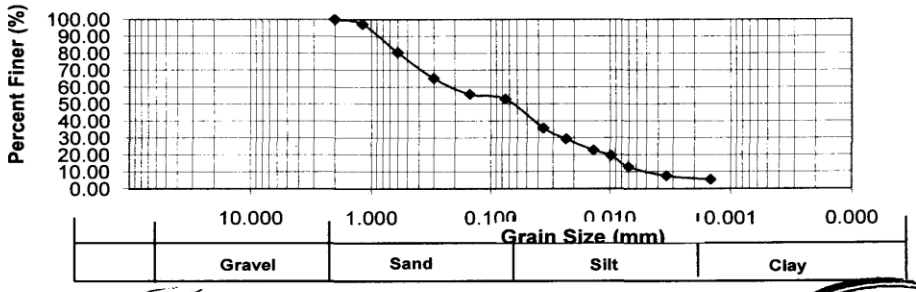
Sieve No	Sieve Opening(mm)	Mass of Sieve(g)	Mass of sieve + Ret .soil(g)	Mass of Ret. soil (g)	Percentage Retained	Cumulative % Retained	Percentage Passing
No 10	2.000	551.100	551.100	0.000	0.000	0.000	100.000
No 16	1.180	538.900	540.330	1.430	2.860	2.860	97.140
No 30	0.600	516.700	525.060	8.360	16.720	19.580	80.420
No 50	0.300	488.200	495.850	7.650	15.300	34.880	65.120
No 100	0.150	481.900	486.560	4.660	9.320	44.200	55.800
No 200	0.075	459.200	460.620	1.420	2.840	47.040	52.960
pan		0.000	0.000	0.000	0.000	0.000	0.000

Hydrometer Analysis

Specific Gravi 2.59 20.0

Elapsed Time (min)	Actual Hydrometer Reading	Tenprature deg.c	Corrected Hydrometer Reading	Effective Depth (cm)	Coefficient K	Grain Size (mm)	Percentage Finer Combined
2	23.0000	20.0	16.5000	13.60	0.01386	0.0361	35.83
5	20.0000	20.0	13.5000	14.10	0.01386	0.0233	29.31
15	17.0000	20.0	10.5000	14.60	0.01386	0.0137	22.80
30	15.5000	20.0	9.0000	14.80	0.01386	0.0097	19.54
60	12.5000	20.0	6.0000	15.30	0.01386	0.0070	13.03
250	10.0000	22.0	3.5000	15.70	0.01353	0.0034	7.60
1440	9.000	20.0	2.5000	15.90	0.01386	0.0015	5.43

Grain Size Distribution Curve,BS



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ANNEX-1.3 Compaction Graphs

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Water Works Design and Supervision Enterprise Laboratory service Sub Process

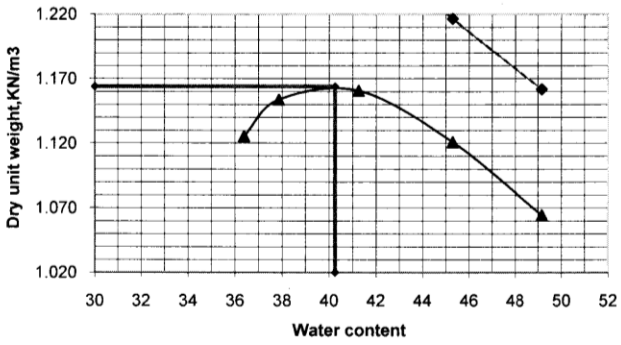
የአፈር ምህንድስና ክፍል — ***Soil & Material Testing Section***

Tel. 251 - 116 - 18 55 16/61 45 01
Fax. 251 - 116 - 61 53 71/61 08 98
e-mail w.w.d.s.e@ethionet.et

P.O.Box 2561
Addis Ababa
Ethiopia

Project : Geological & Environmental Appraisal for Chebe Weregenu Sanitary Landfill Site
Client : Netsanet Mengistie, AAU — Sample type : Disturbed
Location : 491845E:0999586N, 2481m — Test type : Standard Proctor
Test Pit : TP-1 — Date : 22/11/2011
Depth(m) : 0.0-1.30

Lab.test No.	1	2	3	4	5
Water in cc	420	480	540	600	660
Wt.of mould + Wet sample(g)	3198.1	3233.5	3279.8	3269.5	3247.9
Wt.of mould (g)	1749	1732	1732	1732	1749
Wt.of wet soil(g)	1449.1	1501.5	1547.8	1537.5	1498.9
Volume of mould cm3	944	944	944	944	944
Wet Density gm /cm3	1.54	1.59	1.64	1.63	1.59
Moisture content					
Tin No.	105	106	107	108	109
Wet soil + tin (g)	122.53	138.66	139.72	144.09	146.19
Dry soil + tin (g)	94.06	105.17	103.68	104.27	103.37
Wt of tin (g)	15.82	16.7	16.32	16.36	16.28
Wt of Water (g)	28.47	33.49	36.04	39.82	42.82
Wt of Dry soil (g)	78.24	88.47	87.36	87.91	87.09
Moisture content %	36.39	37.85	41.25	45.30	49.17
Dry Density gm /cm3	1.126	1.154	1.161	1.121	1.064
Zero Air Voids 100%	1.36	1.34	1.28	1.22	1.16



MDD : 1.164gm/cc
OMC : 40.25%

Tested by:-
Checked by :-
Approved by:-

Daniel

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Water Works Design and
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Soil & Material Testing Section

Tel. 251 - 116 - 18 55 16/61 45 01
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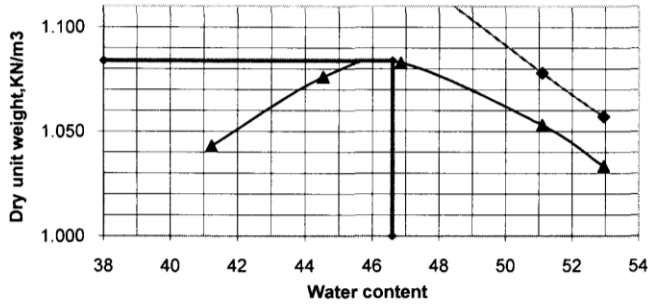
e-mail w.w.d.s.e@ethionet.et

P.O.Box 2561
Addis Ababa
Ethiopia

Project : Geological & Environmental Appraisal for Chebe Weregenu Sanitary Landfill Site
Client : Netsanet Mengistie, AAU
Location : 491845E:0999586N, 2481m
Test Pit : TP-1
Depth(m) : 1.30-2.0

Sample type : Disturbed
Test type : Standard Proctor
Date : 22/11/2011

Lab.test No.	1	2	3	4	5
Water in cc	460	520	580	640	700
Wt.of mould + Wet sample(g)	3140.4	3218.3	3243.1	3244.0	3241.9
Wt.of mould (g)	1750	1750	1742	1742	1750
Wt.of wet soil(g)	1390.4	1468.3	1501.1	1502	1491.9
Volume of mould cm3	944	944	944	944	944
Wet Density gm /cm3	1.47	1.56	1.59	1.59	1.58
Moisture content					
Tin No.	17	4	15	211	39
Wet soil + tin (g)	170.65	189.90	171.35	181.20	180.14
Dry soil + tin (g)	125.79	136.43	122.06	125.57	123.45
Wt of tin (g)	16.97	16.38	16.83	16.69	16.37
Wt of Water (g)	44.86	53.47	49.29	55.63	56.69
Wt of Dry soil (g)	108.82	120.05	105.23	108.88	107.08
Moisture content %	41.22	44.54	46.84	51.09	52.94
Dry Density gm /cm3	1.043	1.076	1.083	1.053	1.033
Zero Air Voids 100%	1.21	1.16	1.13	1.08	1.06



MDD : 1.084 gm/cc
OMC : 46.60 %

Tested by:-
Checked by :-
Approved by:-

Daniel

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Water Works Design and Supervision Enterprise Laboratory service Sub Process

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Soil & Material Testing Section

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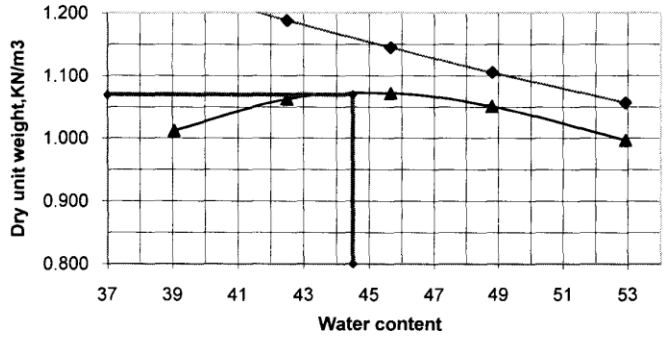
Fax. 251 - 116 - 61 53 71/61 08 98
e-mail w.w.d.s.e@ethionet.et

P.O.Box 2561
Addis Ababa
Ethiopia

Project : Geological & Environmental Appraisal for Chebe Weregenu Sanitary Landfill Site
Client : Netsanet Mengistie, AAU
Location : 491843E:0999589N, 2467m
Test Pit : TP-2
Depth(m) : 1.20-2.0

Sample type : Disturbed
Test type : Standard Proctor
Date : 23/11/2011

Lab.test No.	1	2	3	4	5
Water in cc	360	420	480	540	600
Wt.of mould + Wet sample(g)	3078.5	3171.8	3223.9	3218.4	3189.5
Wt.of mould (g)	1750	1742	1750	1742	1750
Wt.of wet soil(g)	1328.5	1429.8	1473.9	1476.4	1439.5
Volume of mould cm3	944	944	944	944	944
Wet Density gm/cm3	1.41	1.51	1.56	1.56	1.52
Moisture content					
Tin No.	33	52	32	0	15
Wet soil + tin (g)	158.18	161.86	176.09	176.99	174.13
Dry soil + tin (g)	118.34	118.6	125.83	124.37	119.52
Wt of tin (g)	16.31	16.81	15.76	16.54	16.35
Wt of Water (g)	39.84	43.26	50.26	52.62	54.61
Wt of Dry soil (g)	102.03	101.79	110.07	107.83	103.17
Moisture content %	39.05	42.50	45.66	48.80	52.93
Dry Density gm /cm3	1.012	1.063	1.072	1.051	0.997
Zero Air Voids 100%	1.24	1.19	1.15	1.11	1.06



MDD : 1.070 gm/cc
OMC : 44.5 %

Tested by:-
Checked by :-
Approved by:-

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Water Works Design and Supervision Enterprise Laboratory service Sub Process

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Soil & Material Testing Section

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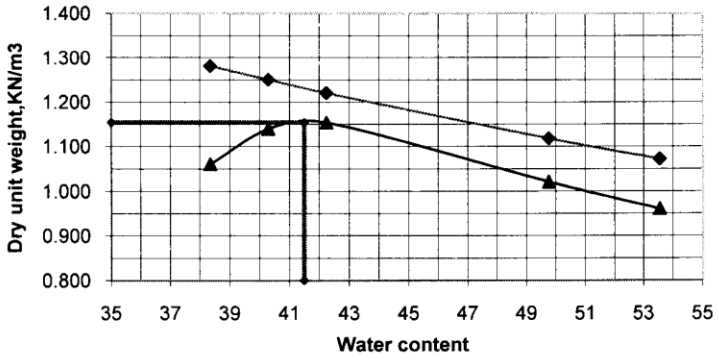
P.O.Box 2561
Addis Ababa
Ethiopia

Project : Geological & Environmental Appraisal for Chebe Weregenu Sanitary Landfill Site
Client : Netsanet Mengistie, AAU
Location : 491899E:0998562N, 2476m
Test Pit : TP-3
Depth(m) : 0.0-2.0

Sample type : Disturbed
Test type : Standard Proctor
Date : 18/11/2011

Lab.test No.	1	2	3	4	5
Water in cc	420	480	540	600	660
Wt.of mould + Wet sample(g)	3134.5	3241.8	3281.6	3192.5	3125.3
Wt.of mould (g)	1749	1732	1732	1749	1732
Wt.of wet soil(g)	1385.5	1509.8	1549.6	1443.5	1393.3
Volume of mould cm3	944	944	944	944	944
Wet Density gm /cm3	1.47	1.60	1.64	1.53	1.48
Moisture content					
Tin No.	100	101	102	103	104
Wet soil + tin (g)	118	162.78	112.19	143.29	145.98
Dry soil + tin (g)	88.00	120.78	83.82	101	100.75
Wt of tin (g)	9.77	16.55	16.65	16	16.29
Wt of Water (g)	30	42	28.37	42.29	45.23
Wt of Dry soil (g)	78.23	104.23	67.17	85	84.46
Moisture content %	38.35	40.30	42.24	49.75	53.55
Dry Density gm /cm3	1.061	1.140	1.154	1.021	0.961
Zero Air Voids 100%	1.28	1.25	1.22	1.12	1.07



MDD : 1.154 gm/cc
OMC : 41.54 %

Tested by:-
Checked by :-
Approved by:-

Daniel

Water Works Design and Supervision Enterprise

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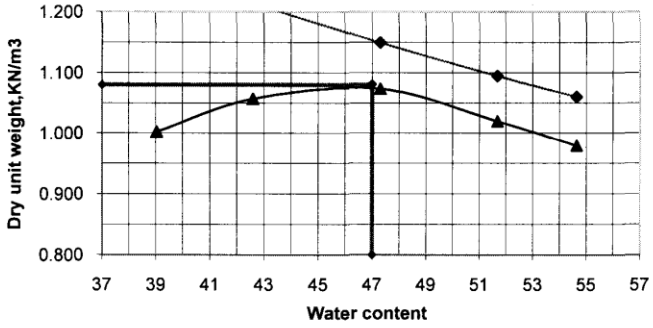
P.O.Box 2561
Addis Ababa
Ethiopia

Project : Geological & Environmental Appraisal for Chebe Weregenu Sanitary Landfill Site
Client : Netsanet Mengistie, AAU
Location :491800E:0997398N, 2454m
Test Pit : TP-5
Depth(m) : 1.20-2.0

Sample type : Disturbed
Test type : Standard Proctor
Date : 18/11/2011

Lab.test No.	1	2	3	4	5
Water in cc	300	360	420	480	540
Wt.of mould + Wet sample(g)	3057.9	3173.1	3234.8	3210.38	3171.5
Wt.of mould (g)	1742	1750	1742	1750	1742
Wt.of wet soil(g)	1315.9	1423.1	1492.8	1460.38	1429.5
Volume of mould cm3	944	944	944	944	944
Wet Density gm /cm3	1.39	1.51	1.58	1.55	1.51
Moisture content					
Tin No.	14	44	20	14	16
Wet soil + tin (g)	165.63	177.92	172.98	184.96	216.56
Dry soil + tin (g)	123.66	127.69	122.71	127.81	145.88
Wt of tin (g)	16.16	9.77	16.44	17.21	16.53
Wt of Water (g)	41.97	50.23	50.27	57.15	70.68
Wt of Dry soil (g)	107.5	117.92	106.27	110.6	129.35
Moisture content %	39.04	42.60	47.30	51.67	54.64
Dry Density gm/cm3	1.003	1.057	1.074	1.020	0.979
Zero Air Voids 100%	1.27	1.22	1.15	1.09	1.06



MDD : 1.082 gm/cc
OMC : 47.0 %

Tested by:-
Checked by :-
Approved by:-

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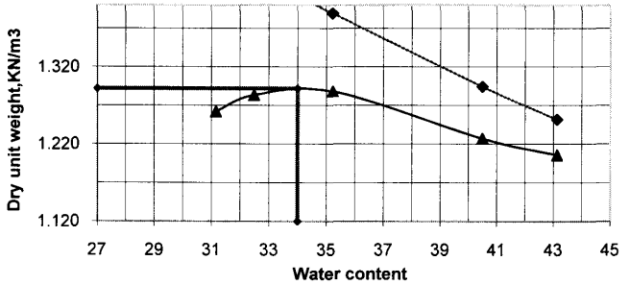
P.O.Box 2561
Addis Ababa
Ethiopia

Project : Geological & Environmental Appraisal for Chebe Weregenu Sanitary Landfill Site
Client : Netsanet Mengistie, AAU
Location : 493507E: 1000070N, 2450m
Test Pit : TP-6
Depth(m) : 0.0-1.20

Sample type : Disturbed
Test type : Modified Proctor
Date : 18/11/2011

Lab.test No.	1	2	3	4	5
Water in cc	420	480	540	600	660
Wt.of mould + Wet sample(g)	3304.2	3354.8	3386	3377	3370.9
Wt.of mould (g)	1742	1750	1742	1750	1742
Wt.of wet soil(g)	1562.2	1604.8	1644	1627	1628.9
Volume of mould cm3	944	944	944	944	944
Wet Density gm /cm3	1.65	1.70	1.74	1.72	1.73
Moisture content					
Tin No.	6	7	115	4	98
Wet soil + tin (g)	117.26	96.46	109.86	132.36	143.86
Dry soil + tin (g)	93.32	76.87	85.51	99.02	105.43
Wt of tin (g)	16.48	16.56	16.37	16.7	16.33
Wt of Water (g)	23.94	19.59	24.35	33.34	38.43
Wt of Dry soil (g)	76.84	60.31	69.14	82.32	89.1
Moisture content %	31.16	32.48	35.22	40.50	43.13
Dry Density gm /cm3	1.262	1.283	1.288	1.227	1.206
Zero Air Voids 100%	1.47	1.44	1.39	1.29	1.25



MDD : 1.292 gm/cc
OMC : 34.0 %

N.B. Test conducted by 944cc volume, 5 layers 4.5 kg rammer and 27 blows.

Tested by:- Daniel
Checked by :-
Approved by:-

በውሃ ሥራዎች ዲዛይንና ቁጥጥር ድርጅት
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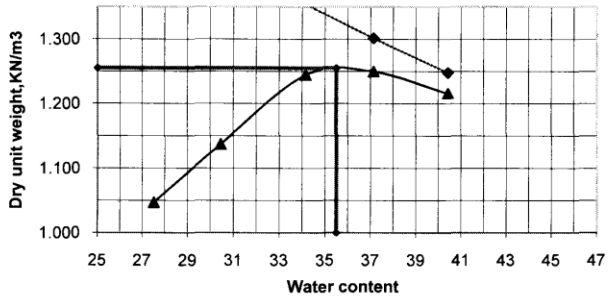
P.O.Box 2561
Addis Ababa
Ethiopia

Project : Geological & Environmental Appraisal for Chebe Weregenu Sanitary Landfill Site
Client : Netsanet Mengistie, AAU
Location : 493519E:1000111N, 2440m
Test Pit : TP-7
Depth(m) : 3.30 - 4.00

Sample type : Disturbed
Test type : Standard Proctor
Date : 06/02/2012

Lab.test No.	1	2	3	4	5
Water in cc	400	460	520	580	600
Wt.of mould + Wet sample(g)	2953.9	3098.5	3274.5	3311.0	3305.1
Wt.of mould (g)	1693	1698	1698	1693	1693
Wt.of wet soil(g)	1260.9	1400.5	1576.5	1618	1612.1
Volume of mould cm3	944	944	944	944	944
Wet Density gm /cm3	1.34	1.48	1.67	1.71	1.71
Moisture content					
Tin No.	4	10	9	27	212
Wet soil + tin (g)	137.18	140.50	142.36	146.04	149.43
Dry soil + tin (g)	111.21	111.74	110.2	111.03	111.26
Wt of tin (g)	16.86	17.28	16.05	16.76	16.85
Wt of Water (g)	25.97	28.76	32.16	35.01	38.17
Wt of Dry soil (g)	94.35	94.46	94.15	94.27	94.41
Moisture content %	27.53	30.45	34.16	37.14	40.43
Dry Density gm /cm3	1.047	1.137	1.245	1.250	1.216
Zero Air Voids 100%	1.49	1.43	1.35	1.30	1.25



MDD : 1.255 gm/cc
OMC : 35.5 %

Tested by:-
Checked by :-
Approved by:-

ANNEX-1.4: Direct Shear Graphs

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Water Works Design and Supervision Enterprise Laboratory service Sub Process

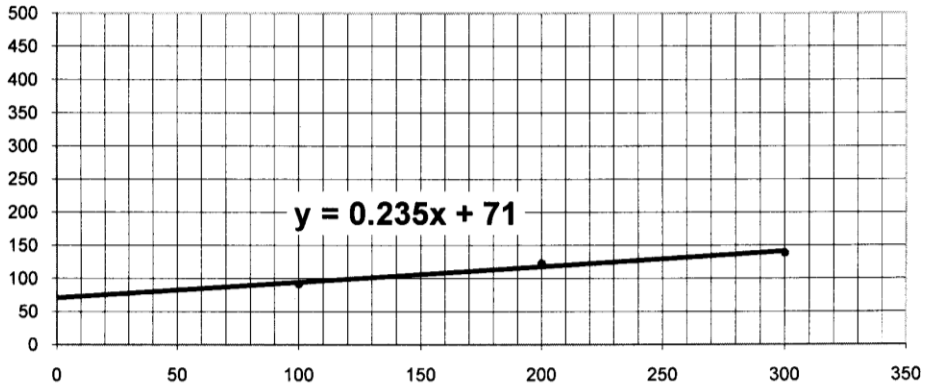
Soil & Material Testing Section

P.O.Box 2561
Addis Ababa
Ethiopia

Prject : Geological & Environmental Appraisal for Chebe Weregenu Sanitary Landfill Site
Client : Netsanet Mengistie, AAU — Sam. Type : Undisturbed
Location : 491845E:0999586N, 2481m — Test Type : Direct Shear
T.Pit. No. TP-1 — Strain rate 0.1250mm/min
Depth(m) : 1.30-2.0 — Date : 16/11/2011

Normal Stress		Shear Stress	
0		0	
100		92	
200		123	
300		139	

Direct Shear Graph



C= 71 kPa

∅ = 13.22^0

Tested by _____

Checked by _____

Approved by _____

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Water Works Design and Supervision Enterprise Laboratory service Sub Process

Soil & Material Testing Section

P.O.Box 2561
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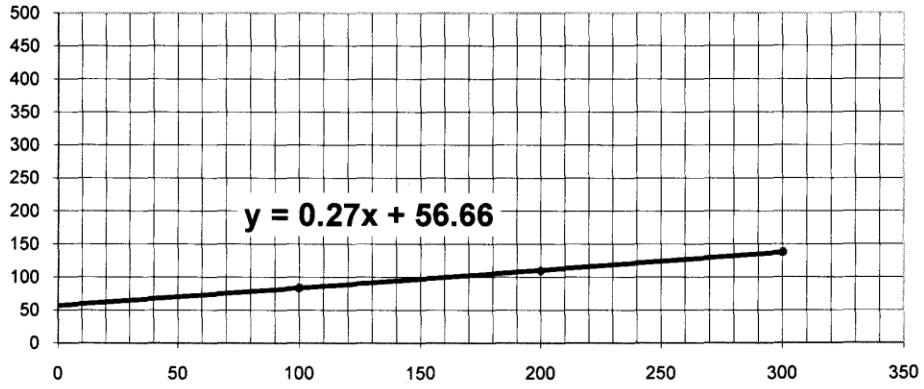
Ethiopia

Prject : Geological & Environmental Appraisal for Chebe Weregenu Sanitary Landfill Site
Client : Netsanet Mengistie, AAU
Location : 491843E:0999589N, 2467m
T.Pit. No. TP-2
Depth(m) : 1.20-2.0

Sam. Type : Undisturbed
Test Type : Direct Shear
Strain rate 0.1250mm/min
Date : 23/11/2011

Normal Stress	Shear Stress
0	0
100	84
200	110
300	138

Direct Shear Graph



C= 56.66kPa

∅ = 15.10^0

Tested by _____

Checked by _____

Approved by _____

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Water Works Design and Supervision Enterprise Laboratory service Sub Process

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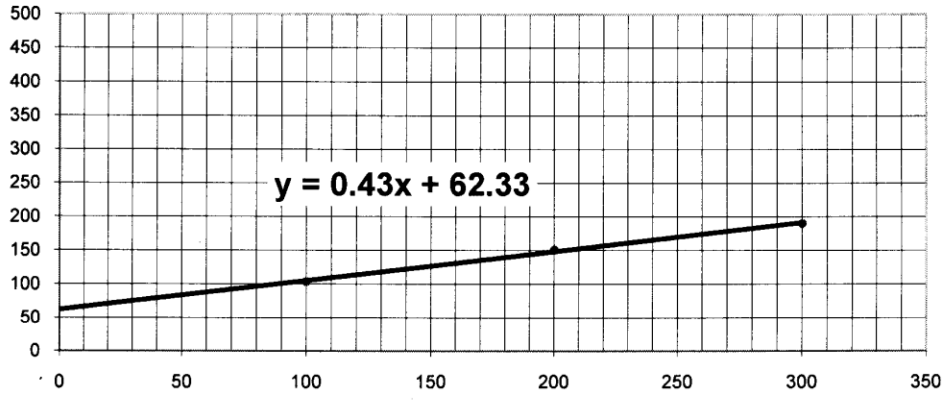
Addis Ababa
Ethiopia

Prject : Geological & Environmental Appraisal for Chebe Weregenu Sanitary Landfill Site
Client : Netsanet Mengistie, AAU — Sam. Type : Disturbed
Location : 491800E:0997398N, 2454m — Test Type : Direct Shear
T.Pit. No. TP-5 — Strain rate 0.1250mm/min
Depth(m) : 1.20-2.0 — Date : 13/12/2011

Normal Stress		Shear Stress	
0		0	
100		104	
200		151	
300		190	

Direct Shear Graph



C= 62.30 kPa

∅ = 23.27^0

Tested by _____

Checked by _____

Approved by _____

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የሥራሂደት

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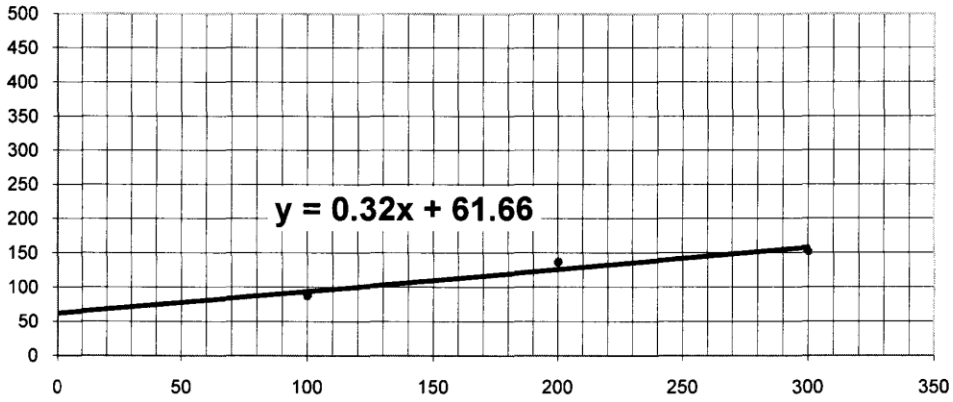
Ethiopia

Prject : Geological & Environmental Appraisal for Chebe Weregenu Sanitary Landfill Site
Client : Netsanet Mengistie, AAU — Sam. Type : Undisturbed
Location : 493507E: 1000070N, 2450m — Test Type : Direct Shear
T.Pit. No. TP-6 — Strain rate 0.1250mm/min
Depth(m) : 0.0-1.20 — Date : 18/11/2011

Normal Stress		Shear Stress	
0		0	
100		88	
200		137	
300		152	

Direct Shear Graph



C= 61.66 kPa

∅ = 17.74^0

Tested by _____

Checked by _____

Approved by _____

በውሃ ሥራዎች ዲዛይንና ቁጥጥር ድርጅት የላብራቶሪ አገልግሎት ንዑስ የሥራሂደት

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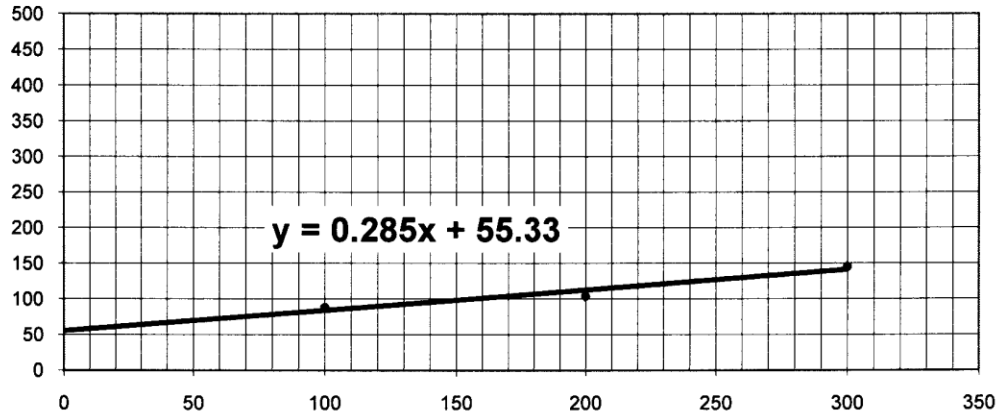
Addis Ababa
Ethiopia

Prject : Geological & Environmental Appraisal for Chebe Weregenu Sanitary Landfill Site
Client : Netsanet Mengistie, AAU
Location : 491800E:0997398N, 2454m
T.Pit. No. TP-7
Depth(m) : 4.00

Sam. Type : Undisturbed
Test Type : Direct Shear
Strain rate 0.1250mm/min
Date : 07/02/2012

Normal Stress		Shear Stress	
0		0	
100		88	
200		104	
300		145	

Direct Shear Graph



C= 55.33 kPa

Ø = 15.91^0

Tested by _____

Checked by _____

Approved by _____

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የሥራሂደት

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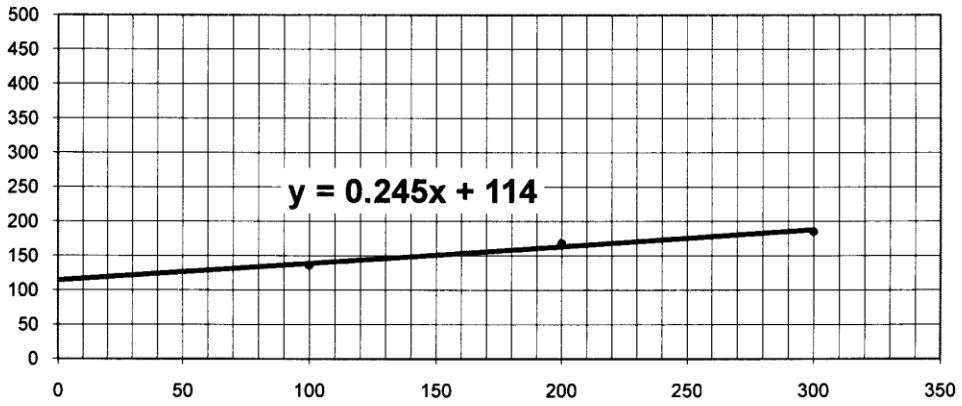
Addis Ababa
Ethiopia

Prject : Geological & Environmental Appraisal for Chebe Weregenu Sanitary Landfill Site
Client : Netsanet Mengistie, AAU
Location : 491691E:0998769N, 2462m
T.Pit. No. TP-8
Depth(m) : 4.10

Sam. Type : Undisturbed
Test Type : Direct Shear
Strain rate 0.1250mm/min
Date :20/02/2012

Normal Stress		Shear Stress	
0		0	
100		136	
200		168	
300		185	

Direct Shear Graph



C= 114.0 kPa

Ø = 13.76^0

Tested by _____

Checked by _____

Approved by _____

ANNEX-1.5: Consolidation Graphs

Consolidation Test Calculation Sheet

Project : Geological and Environmental Appraisal for the New Chebe Weregenu Sanitary Landfill Site
Client : Netsanet Mengistie, AAU
Sample No. TP-1
Location : 491845E: 0999586N, 2485m
Depth(m) 2.0 m
Date Tested: 15/11/2011
Specfic gravity 2.40

Before Test

		Diameter,D	75.00	mm
Weight of sample+Ring	258.81	Area, A	4418.00	mm^2
Weight of Ring	110.58	Thickness, H	20.00	mm
Weight of sample	148.23	Volume	88.36	cm^3
Weight of dry sample	102.56	Density	1.68	g/cc
Initial moisture content Mo	44.53	Dry Density	1.16	g/cc

Initial $e_{o=}$ 1.07

Initial $s_{o=}$ 100.09497

Volume change Factor F= 0.1034

After Test

Weight of sample+ring	262.88	Overall settlement	0.3090	mm
Weight of dry sample+ring	213.14	Volume change	1.3652	cm^3
Weight of Ring	110.58	Final volume	86.9948	cm^3
Weight of wet sample	152.30	Final density	1.7507	g/cc
Weight of dry sample	102.56	Final Dry density	1.1789	g/cc
Weight of moisture	49.74	Final void ratio	1.04	
Final moisture content	48.50%			
Final saturation Sf=	112.38			

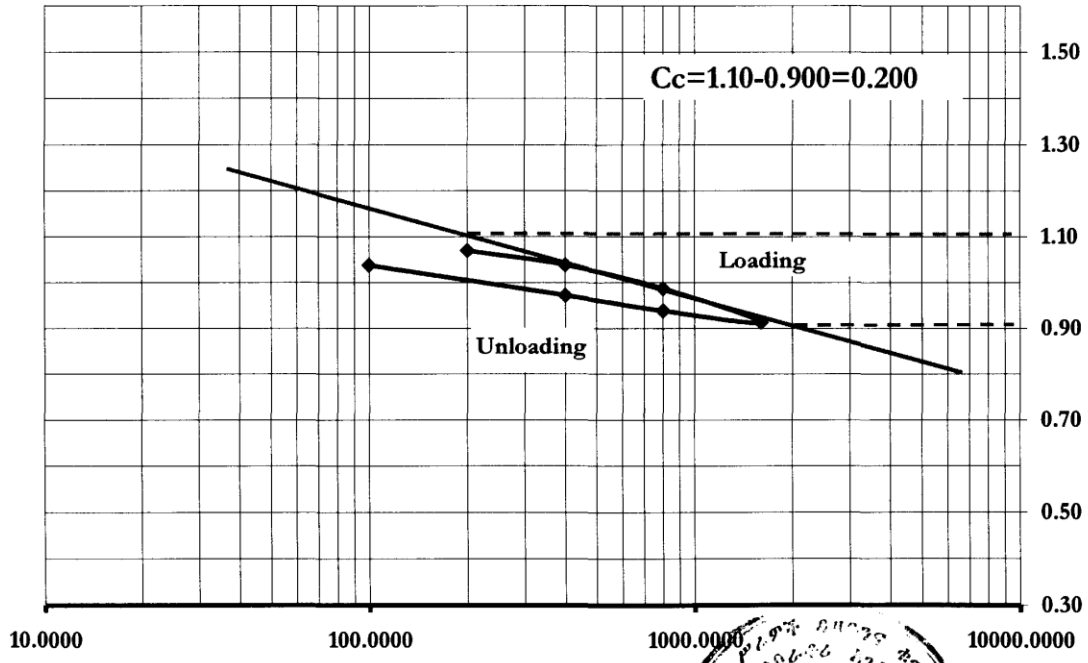
Cosolidation test -data for e-logp curve

Inc.no	Void Ratio				Volume Compressiblity				Coefficent of consolidation					Compression Index,Cc
	Pressure	Settlement	δe=	e=e0-δe	Incremental Changes			Mv=	tb0	H=H-δH	$H_{ave}=(H_1+H_2)/2$	$(H_{ave})^2$	Cv=	
	KN/m^2	Δ H mm	F*δH	e_0=1.07	δe	δp	1+e_1	δe/δp*1000/1+e	min.	H_0=20mm	mm	mm2	0.026*$(H_{ave})^2$/t50	
			F=0.1034			KN/m2		m^2/MN					m^2/year	
	0	0	0.1034	1.070	0	0				20				
1	50	0.000	0.000	0.000	0.000	50	0.000	0.000	0.000	0.000	0.000	0.000	0.000	
2	100	0.000	0.000	0.000	0.000	50	0.000	0.000	0.000	0.000	0.000	0.000	0.000	
3	200	0.000	0.000	1.070	0.000	100	2.070	0.000	0.000	20.000	20.000	400.000	0.000	0.200
4	400	0.304	0.031	1.039	0.031	200	2.039	0.077	6.250	19.696	19.848	393.943	1.639	
5	800	0.804	0.083	0.987	0.052	400	1.987	0.065	12.250	19.196	19.446	378.147	0.803	
6	1600	1.521	0.157	0.913	0.074	800	1.913	0.048	15.210	18.479	18.838	354.851	0.607	
7	800	1.276	0.132	0.938	-0.025	-800								
8	400	0.946	0.098	0.972	-0.034	-400								
9	100	0.309	0.032	1.038	-0.066	-300								

Project: Geological & Environmental Appraisal for the New Chebe Weregenu Landfill Site
Client: Netsanet Mengistie, AAU
Location: 491845E: 0999586N, 2485m
Test Pit No.: TP-1
Depth(m) : 2.0

Sample No.: _
Type: Undisturbed
Date: 15/11/2011
Tested By: G.M

Void ratio Vs Pressure curve



Consolidation Test Calculation Sheet

Project : Geological and Environmental Appraisal for the New Chebe Weregenu Sanitary Landfill Site
Client : Netsanet Mengistie, AAU
Sample No. TP-2
Location : 491843E: 0999589N, 2467m
Depth(m) 2.0 m
Date Tested 15/11/2011
Specfic gravity 2.40

Before Test

		Diameter,D	75.00	mm
Weight of sample+Ring	240.54	Area, A	4418.00	mm^2
Weight of Ring	111.48	Thickness, H	20.00	mm
Weight of sample	129.06	Volume	88.36	cm^3
Weight of dry sample	96.79	Density	1.46	g/cc
Initial moisture content Mo	33.34	Dry Density	1.10	g/cc

Initial $e_{o=}$ 1.19

Initial $s_{0=}$ 67.186009

Volume change Factor F= 0.1095

After Test

Weight of sample+ring	238.39	Overall settlement	3.3920	mm
Weight of dry sample+ring	208.27	Volume change	14.9859	cm^3
Weight of Ring	111.48	Final volume	73.3741	cm^3
Weight of wet sample	126.91	Final density	1.7296	g/cc
Weight of dry sample	96.79	Final Dry density	1.3191	g/cc
Weight of moisture	30.12	Final void ratio	0.82	
Final moisture content	31.12%			
Final saturation Sf=	91.15			

Cosolidation test -data for e-logp curve

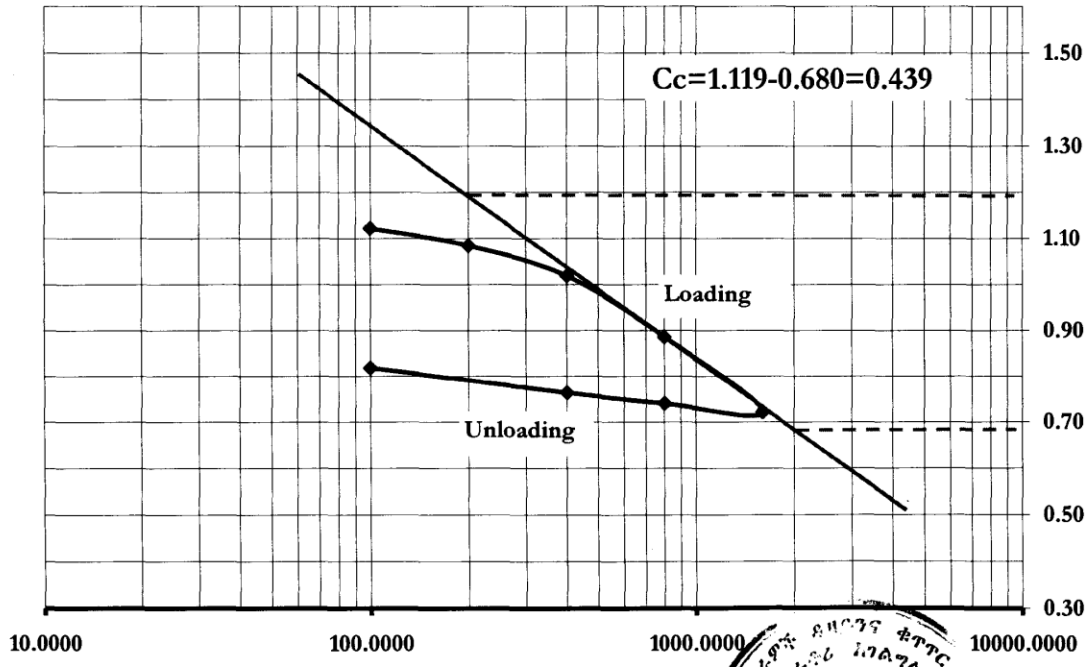
Inc.no	Void Ratio				Volume Compressiblity				Coefficent of consolidation					Compression
	Pressure KN/m^2	Settlement Δ H mm	δe= Ϸ*δH F=0.1095	e=e_0-δe e_0= 1.19	Incremental Changes δe	δp KN/m2	1+e_1	Mv= δe/δp*1000/1+e m^2/MN	tδU min.	H=H_0-δH H_0=20mm	$H_{ave.}$=(H_1+H_2)/2 mm	($H_{ave.}$)^2 mm2	Cv= 0.026*($H_{ave.}$)^2/t50 m^2/year	Index,Cc
	0	0	0.1095	1.190	0	0				20				
1	50	0.000	0.000	0.000	0.000	50	0.000	0.000	0.000	0.000	0.000	0.000	0.000	
2	100	0.614	0.067	1.123	0.067	50	2.123	0.232	1.690	19.386	9.693	93.954	1.445	
3	200	0.961	0.105	1.085	0.038	100	2.085	0.182	2.250	19.039	19.520	381.011	4.403	
4	400	1.563	0.171	1.019	0.066	200	2.019	0.163	4.840	18.437	19.219	369.351	1.984	
5	800	2.780	0.304	0.886	0.133	400	1.886	0.177	5.290	17.220	17.829	317.855	1.562	
6	1600	4.276	0.468	0.722	0.164	800	1.722	0.119	20.250	15.724	16.472	271.327	0.348	
7	800	4.108	0.450	0.740	-0.018	-800								
8	400	3.893	0.426	0.764	-0.024	-400								
9	100	3.392	0.371	0.819	-0.055	-300								

0.439

Project: Geological & Environmental Appraisal for the New Chebe Weregenu Landfill Site
Client: Netsanet Mengistie, AAU
Location: 491843E: 0999589N, 2467m
Test Pit: TP-2
Depth(m): 2.0

Sample No.: _
Sample Type: Undisturbed
Date: 15/11/2011
Tested By: G.M

Void ratio Vs Pressure curve



Consolidation Test Calculation Sheet

Project : Geological and Environmental Appraisal for the New Chebe Weregenu Sanitary Landfill Site
Client : Netsanet Mengistie, AAU
Sample No. TP-3
Location : 491888E: 0998562N, 2476m
Depth(m) 2.0 m
Date Tested 25/11/2011
Specfic gravity 2.75

Before Test

		Diameter,D	75.00	mm
Weight of sample+Ring	269.57	Area, A	4418.00	mm^2
Weight of Ring	113.94	Thickness, H	20.00	mm
Weight of sample	155.63	Volume	88.36	cm^3
Weight of dry sample	113.18	Density	1.76	g/cc
Initial moisture content Mo	37.51	Dry Density	1.28	g/cc

Initial $e_{o=}$ 1.15

Initial $s_{o=}$ 89.929512

Volume change Factor F= 0.1073

After Test

Weight of sample+ring	273.43	Overall settlement	0.3840	mm
Weight of dry sample+ring	227.12	Volume change	1.6965	cm^3
Weight of Ring	113.94	Final volume	86.6635	cm^3
Weight of wet sample	159.49	Final density	1.8403	g/cc
Weight of dry sample	113.18	Final Dry density	1.3060	g/cc
Weight of moisture	46.31	Final void ratio	1.11	
Final moisture content	40.92%			
Final saturation Sf=	101.76			

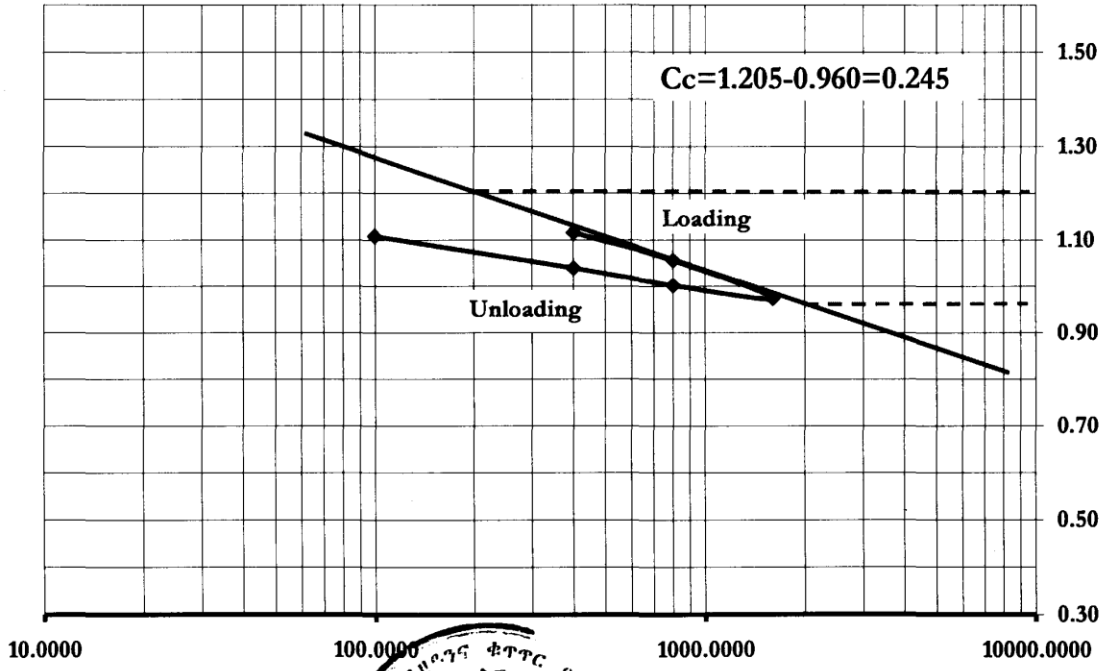
Cosolidation test -data for e-logp curve

Inc.no	Void Ratio				Volume Compressiblity				Coefficent of consolidation					Compression Index,Cc
	Pressure KN/m^2	Settlement Δ H mm	δe= Ι-*δH F=0.1073	e=e0-δe e0= 1.15	Incremental Changes δe	δp KN/m2	1+e1	Mv= δe/δp*1000/1+e m²/MN	tδU min.	H=H-δH H0=20mm	Have.=(H1+H2)/2 mm	(Have.)² mm2	Cv= 0.026*(Have.)²/t50 m²/year	
	0	0	0.1073	1.150	0	0				20				
1	50	0.000	0.000	0.000	0.000	50	0.000	0.000	0.000	0.000	0.000	0.000	0.000	
2	100	0.000	0.000	0.000	0.000	50	0.000	0.000	0.000	0.000	0.000	0.000	0.000	
3	200	0.000	0.000	0.000	0.000	100	0.000	0.000	0.000	0.000	0.000	0.000	0.000	
4	400	0.313	0.034	1.116	0.034	200	2.116	0.079	8.410	19.687	19.844	393.764	1.217	
5	800	0.872	0.094	1.056	0.060	400	2.056	0.073	11.560	19.128	19.408	376.651	0.847	
6	1600	1.642	0.176	0.974	0.083	800	1.974	0.052	47.610	18.358	18.743	351.300	0.192	
7	800	1.379	0.148	1.002	-0.028	-800								
8	400	1.030	0.111	1.039	-0.037	-400								
9	100	0.384	0.041	1.109	-0.069	-300								

Project: Geological & Environmental Appraisal for the New Chebe Weregenu Landfill Site
Client: Netsanet Mengistie, AAU
Location: 491888E: 0998562N, 2476m
Test Pit: TP-3
Depth(m): 2.0

Sample No.: _
Sample Type: Undisturbed
Date: 25/11/2011
Tested By: G.M

Void ratio Vs Pressure curve



Consolidation Test Calculation Sheet

Project : Geological and Environmental Appraisal for the New Chebe Weregenu Sanitary Landfill Site
Client : Netsanet Mengistie, AAU
Sample No. TP-4
Location : 492460E: 0997510N, 2452m
Depth(m) 2.0 m
Date Tested 15/11/2011
Specfic gravity 2.61

Before Test

		Diameter,D	75.00	mm
Weight of sample+Ring	259.20	Area, A	4418.00	mm^2
Weight of Ring	113.94	Thickness, H	20.00	mm
Weight of sample	145.26	Volume	88.36	cm^3
Weight of dry sample	106.21	Density	1.64	g/cc
Initial moisture content Mo	36.77	Dry Density	1.20	g/cc

Initial $e_{o=}$ 1.17

Initial $s_{0=}$ 81.92334

Volume change Factor F= 0.1086

After Test

Weight of sample+ring	266.69	Overall settlement	1.8380	mm
Weight of dry sample+ring	220.15	Volume change	8.1203	cm^3
Weight of Ring	113.94	Final volume	80.2397	cm^3
Weight of wet sample	152.75	Final density	1.9037	g/cc
Weight of dry sample	106.21	Final Dry density	1.3237	g/cc
Weight of moisture	46.54	Final void ratio	0.97	
Final moisture content	43.82%			
Final saturation Sf=	117.69			

Cosolidation test -data for e-logp curve

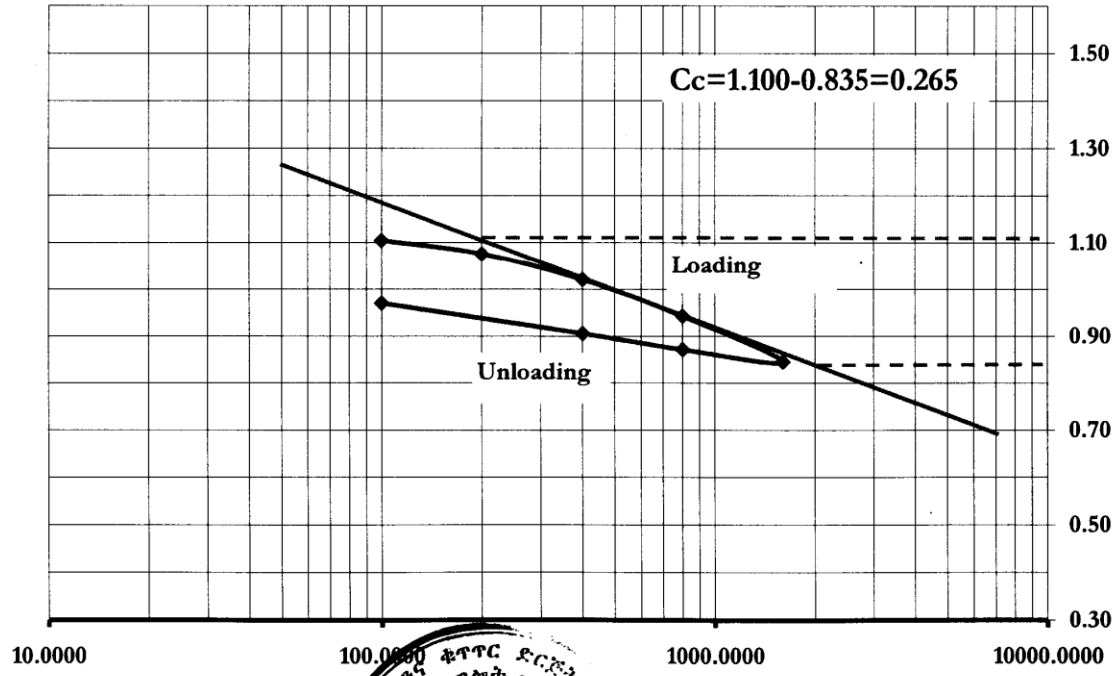
Inc.no	Void Ratio				Volume Compressiblity				Coefficent of consolidation					Compression Index,Cc
	Pressure KN/m^2	Settlement Δ H mm	δe= F*δH F=0.1086	$e=e_0-\delta e$ e_0= 1.17	Incremental Changes δe	δp KN/m2	$1+e_1$	Mv= δe/δp*1000/1+e m^2/MN	tδU min.	H=H-δH H_0=20mm	$H_{ave.}=(H_1+H_2)/2$ mm	$(H_{ave.})^2$ mm2	Cv= $0.026*(H_{ave.})^2/t50$ m^2/year	
	0	0	0.1086	1.170	0	0				20				
1	50	0.000	0.000	0.000	0.000	50	0.000	0.000	0.000	0.000	0.000	0.000	0.000	
2	100	0.602	0.065	1.105	0.065	50	2.105	0.229	2.560	19.398	19.699	388.051	3.941	
3	200	0.870	0.094	1.076	0.029	100	2.076	0.225	6.250	19.130	19.264	371.102	1.544	0.265
4	400	1.378	0.150	1.020	0.055	200	2.020	0.137	17.640	18.622	18.876	356.303	0.525	
5	800	2.094	0.227	0.943	0.078	400	1.943	0.100	22.040	17.906	18.264	333.574	0.321	
6	1600	2.993	0.325	0.845	0.098	800	1.845	0.066	92.160	17.007	17.457	304.729	0.086	
7	800	2.753	0.299	0.871	-0.026	-800								
8	400	2.438	0.265	0.905	-0.034	-400								
9	100	1.838	0.200	0.970	-0.065	-300								

Water Works Design and Supervision Enterprise Laboratory Service

Project: Geological & Environmental Appraisal for the New Chebe Weregenu Landfill Site
Client: Netsanet Mengistie, AAU
Location: 492460E: 0997510N, 2452m
Test Pit: TP-4
Depth(m): 2.0

Sample No.: _
Sample Type: Undisturbed
Date: 15/11/2011
Tested By: G.M

Void ratio Vs Pressure curve



Consolidation Test Calculation Sheet

Project : Geological and Environmental Appraisal for the New Chebe Weregenu Sanitary Landfill Site
Client : Netsanet Mengistie, AAU
Sample No. TP-5
Location : 491800E:0997398N, 2454m
Depth(m) 2.0 m
Date Tested 25/11/2011
Specfic gravity 2.52

Before Test

		Diameter,D	75.00	mm
Weight of sample+Ring	250.93	Area, A	4418.00	mm^2
Weight of Ring	111.48	Thickness, H	20.00	mm
Weight of sample	139.45	Volume	88.36	cm^3
Weight of dry sample	98.34	Density	1.58	g/cc
Initial moisture content Mo	41.80	Dry Density	1.11	g/cc

Initial $e_{o=}$ 1.26

Initial $s_{0=}$ 83.326255

Volume change Factor F= 0.1132

After Test

Weight of sample+ring	257.28	Overall settlement	1.8270	mm
Weight of dry sample+ring	209.82	Volume change	8.0717	cm^3
Weight of Ring	111.48	Final volume	80.2883	cm^3
Weight of wet sample	145.80	Final density	1.8160	g/cc
Weight of dry sample	98.34	Final Dry density	1.2248	g/cc
Weight of moisture	47.46	Final void ratio	1.06	
Final moisture content	48.26%			
Final saturation Sf=	115.01			

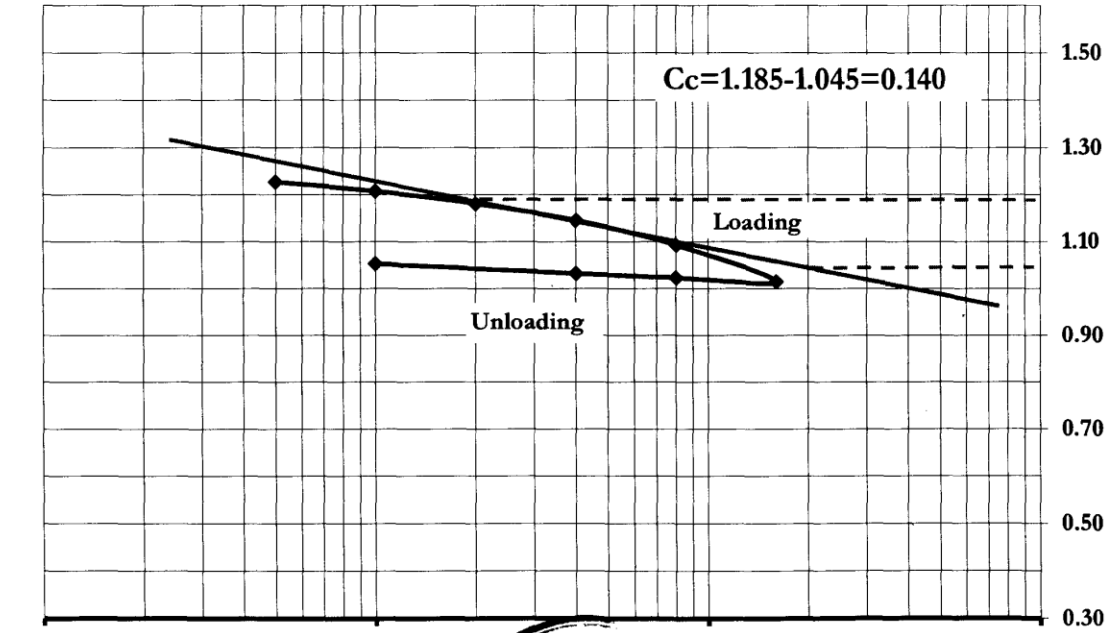
Cosolidation test -data for e-logp curve

Inc.no	Void Ratio				Volume Compressiblity				Coefficent of consolidation					Compression Index,Cc
	Pressure KN/m^2	Settlement Δ H mm	δe= Ⱶ*δH F=0.1132	e=e_0-δe e_0= 1.26	Incremental Changes δe	δp KN/m2	1+e_1	Mv= δe/δp*1000/1+e m^2/MN	t50 min.	H=H-δH H_0=20mm	$H_{ave.}$=(H_1+H_2)/2 mm	$(H_{ave.})^2$ mm2	Cv= 0.026*$(H_{ave.})^2$/t50 m^2/year	
	0	0	0.1132	1.260	0	0				20				
1	50	0.286	0.032	1.228	0.032	50	2.228	0.252	9.610	19.714	19.857	394.300	1.067	
2	100	0.462	0.052	1.208	0.020	50	2.208	0.250	4.410	19.538	19.626	385.180	2.271	
3	200	0.698	0.079	1.181	0.027	100	2.181	0.247	1.690	19.302	19.420	377.136	5.802	0.140
4	400	1.011	0.114	1.146	0.035	200	2.146	0.083	6.760	18.989	19.146	366.550	1.410	
5	800	1.475	0.167	1.093	0.053	400	2.093	0.063	2.890	18.525	18.757	351.825	3.165	
6	1600	2.164	0.245	1.015	0.078	800	2.015	0.048	9.000	17.836	18.181	330.531	0.955	
7	800	2.092	0.237	1.023	-0.008	-800								
8	400	2.010	0.228	1.032	-0.009	-400								
9	100	1.827	0.207	1.053	-0.021	-300								

Project: Geological & Environmental Appraisal for the New Chebe Weregenu Landfill Site
Client: Netsanet Mengistie, AAU
Location: 491800E: 0997398N, 2454m
Test Pit: TP-5
Depth(m): 2.0

Sample No.: _
Sample Type: Undisturbed
Date: 25/11/2011
Tested By: G.M

Void ratio Vs Pressure curve



Consolidation Test Calculation Sheet

Project : Geological and Environmental Appraisal for the New Chebe Weregenu Sanitary Landfill Site
Client : Netsanet Mengistie, AAU
Sample No. TP-6
Location : 493507E: 1000070N, 2450m
Depth(m) 1.20 m
Date Tested 25/11/2011
Specfic gravity 2.72

Before Test

		Diameter,D	75.00	mm
Weight of sample+Ring	255.32	Area, A	4418.00	mm^2
Weight of Ring	110.55	Thickness, H	20.00	mm
Weight of sample	144.77	Volume	88.36	cm^3
Weight of dry sample	99.85	Density	1.64	g/cc
Initial moisture content Mo	44.99	Dry Density	1.13	g/cc

Initial $e_{o=}$ 1.41

Initial $s_{0=}$ 86.969247

Volume change Factor F= 0.1204

After Test

Weight of sample+ring	250.91	Overall settlement	2.5090	mm
Weight of dry sample+ring	210.4	Volume change	11.0848	cm^3
Weight of Ring	110.55	Final volume	77.2752	cm^3
Weight of wet sample	140.36	Final density	1.8164	g/cc
Weight of dry sample	99.85	Final Dry density	1.2921	g/cc
Weight of moisture	40.51	Final void ratio	1.11	
Final moisture content	40.57%			
Final saturation Sf=	99.86			

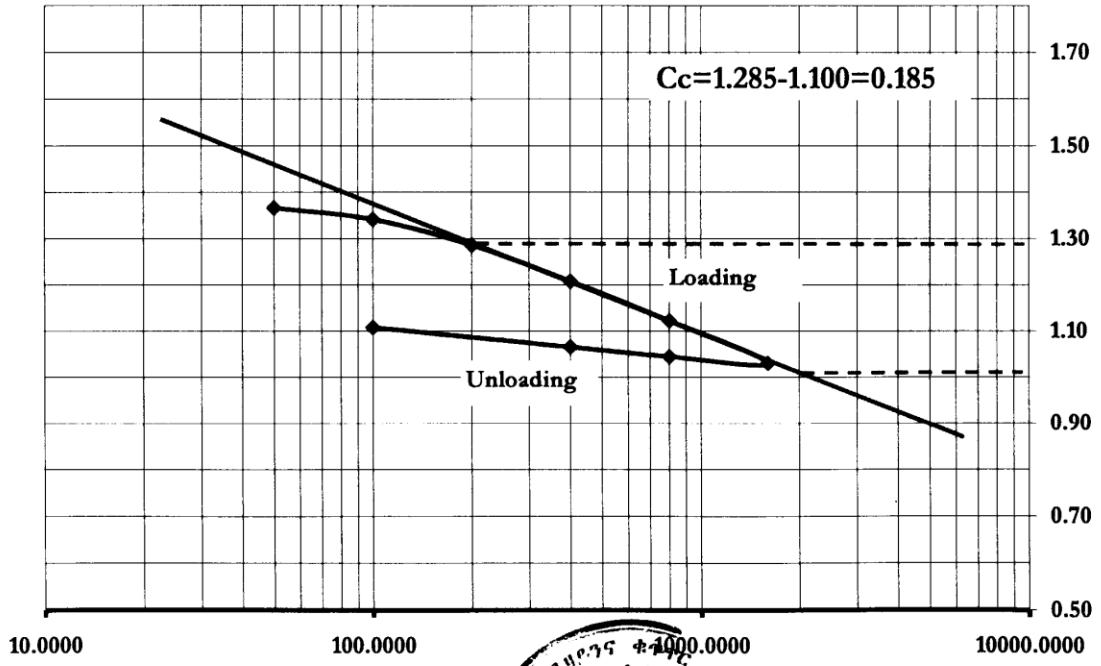
Cosolidation test -data for e-logp curve

Inc.no	Void Ratio				Volume Compressiblity				Coefficent of consolidation					Compression Index,Cc
	Pressure KN/m^2	Settlement Δ H mm	δe= ⊢*δH F=0.1204	e=e_0-δe e_0= 1.41	Incremental Changes δe	δp KN/m2	1+e_1	Mv= δe/δp*1000/1+e m^2/MN	t50 min.	H=H-δH H_0=20mm	$H_{ave.}$=$(H_1+H_2)/2$ mm	$(H_{ave.})^2$ mm2	Cv= 0.026*$(H_{ave.})^2$/t50 m^2/year	
	0	0	0.1204	1.410	0	0				20				
1	50	0.359	0.043	1.367	0.041	50	2.367	0.285	3.240	19.641	19.821	392.852	3.153	
2	100	0.566	0.068	1.342	0.025	50	2.342	0.282	4.000	19.434	19.538	381.714	2.481	
3	200	1.027	0.124	1.286	0.056	100	2.286	0.275	9.000	18.973	19.204	368.774	1.065	0.185
4	400	1.679	0.202	1.208	0.079	200	2.208	0.178	5.290	18.321	18.647	347.711	1.709	
5	800	2.393	0.288	1.122	0.086	400	2.122	0.101	10.240	17.607	17.964	322.705	0.819	
6	1600	3.158	0.380	1.030	0.092	800	2.030	0.057	15.210	16.842	17.225	296.683	0.507	
7	800	3.036	0.366	1.044	-0.015	-800								
8	400	2.864	0.345	1.065	-0.021	-400								
9	100	2.509	0.302	1.108	-0.043	-300								

Project: Geological & Environmental Appraisal for the New Chebe Weregenu Landfill Site
Client: Netsanet Mengistie, AAU
Location: 493507E: 1000070N, 2450m
Test Pit: TP-6
Depth(m): 1.20

Sample No.: _
Sample Type: Undisturbed
Date: 25/11/2011
Tested By: G.M

Void ratio Vs Pressure curve



Consolidation Test Calculation Sheet

Project : Geological and Environmental Appraisal for the New Chebe Weregenu Sanitary Landfill Site
Client : Netsanet Mengistie, AAU
Sample No. TP-7
Location : 493519E:1000111N, 2440m
Depth(m) 4.0 m
Date Tested 4/3/2012
Specfic gravity 2.73

Before Test

		Diameter,D	75.00	mm
Weight of sample+Ring	261.05	Area, A	4418.00	mm^2
Weight of Ring	111.36	Thickness, H	20.00	mm
Weight of sample	149.69	Volume	88.36	cm^3
Weight of dry sample	108.31	Density	1.69	g/cc
Initial moisture content Mo	38.21	Dry Density	1.23	g/cc

Initial $e_{o=}$ 1.23

Initial $s_{0=}$ 84.99362

Volume change Factor F= 0.1114

After Test

Weight of sample+ring	259.82	Overall settlement	1.8460	mm
Weight of dry sample+ring	219.67	Volume change	8.1556	cm^3
Weight of Ring	111.36	Final volume	80.2044	cm^3
Weight of wet sample	148.46	Final density	1.8510	g/cc
Weight of dry sample	108.31	Final Dry density	1.3504	g/cc
Weight of moisture	40.15	Final void ratio	1.02	
Final moisture content	37.07%			
Final saturation Sf=	99.06			

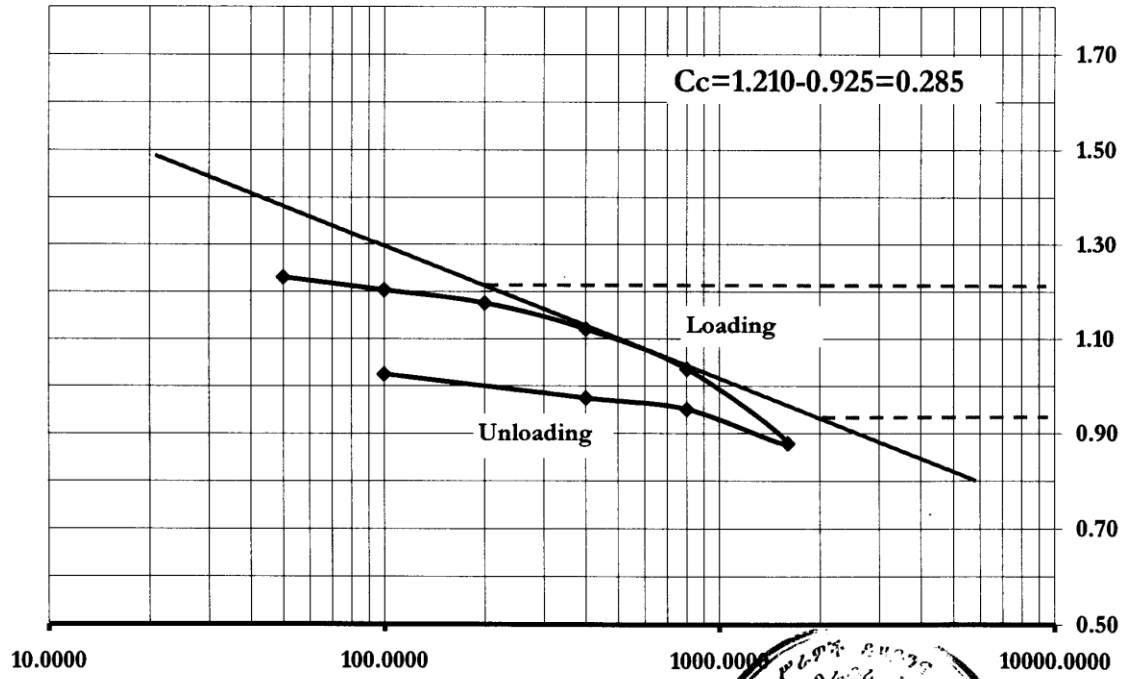
Cosolidation test -data for e-logp curve

Inc.no	Void Ratio				Volume Compressiblity				Coefficent of consolidation					Compression Index,Cc
	Pressure KN/m^2	Settlement Δ H mm	δe= F*δH F=0.1114	$e=e_0-\delta e$ e_0= 1.23	Incremental Changes δe	δp KN/m2	$1+e_1$	Mv= δe/δp*1000/1+e m^2/MN	t50 min.	H=H-δH H_0=20mm	$H_{ave.}=(H_1+H_2)/2$ mm	$(H_{ave.})^2$ mm2	Cv= 0.026*$(H_{ave.})^2$/t50 m^2/year	
	0	0	0.1114	1.230	0	0				20				
1	50	0.000	0.000	1.230	0.000	50	0.000	0.000	0.000	0.000	0.000	0.000	0.000	
2	100	0.245	0.027	1.203	0.027	50	2.203	0.245	3.610	19.755	9.878	97.565	0.703	
3	200	0.493	0.055	1.175	0.028	100	2.175	0.242	4.000	19.507	19.631	385.376	2.505	0.285
4	400	0.988	0.110	1.120	0.055	200	2.120	0.130	3.240	19.012	19.260	370.928	2.977	
5	800	1.750	0.195	1.035	0.085	400	2.035	0.104	12.960	18.250	18.631	347.114	0.696	
6	1600	3.158	0.352	0.878	0.157	800	1.878	0.104	11.560	16.842	17.546	307.862	0.692	
7	800	2.514	0.280	0.950	-0.072	-800								
8	400	2.299	0.256	0.974	-0.024	-400								
9	100	1.846	0.206	1.024	-0.050	-300								

Project: Geological & Environmental Appraisal for the New Chebe Weregenu Landfill Site
Client: Netsanet Mengistie, AAU
Location: 493519E: 1000111N, 2440m
Test Pit: TP-7
Depth(m): 4.0

Sample No.: _
Sample Type: Undisturbed
Date: 04/3/2012
Tested By: G.M

Void ratio Vs Pressure curve



Consolidation Test Calculation Sheet

Project : Geological and Environmental Appraisal for the New Chebe Weregenu Sanitary Landfill Site
Client : Netsanet Mengistie, AAU
Sample No. TP-8
Location : 491691E: 0998769N, 2462m
Depth(m) 4.10 m
Date Tested 29/02/2012
Specfic gravity 2.59

Before Test

		Diameter,D	75.00	mm
Weight of sample+Ring	237.21	Area, A	4418.00	mm^2
Weight of Ring	112.89	Thickness, H	20.00	mm
Weight of sample	124.32	Volume	88.36	cm^3
Weight of dry sample	69.93	Density	1.41	g/cc
Initial moisture content Mo	77.78	Dry Density	0.79	g/cc

Initial $e_{0=}$ 2.27

Initial $s_{0=}$ 88.640808

Volume change Factor F= 0.1636

After Test

Weight of sample+ring	225.16	Overall settlement	3.8480	mm
Weight of dry sample+ring	182.82	Volume change	17.0005	cm^3
Weight of Ring	112.89	Final volume	71.3595	cm^3
Weight of wet sample	112.27	Final density	1.5733	g/cc
Weight of dry sample	69.93	Final Dry density	0.9800	g/cc
Weight of moisture	42.34	Final void ratio	1.64	
Final moisture content	60.55%			
Final saturation Sf=	95.45			

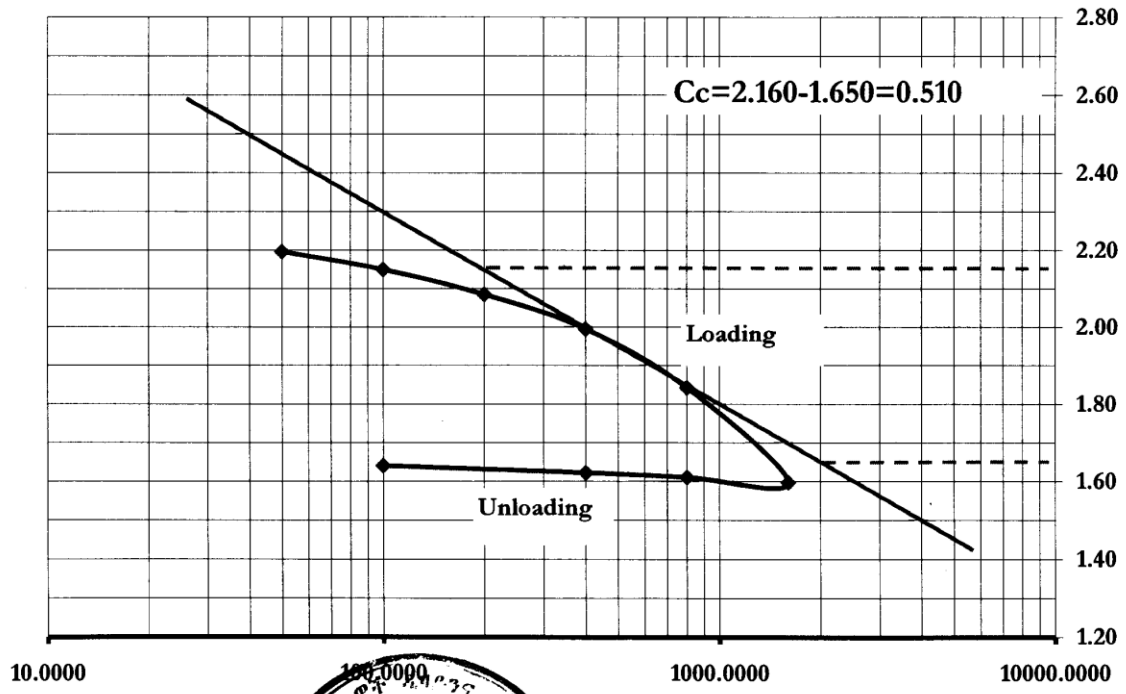
Cosolidation test -data for e-logp curve

Inc.no	Void Ratio				Volume Compressiblity				Coefficent of consolidation					Compression Index,Cc
	Pressure KN/m^2	Settlement Δ H mm	δe= Ⱶ*δH F=0.1638	e=e_0-δe e_0= 2.27	Incremental Changes δe	δp KN/m2	1+e_1	Mv= δe/δp*1000/1+e m^2/MN	tδU min.	H=H-δH H_0=20mm	H_{ave}=(H_1+H_2)/2 mm	$(H_{ave})^2$ mm2	Cv= 0.026*$(H_{ave})^2$/t50 m^2/year	
	0	0	0.1638	2.270	0	0				20				
1	50	0.458	0.075	2.195	0.041	50	3.195	0.523	6.250	19.542	19.771	390.892	1.626	
2	100	0.737	0.121	2.149	0.046	50	3.149	0.516	7.840	19.263	19.403	376.457	1.248	
3	200	1.137	0.186	2.084	0.066	100	3.084	0.505	3.240	18.863	19.063	363.398	2.916	0.510
4	400	1.682	0.276	1.994	0.089	200	2.994	0.149	4.000	18.318	18.591	345.607	2.246	
5	800	2.614	0.428	1.842	0.153	400	2.842	0.134	9.000	17.386	17.852	318.694	0.921	
6	1600	4.115	0.674	1.596	0.246	800	2.596	0.118	12.250	15.885	16.636	276.740	0.587	
7	800	4.032	0.660	1.610	-0.014	-800								
8	400	3.962	0.649	1.621	-0.011	-400								
9	100	3.848	0.630	1.640	-0.019	-300								

Project: Geological & Environmental Appraisal for the New Chebe Weregenu Landfill Site
Client: Netsanet Mengistie, AAU
Location: 491691E: 0998769N, 2462m
Test Pit: TP-8
Depth(m): 4.10

Sample No.: _
Sample Type: Undisturbed
Date: 29/02/2012
Tested By: G.M

Void ratio Vs Pressure curve



ANNEX -2 Water Quality and Soil Fertility Test Results

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Water Works Design and
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Laboratory Service
Water Quality Section

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Addis Ababa
Tel. 251 - 116 - 18 55 16/61 45 01
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e-mail w.w.d.s.e@ethionet.et

SELECTED PHYSIO CHEMICAL AND BACTERIOLOGICAL WATER ANALYSIS RESULTS
Project: Addis Ababa Sanitary Landfill

SOURCE OF SAMPLE	Ground water	Spring			WHO maximum allowable Concentration (mg/l)
LOCATION	Chebie Weregenu 493020E 1000513N	Chebie Weregenu 490570E 0997563N			
DATE OF COLLECTION	12/3/2010	12/3/2010			
DATE RECEIVED	15/3/2010	15/3/2010			
CLIENTS ID.NO.	Netsanet Mengistie	Netsanet Mengistie			
LAB.ID NO.	1507/2002	1508/2002			–
Colour (app)	–	–			–
Turbidity (NTU)	2.0	3.0			5.0
Total Solids I05 ^{0}C (mg/l)	238.0	176			–
T. Dissolved Solid 105^{0}C(mg/l)	228.0	160.0			1000.0
Electrical Conductivity (µS/cm)	367.0	254			–
P^H	7.5	6.84			6.5-8.5
Ammonia (mg/l NH_3)	0.190	0.16			–
Sodium (mg/l Na)	13.5	13.5			200.0
Potassium (mg/l K)	2.5	7.1			–
Total Hardness (mg/l Ca CO_3)	161.5	100.7			500.0
Calcium (mg/l Ca)	53.20	38			200.0
Magnesium (mg/l Mg)	6.90	1.38			150.0
Total Iron (mg/l Fe)	0.02	Trace			0.3
Manganese (mg/l Mn)	0.02	Trace			0.1
Fluoride (mg/l F)	0.37	0.51			1.5
Chloride (mg/l Cl)	1.00	1.0			250.0
Nitrite (mg/l NO_2)	–	–			–
Nitrate (mg/l NO_3)	11.4	9			45.0
Alkalinity (mg/l $CaCO_3$)	189.0	121.8			–
Carbonate (mg/l CO_3)	Nil	Nil			–
Bicarbonate (mg/l HCO_3)	230.6	148.6			–
Sulphate (mg/l SO_4)	0.09	0.09			400
Phosphate (mg/l PO_4)	0.31	0.25			–
Total Coliform Per 100 ml	–	–			–
Fecal Coliform Per 100 ml	–	–			–

REMARK:- The test result can be compared with the WHO maximum allowable concentration (mg/l) presented on the last column.The water sample was collected and submitted to our laboratory by the client.

Checked by: _____ Approved by: _____
Date: 25/3/2010 Date: 25/3/2010

Water Works Design and Supervision Enterprise Laboratory Service

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Water Works Design and
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SELECTED PHYSIC CHEMICAL AND BACTERIOLOGICAL WATER ANALYSIS RESULTS
Client/Project: W/Ro Netsanet Mengistie

SOURCE OF SAMPLE	Spring	Spring	Ground water		WHO maximum allowable Concentration (mg/l)
LOCATION	_	_	_		
DATE OF COLLECTION	24/05/2004	_	12/3/2010		
DATE RECEIVED	3/2/2012	3/2/2012	3/2/2012		
CLIENTS ID.NO.	Kawa spring Chebe	Nebe spring Chebe	Chebe		
LAB.ID NO.	1278/2004	1279/2004	1280/2004		_
Turbidity (NTU)	7.67	5.48	_		5.0
Total Solids 105 °C (mg/l)	240.00	260.00			_
T. Dissolved Solid 105°C(mg/l)	220.00	240.00	_		1000.0
Electrical Conductivity (uS/cm)	365.00	378.00	_		_
P^H	7.19	7.17	_		6.5-8.5
Ammonia (mg/l NH_3)	0.22	0.29	_		_
Sodium (mg/l Na)	12.00	20.00	_		200.0
Potassium (mg/l K)	1.90	4.70	_		_
Total Hardness (mg/l Ca CO_3)	182.00	174.00	_		500.0
Calcium (mg/l Ca)	56.00	56.00	_		200.0
Magnesium (mg/l Mg)	10.08	8.16	_		150.0
Total Iron (mg/l Fe)	0.02	0.06	_		0.3
Manganese (mg/l Mn)	0.00	0.05	_		0.1
Fluoride (mg/l F)	0.50	0.51	_		1.5
Chloride (mg/l Cl)	10.92	10.92	_		250.0
Nitrite (mg/l NO_2)	0.13	0.15	_		_
Nitrate (mg/l NO_3)	5.05	1.10	_		45.0
Alkalinity (mg/l $CaCO_3$)	180.50	193.80	_		_
Carbonate (mg/l CO_3)	Nil	Nil	_		_
Bicarbonate (mg/l HCO_3)	220.21	236.44	_		_
Sulphate (mg/l SO_4)	0.19	0.76	_		400
Phosphate (mg/l PO_4)	0.23	0.09	_		_
Copper(mg/l Cu)	_	_	0.006		1.5
Aluminum(mg/l Al)	_	_	0.014		0.2
Chromium(mg/l Cr)	_	_	0.011		0.05
Molibidium (mg/l)	_	_	0.782		_
Silicon (mg/l)	_	_	31.14		_
Zinc (mg/l)	_	_	0.475		15.0
Organic carbon (mg/l)	_	_	Trace		_
Nickle (mg/l)	_	_	Trace		_

REMARK:- The last result can be compared with the WHO maximum allowable concentration (mg/l) presented on the last column. The water sample was collected and submitted to our laboratory by the client.

Checked by: _____ Approved by _____
Date: 13/02/2012 Date 13/02/2012

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Water Works Design and
Supervision Enterprise
Laboratory Service

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Soil Fertility Section

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e-mail w.w.d.s.e@ethionet.et
P.O.Box 2561
Addis Ababa
Ethiopia

Client:-AAU(Netsanet)

Location :

Test Method: Hydrometer,Acid neutralazaion , Olsen, Kjeldahl Walklay Black , Ammonium Acetate & Instrumental

LABORATORY NUMBER	2328/02	2329/02	2330/02	2331/02	2332/02		
PROFILE CODE	Sample-1	Sample-2	Sample-3	Sample-4	Sample-5		
DEPTH (M)	0.2-1.2	0-1	0-1.28	1.28-1.78	0-1.1		
Sand (%)	7.88	15.67	5.58	43.76	16.49		
Silt (%)	14.43	14.24	11.11	24.26	24.94		
Clay (%)	77.69	70.09	83.31	31.98	58.56		
Texture Class	clay	clay	clay	Clay loam	clay		
P^H-H_2O Saturated Extract	6.96	6.19	7.96	7.85	6.34		
EC(ms/cm) Saturated Extract	0.20	0.09	0.20	0.28	0.21		
Exch.Na(meq/100gm of soil)	0.78	0.40	0.29	0.96	0.48		
Exch.K(meq/100 gm of soil))	0.99	1.15	1.22	0.29	0.65		
Exch.Ca(meq/100 gm of soil)	57.86	30.28	42.49	37.06	46.06		
Exch.Mg(meq/100 gm of soil)	9.94	33.00	23.96	10.40	8.66		
Sum of Cations (meq/100gm of soil)	69.57	64.83	67.96	48.71	55.84		
CEC(meq/100 gm of soil)	71.24	65.83	69.27	50.60	57.99		
Organic Carbon(%)	0.48	1.86	0.68	0.18	1.37		
Nitrogen (%)	0.06	0.25	0.09	0.02	0.15		
Available P(mg P_2O_5/kg soil)	6.88	15.91	2.01	5.16	45.14		
$CaCO_3$ (%)	2.47	Trace	3.93	6.17	Trace		
Gypsum (%)	Trace	Trace	Trace	Trace	Trace		
Exchangeable Sodium %(ESP)	1.09	0.61	0.43	1.90	0.82		
Available K (mg /kg soil)	396.00	462.00	484.00	116.60	264.00		
Soluble Salts (meq/l) 1:5 ext.							
Na (meq/l)	0.65	0.45	0.44	0.64	0.49		
K (meq/l)	0.05	0.06	0.06	0.02	0.04		
Ca (meq/l)	1.80	1.60	2.40	1.40	2.00		
Mg (meq/l)	0.20	0.60	0.20	0.20	0.20		
Sum of Cations	2.71	2.71	3.10	2.26	2.73		
CO_3^{-2} (meq/l)	Nil	Nil	Nil	Nil	Nil		
HCO_3^{-1} (meq/l)	1.20	1.00	1.60	1.20	1.44		
Cl^- (meq/l)	0.21	0.07	0.21	0.21	0.07		
SO_4^{-2} (meq/l)	1.02	1.20	1.00	0.76	1.00		
Sum of Anions	2.43	2.27	2.81	2.17	2.51		
SAR	0.65	0.43	0.39	0.72	0.47		

RemarK:

Checked by_____ Approved by_____

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Water Works Design and Supervision Enterprise
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Soil Fertility Section

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e-mail w.w.d.s.e@ethionet.et

Client : Netsanet Mengisite, AAU

Project : Geological and Environmental Appraisal for the New Chaba Weregenu Sanitary Landfill Site

Test Method: Hydrometer,Acid neutralazaion , Olsen, Kjeldahl Walkley Black , Ammonium Acetate & Instrumental

LABORATORY NUMBER	506/04	507/04	508/04		
PROFILE CODE	TP-1	TP 3	TP-6		
DEPTH (CM)	0.0-1.3	0.0-2.0	0.0-1.2		
Location	491845E 0999586N	491899E 0998562N	493507E 1000070N		
Sand (%)	3.41	28.02	2.01		
Silt (%)	19.55	27.42	11.81		
Clay (%)	77.04	44.56	86.19		
Texture Class	Clay	Clay	Clay		
P^H-H_2O (1:2.5)	6.43	6.01	7.18		
P^H-KCL (1:2.5)	5.41	5.64	6.32		
EC(ms/cm) (1:2.5)	0.06	0.04	0.08		
Exch.Na(meq/100gm of soil)	0.76	0.38	1.04		
Exch.K(meq/100 gm of soil)	0.72	0.35	0.77		
Exch.Ca(meq/100 gm of soil)	17.18	16.90	26.75		
Exch.Mg(meq/100 gm of soil)	17.18	13.50	29.06		
Sum of Cations (meq/100gm of soil)	35.83	33.13	57.62		
CEC(meq/100 gm of soil)	63.38	62.61	65.67		
Organic Carbon(%)	1.20	0.63	0.11		
Nitrogen (%)	0.11	0.05	0.01		
Available P(mg P_2O_5/kg soil)	2.89	44.62	3.25		
Available K(mgK_2O/kg soil)	280.5	138.3	300.1		
$CaCO_3$ (%)	6.92	3.79	1.88		
Exchangeable Sodium %(ESP)	1.19	0.61	1.59		
Gypsum(%) $CaSO_4.2H_2O$	Trace	Trace	Trace		
Soluble Salts (meq/l) 1:5 ext.					
Na (meq/l)	0.29	0.16	0.33		
K (meq/l)	0.02	0.04	0.03		
Ca (meq/l)	1.20	1.00	1.20		
Mg (meq/l)	1.00	1.00	1.00		
CO_3^{-2} (meq/l)	Nil	Nil	Nil		
HCO_3^{-1} (meq/l)	1.68	1.44	1.60		
Cl^- (meq/l)	0.56	0.84	0.56		
SO_4^{-2} (meq/l)	0.12	0.03	0.48		
Micronutrient					
Cu (mg/kg soil)	1.62	1.16	0.79		
Fe (mg/kg soil)	15.16	30.77	6.85		
Mn (mg/kg soil)	10.13	7.50	0.26		
Zn (mg/kg soil)	4.30	1.52	2.47		
Boron	0.30	0.06	0.33		

RemarK:

Checked by _____ 29/02/2012

Approved By _____ 29/02/2012

ANNEX-3: Mineralogical Test Results

Geological Survey of Ethiopia
Geosciences Laboratory Center
Result Form

Case Team: - Chemical: Lab Section: - Silicate ☐ **Gold & Base metal** ☐ **Water** ☐ **Hydrocarbon** ☐

Case Team: - Mineralogical: Lab section: - Mineralogy ☑ **Physical** ☐

Client /Originator Name: - Chebe Weregenu Sanitary Land fill(Netsanet Mengistie) (AAU)

Client Category: - Survey ☐ **Gov.** ☐ **Pvt.** ☑

File name:- 2471/12PVT. **Area Ref:-** Land fill Site Near Sendafa Area **No of Samples:-** 2

Sample No. TP-1 Oriented (0-1.30m)

Sample Type: - Disturbed Soil **Lab No:-** 2471/12

Type of Analysis:-XRD **Preparation required: -** powder <63mic. **Date Submitted:-**25/01/2012

I) Identified Minerals

Mineral	(%)
Dickite	26.8
Muscovite	73.2

Geological Survey of Ethiopia Geological Laboratory

II) Remark note:-

Described By / Analysts Girma Asemu

Checked by

Date Completed 03/02/2012

Geological Survey of Ethiopia
Geosciences Laboratory Center
Result Form

Case Team: - Chemical: Lab Section: - Silicate ☐ **Gold & Base metal** ☐ **Water** ☐
Hydrocarbon ☐

Case Team: - Mineralogical: Lab section: - Mineralogy ☑ **Physical** ☐

Client /Originator Name: - Chebe Weregenu Sanitary Land fill(Netsanet Mengistie) (AAU)

Client Category: - Survey ☐ **Gov.** ☐ **Pvt.** ☑

File name:- 20519/11PVT. **Area Ref-:- Land** fill Site Near Sendafa Area **No of Samples:- 2**

Sample No. TP-2 (1.2-2.0m)

Sample Type:- Disturbed Soil **Lab No:-** 20520/12

Type of Analysis:-XRD **Preparation required: -** powder <63mic. **Date Submitted:-**12/12/2011

II) Identified Minerals

Muscovite

II) Remark note:- The dominant part of the sample is non crystalline mineral(amorphous)

Described By / Analysts Girma Asemu **Checked by** **Date Completed** 03/02/2012

Page 2 of2

Geological Survey of Ethiopia
Geosciences Laboratory Center
Result Form

Case Team: - Chemical: Lab Section: - Silicate ☐ **Gold & Base metal** ☐ **Water** ☐
Hydrocarbon ☐

Case Team: - Mineralogical: Lab section: - Mineralogy ☑ **Physical** ☐

Client /Originator Name: - Chebe Weregenu Sanitary Land fill(Netsanet Mengistie) (AAU)

Client Category: - Survey ☐ **Gov.** ☐ **Pvt.** ☑

File name:- 20519/11PVT. **Area Ref:-** Landfill Site Near Sendafa Area **No of Samples:-** 5

Sample No. TP-3 (0-2.0m)

Sample Type:-Disturbed Soil **Lab No:-** 20521/11

Type of Analysis:-XRD **Preparation required:-** powder <63mic. **Date Submitted:-**12/12/2011

III) Identified Minerals

Mineral	(%)
Quartz	81.6
Dickite	18.4

Geological Survey of Ethiopia Central Geological Laboratory

II) Remark note:-

Described By / Analysts Girma Asemu

Checked by Worku Gebul G/Kirstos
Mineralogy & Physical Analysis Case Team Co-ordinator

Date Completed 04/01/2012

Geological Survey of Ethiopia
Geosciences Laboratory Center
Result Form

Case Team: - Chemical: Lab Section: - Silicate ☐ **Gold & Base metal** ☐ **Water** ☐
Hydrocarbon ☐

Case Team: - Mineralogical: Lab section: - Mineralogy ☑ **Physical** ☐

Client /Originator Name: - Chebe Weregenu Sanitary Land fill(Netsanet Mengistie) (AAU)

Client Category: - Survey ☐ **Gov.** ☐ **Pvt.** ☑

File name:- 20519/11PVT. **Area Ref:- Landfill Site Near Sendafa Area** **No of Samples:-** 5

Sample No. TP-6 (0-1.20m)

Sample Type:-Disturbed Soil **Lab No:-** 20523/11

Type of Analysis:-XRD **Preparation required: -** powder <63mic. **Date Submitted:-**12/12/2011

V) Identified Minerals

Mineral	(%)
Albite	63.9
Hematite	13.0
Quartz	13.9
Dickite	9.1

II) Remark note:-

Described By / Analysts Girma Asemu

Checked by Worku Gebrekirstos
Mineralogy & Physical Analysis
Case Team Co-ordinator

Date Completed 04/01/2012

Geological Survey of Ethiopia
Geosciences Laboratory Center
Result Form

Case Team: - Chemical: Lab Section: - Silicate ☐ **Gold & Base metal** ☐ **Water** ☐
Hydrocarbon ☐

Case Team: - Mineralogical: Lab section: - Mineralogy ☑ **Physical** ☐

Client /Originator Name: - Netsanet Mengistie (A.A University)

Client Category: - Survey ☐ **Gov.** ☐ **Pvt.** ☑

File name: - 20524/11PVT **Area Ref-:** Sendafa **No of Samples:** 2 **Sample No:** TP-6 (1.20)37493507E, 1000070N, E-2450m

Sample Type: - Rock **Lab No: -** 20524/11

Type of Analysis: Petrography **Preparation required: -** Thin section **Date Submitted: -** 12/ 12/2011

I) Hand specimen Description: Gray with brownish tint in color and fine grained in texture.

II) Mineral composition

Mineral	Modal (%)	Texture
Plagioclase	36	Lath
Pyroxene	34	Anhedral
Opaque (Fe-oxide)	10	Fine-anhedral
Olivine	8	Euhedral
Volcanic glass	8	-
Calcite	3	Anhedral
Biotite	1	Platy

Geological Survey of Ethiopia

III) Textural Descriptions / Notes: Flow texture

Plagioclase show parallel orientation. The groundmass is mainly composed of lath plagioclase, anhedral pyroxene, euhedral olivine and euhedral to anhedral opaque (Fe-oxide) minerals. Large olivine grains and clusters of plagioclase are phenocrysts on the ground mass. Volcanic glass devitrified to biotite and calcite.

IV) Rock Name: - Olivine Basalt

Described By / Analysts 1. Workelul G/K

Checked by Workelul G/Kirstos
Mineralogy & Physical Analysis
Case Team Co-ordinator

Date Completed 27/12/2011

Geological Survey of Ethiopia
Geosciences Laboratory Center
Result Form

Case Team: - Chemical: Lab Section: - Silicate ☐ **Gold & Base metal** ☐ **Water** ☐
Hydrocarbon ☐

Case Team: - Mineralogical: Lab section: - Mineralogy ☑ **Physical** ☐

Client /Originator Name: - Netsanet Mengistie (A.A University)

Client Category: - Survey ☐ **Gov.** ☐ **Pvt.** ☑

File name: - 20524/11PVT **Area Ref-:** Sendafa **No of Samples:** 2 **Sample No:** SER (Surface exposed rocks in landfill site)

Sample Type: - Rock **Lab No: -** 20525/11

Type of Analysis: Petrography **Preparation required: -** Thin section **Date Submitted: -** 12/ 12/2011

I) Hand specimen Description: Black in color and very fine grained in texture.

II) Mineral composition

Mineral	Modal (%)	Texture
Microlite Plagioclase	40	Microlitic
Pyroxene	20	Anhedral
Rock fragment	20	-
Opaque (Fe-oxide)	10	Fine-anhedral
Volcanic glass	10	-

III) Textural Descriptions / Notes: Porphyritic and Flow texture

Plagioclase show parallel orientation. The groundmass is mainly composed of microlite plagioclase, anhedral pyroxene, rock fragment (consists of basalt, andesite & pumice) and anhedral opaque (Fe-oxide) minerals. Rock fragments are phenocrysts on fluidal ground mass.

IV) Rock Name:- Andesitic Tuff

Described By / Analysts **Checked by** **Date Completed** 27/12/2011

1. Workelul G/K

Workelul G/Kirstos
Mineralogy & Physical Analysis
Case Team Co-ordinator

Page 2 of 2

ANNEX-4 :Koshe Secondary Soil Data

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ላቦራቶሪ አገልግሎትንዑስ የስራ ሂደት

Water Works Design and Supervision Enterprise
Laboratory Service Sub process

የአፈር ለምነት ክፍል

Soil Fertility Section

Tel. 251 - 116 - 61 45 01
251 - 116 - 61 01 05

Fax. 251 - 116 - 61 53 71/61 08 98
e-mail w.w.d.s.e@ethionet.et

Client:-

Sampling Date: 7-21 October 2011

Test Method: Hydrometer,Acid neutralazaion , Olsen, Kjeldahl
Walklay Black , Ammonium Acetate & Instrumental

Mixed Sample (G+H+I)

LABORATORY NUMBER	464/04	465/04	466/04	467/04	468/04	469/04	470/04
DEPTH (M)	1	5	10	15	20	25	30
Sand (%)	57.17	46.69	45.56	52.56	43.20	43.2	38.81
Silt (%)	26.12	27.18	27.22	26.82	25.25	25.3	26.37
Clay (%)	16.72	26.13	27.22	20.63	31.56	31.6	34.81
Texture Class	Sandy Loam	Sandy clay lo	Sandy cla	Sandy cla	Silt Loam	Clay Loa	Clay Loam
P^H-H_2O (1:2.5)	6.97	8.07	8.20	8.01	8.75	8.79	8.68
P^H-KCL (1:2.5)	6.70	7.90	7.85	7.74	8.20	8.14	8.11
EC(ms/cm) (1:2.5)	12.15	9.22	5.16	6.83	8.29	5.10	5.09
Exch.Na(meq/100gm of soil)	4.57	4.52	3.75	4.30	5.52	4.06	4.11
Exch.K(meq/100 gm of soil))	9.07	8.00	6.83	7.03	8.02	7.59	7.48
Exch.Ca(meq/100 gm of soil)	39.52	25.38	26.62	19.78	16.80	2.58	21.42
Exch.Mg(meq/100 gm of soil)	17.06	13.31	9.98	11.54	10.08	7.14	10.50
Sum of Cations (meq/100gm of soil)	70.21	51.21	47.19	42.64	40.43	39.38	43.51
CEC(meq/100 gm of soil)	44.31	37.53	37.08	35.83	22.83	40.63	42.91
Organic Carbon(%)	26.22	12.99	11.72	12.00	9.58	8.21	9.28
Nitrogen (%)	1.34	1.14	1.14	1.05	0.88	0.81	1.01
Available P(mg P_2O_5/kg soil)	353	437.3	336.6	392.4	529.3	403	397.96
Available K(mgK_2O/kg soil)	3609	3146.5	2681	7369.0	9474	7018	4361.0
Exchangeable Sodium %(ESP)	10.31	12.05	10.12	12.00	24.20	10.0	9.57
Soluble Salts (meq/l) 1:5 ext.							
Na (meq/l)	7.16	15.83	8.78	17.83	20.09	13	12.43
K (meq/l)	9.44	11.59	6.82	11.74	10.72	5.85	5.54
Ca (meq/l)	5.65	6.90	5.06	5.52	2.30	4.14	2.76
Mg (meq/l)	18.85	2.70	1.74	2.88	0.50	2.26	3.24
CO_3^{-2} (meq/l)	2.40	2.40	Nil	Nil	2.40	1.60	Nil
HCO_3^{-1} (meq/l)	16.20	15.20	6.00	18.00	4.40	4.00	12.00
Cl^- (meq/l)	0.84	20.44	12.60	22.12	24.64	18.2	11.76
SO_4^{-2} (meq/l)	19.80	1.76	2.13	1.46	1.74	2.87	2.39
Micronutrient							
Cu (mg/kg soil)	0.36	3.72	6.73	3.74	6.49	6.23	3.49
Fe (mg/kg soil)	72.53	30.40	26.18	60.81	39.20	30.7	35.25
Mn (mg/kg soil)	84.73	80.93	74.95	45.72	69.64	72.4	105.83
Zn (mg/kg soil)	155.3	156.5	154.7	155.7	154.4	156	155.10
Boron (mg/Kg B)	6.33	2.62	4.49	10.38	13.28	9.57	12.07

Checked by_____ Approved By_____

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ላቦራቶሪ አገልግሎትንዑስ የስራ ሂደት

Water Works Design and
Supervision Enterprise
Laboratory Service Sub process

የአፈር ሰምነት ክፍል

Soil Fertility Section

Tel. 251 - 116 - 61 45 01
251 - 116 - 61 01 05

Fax. 251 - 116 - 61 53 71/61 0
e-mail w.w.d.s.e@ethionet.

Client:-

Sampling Date: 7-21 October 2011

Test Method: Hydrometer,Acid neutralazaion , Olsen, Kjeldahl
Walklay Black , Ammonium Acetate & Instrumental

	mixed Sample (G+H+I)						
LABORATORY NUMBER	471/04	472/04	473/04				
DEPTH (CM)	35	40	45				
Sand (%)	16.710047	16.71	16.71				
Silt (%)	30.19	30.19	30.2				
Clay (%)	53.10	53.10	53.1				
Texture Class	clay	clay	clay				
P^H-H_2O (1:2.5)	8.16	7.81	8.60				
P^H-KCL (1:2.5)	7.61	7.55	8.02				
EC(ms/cm) (1:2.5)	2.26	_	_				
Exch.Na(meq/100gm of soil)	4.11	4.29	4.98				
Exch.K(meq/100 gm of soil))	7.48	7.73	7.65				
Exch.Ca(meq/100 gm of soil)	19.55	19.6	20				
Exch.Mg(meq/100 gm of soil)	10.82	11.0	9.63				
Sum of Cations (meq/100gm of soil)	33.19	52.8	39.7				
CEC(meq/100 gm of soil)	29.39	38.7	36.2				
Organic Carbon(%)	22.98	15.7	12.5				
Nitrogen (%)	1.08	1.17	0.95				
Available P(mg P_2O_5/kg soil)	194.21	380	381				
Available K(mgK_2O/kg soil)	1854.7	3054	2714				
Exchangeable Sodium %(ESP)	7.32	11	12.3				
Soluble Salts (meq/l) 1:5 ext.							
Na (meq/l)	4.43	_	_				
K (meq/l)	1.59	_	_				
Ca (meq/l)	3.68	_	_				
Mg (meq/l)	1.52	_	_				
CO_3^{-2} (meq/l)	Nil	_	_				
HCO_3^{-1} (meq/l)	2.80	_	_				
Cl^- (meq/l)	8.40	_	_				
SO_4^{-2} (meq/l)	0.39	_	_				
Micronutrient							
Cu (mg/kg soil)	2.53	3.64	4.68				
Fe (mg/kg soil)	46.35	46.40	46.3				
Mn (mg/kg soil)	92.87	92.50	92.0				
Zn (mg/kg soil)	54.49	54.51	54.5				
Boron (mg/Kg B)	5.67	5.72	5.67				

RemarK:

Checked by_____

ANNEX-4: Site permit and land lease certificate of Chebe Weregenu Landfill

Bulchiinsa Mootummaa Naannoo Oromiyaatti
Biiroo Lafaa fi Eegumsa Naannoo
The Oromia regional Government
Bureau of Land and Environmental Protection
Finfinnee/ Addis Ababa

በኦሮሚያ ክልላዊ መንግስት መስተዳድር
የመሬትና የአካባቢ ጥበቃ ቢሮ
ፊንፊኔ / አዲስ አበባ

Lakk. /ቁጥር/ Ref. No. BLEN/123/1386

Guyyaa /ቀን/Date 7-10-2013

Bulchiinsa Magaalaa Finfinneeti Waajjira projeektii "Solid Waste Recycling and Disposal" tiif
Finfinnee

Dhimmi;- Waraqaa Ragaa qabiyee lafaa mirkana'e kennu ta'a.

Godina **Addaa Oromiyaa N/Finfinnee** Aanaa **Barak** G/Q/B/**Aqaaqii Qiillee Seerii Goyyuu fi Haabraqanuu Kurraa Jaadaa iddoo Cabee Warra Gannuu jedhamu** keesattii lafa balinissa **heek 136.6** ta'e tajaajila **"Solid Waste Recycling and Disposal"** tiif oolu haala Mootummaan Naannoo Oromiyaa fi Bulchiinsi Magaalaa Finfinnee walii galameen ragaaqabiyyee lafa akkaa isini kennamuuf nu gaafachuun keessan ni yaadatama.

Kanaafu haala bal'ina lafaa olitti eerameen Waraqaa ragaa qabiyyee itti fayyadama lafaa maqaa keessaniin hojjatame fuula tokko mirkaneesine isini kennu keenya ibsaa, haali ittifaayyadama lafaas haaluma tajaajila waliigalameen akka raawwatu beeksiisaa qaamiin Mootummaa ilaaltuu deeggersa barbaachisaa akka godhuuf koppy xalayaa eerguu keenya ni beeksifina.

Nagaa Waajjin

Ashoomaa Damissee
Gaggeessaa Adeemsa
Hojii Ittifayyadama Lafaa

G/G
- Biiroo Galii Oromiyaatiif

Finfinnee
- Waajjira La/ fi Ee/N/ Godina AON Finfinnee tiif

Finfinnee
- Waajjira La/fi Ee/N/Aanaa Barak tiif

Sandaafaa
- Oogana Biirootiif
- AH Eegumsa Naannoo tiif
- AH Itti Fayyadama lafaa tiif
- AH Bulchinsa lafa Baadiyaatif

BLENO

☎ 251-011-369-01-59; 251-011-371-72-92. 251-011-371-73-81 ✉ 22736 E.mail:-blenoromia@yahoo.com
Deebii yeroo kennitan lakkoofsa xalayaa kennyaa caqasaa
እባክም መልስ ሲሰጡ የደብዳቤያችንን ቁጥር ይጥቀሱ
please quote our Ref. No. While Replying

Guyyaa/Date ቀን 7-10-2003

Lakk/Reg. No ቁጥር BLL/W 123/1386

WARAQAA RAGAA LIIZII/KIRAA LAFAA

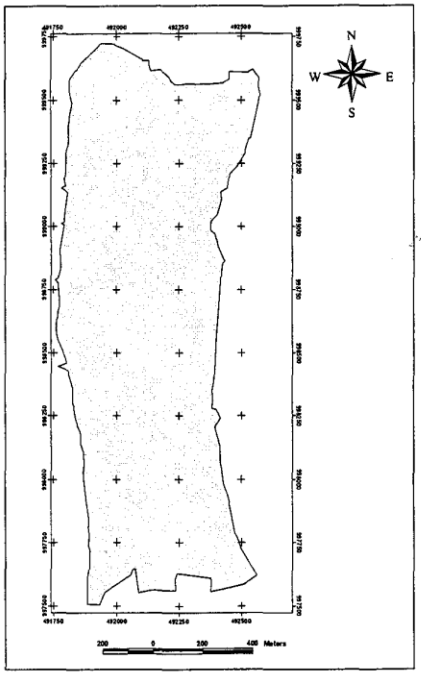
Bulchiinsa Mootummaa Naannoo Oromiyaatti Biiroo Lafaa fi Eegumsa Naannoo hundeessuu fi Aangoo fi hojii Biirichaa murteessuuf bahe Labsii Lakk. 147/2001 irratti hunda'udhaan lafa **Heek** 136.61 Godina **AON Finfinnee** Aanaa **Barak** ganda **Aqaaqii Qiillee Seerii Goyyuu fi Haabraqanuu Kurraa Jaadaa** iddoo **Cabee Warra Gannuu** keessatti argamu **03/07/2002** irraa kaassee **iddoon gataa hanga tajaajila kennuu danda'u** liizii/ Kiraadhaan/**Bilisaan** akka tajaajila jedhameef oolchan **"City Government of Addis Ababa Solid Waste Recycling and Disposal Project office" tiif** kennameera.

የመሬት ኪራይ/ሊዝ ምስክር ወረቀት

በኦሮሚያ ብሔራዊ ክልላዊ መንግሥት የመሬትና የአካባቢ ጥበቃ ቢሮ ለማቋቋምም ሥልጣንና ተግባሩን ለመወሰን በወጣው አዋጅ ቁጥር 147/2001 መሠረት በማድረግ በፊንፊኔ ዙሪያ የኦሮሚያ ልዩ ዞን በረከ ወረዳ አቃቂ ቂሊ ሴሪ ጎዩ እና ሃብረቀኑ ኩራ ጃዳ ልዩ ስሙ ጨቤ ወራጎኑ የሚገኘውን 136.61 ሄ/ር መሬት ከዛሬ 03/07/2002 ዓ.ም ጀምሮ መሬቱ የላንድ ፊል ሳኔታሪ አገልግሎት መስጠት እስከቻለ ጊዜ ድረስ በለገዢ/በኪራይ/በነፃ ለቆሻሻ መልሶ መጠቀምና ማስወገድ አገልግሎት እንዲያውሉ በአበባ ከተማ አስተዳደር የመልሶ መጠቀምና ማስወገድ ፕሮጀክት ጽ/ቤት ተሰጥቷል.

LAND LEASE/RENT CERTIFICATE

Based on the proclamation to provide for Establishment and definition of powers and duties of Bureau of Land and Environmental Protecition of Oromia National Regional Government No.147/2009 **136.61 ha** of land located in **OSZS Finfine Berek** Woreda, **Akaki kile Seri Goyu and Habrekenu Kura Jada** kebele specific place **Chebe Wera genu** is Leased/Rented/**given Free** to **"City Government of Addis Ababa Solid Waste Recycling and Disposal Project office"** for Solid Waste Recycling and Disposal services from **03/07/2002** E.C to till the place can give services



Teessoo/ አድራሻ /Address			Lakk. Addaa iddichaa የቦ ቁጥር Unique No	Sadarkaa Lafaa የቦ ደረጃ Land Standard	Bal'ina Lafa (Heek/sq. meetrii) Area of Land (He/m². meter) የቦ ስፋት /ሄ/ር/ሜ.ካ/	Tajaajjila Lafa የቦ አገልግሎት Type of Service
Godina ዞን Zone	Aanaa ወረዳ Woreda	Ganda ቀበሌ Kebele				
GAON Finfinnee በፊኒፊኔ ዙሪያ የኦሮሚያ ልዩ ዞን	Barak በረከ	Aqaaqii Qiillee Seerii Goyyuu fi Haabraqanuu Kurraa አቃቂ ቂሊ ሴሪ ጎዩ እና ሃብረቀኑ ኩራ ጃዳ	----------	----------	**136.61 ha**	**Solid Waste Recycling and Disposal**

Kan Qopheesse /Prepared By

Kan Mirkaneesse/ Approved By

ያዚጋጀዉ

Maqaa/Name _____
ስም
Gahee Hojii/Position _____
ሥራ ድርሻ
Mallattoo/Signature _____
ፊርማ

ያፀደቀው

Maqaa /Name _____
ስም
Gahee Hojii/Position _____
ሥራ ድርሻ
Mallattoo/Signature _____
ፊርማ

Teshome Demissie
Land Use
Process Leader

ANNEX – 5 Soil Description during site investigation

TP-1(0.0-1.3m): dark black, dry, firm to stiff, highly plastic expansive (black cotton) clay, highly cracked is about 10 centimeters observed after one week pit excavation. The in situ unconfined compression strength measured was 375 Kpa.

TP-1(1.30-2.0m): Light grayish wet, highly to extremely plastic expansive clay. The in situ unconfined compression strength measured was 300 Kpa.

TP-2(0.0-1.2m): Dark black, dry, firm to stiff, highly plastic expansive (black cotton) clay. Grain roots have penetrated up to 0.5 meters. The in situ UCS value measured 375 Kpa.

TP-2(1.20-2.0m): pinkish light brown (variegated) tuff with mottling and muscovite minerals and very wet. The in situ unconfined compression strength (UCS) measured in the pit was 350Kpa.

TP-3(0.0-2.0m): Light grayish wet soft highly to extremely plastic expansive clay. The in situ UCS value measured was 250 Kpa.

TP-4 (0.0-2.0m): Light grayish wet soft highly to extremely plastic expansive clay. The in situ UCS value measured was 250 Kpa.

TP-5(0-1.2m) is similar to TP-2(0-1.2m). TP-5(1.20-2.0m) was found pinkish light brown soft, friable, light weight with mottling and wet. The in situ UCS value measured was 325 Kpa.

TP-5(1.2-2.0m): Pinkish, light brown soft, friable, light weight with mottling and wet.

TP-7(0.0-4.0m): Reddish brown, stiff homogeneous residual silty clay, moist with no grass root penetration.

TP-8(0-1.87m): dark black dry, firm (black cotton) clay with no grass root penetration. The crack width is about 10 centimeters measured after one week of pit excavation. Thein situ UCS value measured was 375 Kpa.

TP-8 (1.87-3.17m) light yellowish, soft, tuff (Lapilli), very light weight, friable, amorphous and very wet. Thein situ UCS value measure was 350 Kpa.

TP-8 (3.17-4.07m): light grayish, soft lapilli tuff; very light weight, friable, amorphous and very high moisture content was observed during extraction of undisturbed sample at 4meter. Thein situ UCS value measured was Refusal (> 450Kpa).

ANNEX – 6: Definitions

MOISTURE CONTENT (w) The mass of water which can be removed from the soil by heating at 105^0C, expressed as a percentage of the dry mass. This also referred to as Water Content.

NATURAL MOISTURE CONTENT The moisture content of natural undisturbed soil in situ.

LIQUID LIMIT (LL) The moisture content at which soil passes from the plastic to the liquid state, as determined by the liquid limit test.

PLASTIC LIMIT (PL) The moisture content at which a soil passes from the plastic state to the solid state, and becomes too dry to be in a plastic condition, as determined by the plastic limit test.

PLASTIC INDEX (PI): The numerical difference between liquid limit and plastic limit.

SHRINKAGE LIMITS (SL) The moisture content at which a soil on being dried ceases to shrink.

PARTICLE SIZE ANALYSIS expresses quantitatively the proportions by mass of the various sizes of particles present in the soil.

PARTICLE SIZE is usually given in terms of the equivalent particle diameter.

GRAVEL: Particles from 60mm to 2mm.

SAND: Particles from 2mm to 0.06mm.

SILT: Particles from 0.06mm to 0.002mm.

CLAY: Particles (clay minerals) smaller than 0.002mm (2μm).

FINES: are particles which pass a 63μm sieve.

COMPACTION The process of packing soil particles more closely together, usually by mechanical means, thus increases the dry density of the soil.

OPTIMUM MOISTURE CONTENT (OMC) The moisture content of a soil at which a specified amount of compaction will produce the maximum dry density.

MAXIMUM DRY DENSITY (MDD) The dry density obtained using a specified amount of compaction at the optimum moisture content.

SPECIFIC GRAVITY is a number representing the ratio of the weight of a mineral to the weight of an equal volume of water.

PERMEABILITY The rate at which a fluid (usually water) under pressure can diffuse through the voids of soil.

SHEAR STRENGTH The maximum shear resistance which a soil can offer under defined conditions of effective pressure and drainage.

UNCONFINED COMPRESSION STRENGTH (qu) The compressive strength at failure of a specimen subjected to unconfined compression.

CONSOLIDATION The process whereby soil particles are packed more closely together over a period of time under the application of continued pressure. It is accompanied by drainage of water from the pore space between solid particles.

(Source: H. Head Manual of Soil Laboratory Testing Volume 1: Soil Classification and Compaction Tests. ELE International Ltd.)

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