ADDIS ABABA UNIVERSITY

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Preliminary investigation to Use Water Hyacinths ("EMBOCH") for Stabilization of Expansive soils: A Case Study on source of Water Hyacinth LakeTANA

A Thesis Submitted to

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The requirements for the Degree of

Master of Science in Civil Engineering (Road & Transport Engineering)

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Advisor: Dr. Alemayehu Ambo

October, 2018

CERTIFICATION

The thesis titled "Preliminary investigation to Use Water Hyacinths ("EMBOCH") for Stabilization of Expansive soils: A Case Study on source of Water Hyacinth LakeTANA" by Mussie Lemma meets the regulations governing the award of the degree of Master of Science (M.Sc) in Civil Engineering Addis Ababa University and is approved for its contribution to knowledge and literary presentation.

Approved by board of examiners

Dr. Alemayehu Ambo	……………………….	……………………
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Chairman	Signature	Date

DECLARATION

I hereby declare that the thesis entitled "Preliminary investigation to Use Water Hyacinths ("EMBOCH") for Stabilization of Expansive soils: A Case Study on source of Water Hyacinth LakeTANA" has been carried out by me under the supervision of Dr. Alemayehu Ambo during the year 2017/18 as part of Master of Science Program in Road & Transport Engineering. I further declare that this work has not been submitted to any other University or institution for the award of any degree. All quotations and their sources are specifically acknowledged by means of references.

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ABSTRACT

Since long, improvement in characteristics of expansive soil by using different materials has been a challenging job for engineers. Construction in the 21st Century saw the advancement of a large number of new materials and products accompanied by the emergence of new methods for the utilization of waste materials. Many researchers have made an attempt with the use of different materials like cement, Fly ash, lime Etc. but the aim of this study is to stabilize expansive soils by the use of water hyctine locally known as 'emboch'.

The Expansive soil, collected from Ayira, Gondar, has been classified as an A-2-7 soil on the AASHTO classification. It was stabilized using a dry water hyctine from 5% to 15% replacement by dry weight of the soil. The effect of the additives on the soil was investigated with respect to atterberg limits, Specific gravity, free swell, moisture density relationships California bearing ratio (Soaked CBR) and CBR Swell.

After the investigation, with the increment of water hyctine (WH), it was found that the optimum moisture content increased until 10% and decreased on 15% while the maximum dry density values decreased until 10% and increased on 15%. Free swell ratio of the stabilized samples decreased with increasing WH content. CBR values slightly increased with the addition of WH. The CBR of the soil at 15% of WH almost fall in to the category of fair sub grade. This shows a potential of using WDE as potential material in stabilization of expansive soils.

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LIST OF ABBREVIATIONS

AASHTO	American Association of Highway and Transportation Officials
ASTM	American Society for Testing and Materials
BoEPLUA	Bureau of Environmental Protection Land Use and Administration.
CBR	California Bearing Ratio
ERA	Ethiopian Roads Authority
IFAD	International Fund for Agricultural Development
IS	Indian Standard
LL	Liquid Limit
MDD	Maximum Dry Density
OMC	Optimum Moisture Content
PI	Plastic Index
PL	Plastic Limit
PL	Plastic Limit
USCS	Unified Soil Classification System

Units

^oC	Degree Centigrade
cc	Centimeter cube
Gm	Gram
kg	Kilogram
km	Kilometer
kN/m^2	Kilo Newton per meter square
kPa	Kilo Pascal
kN	Kilo Newton
mm	Millimeter
g/cm^3	Gram per centimeter cube
cm^3	Centimeter cube

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CHAPTER ONE: INTRODUCTION

1.1 Background of the study

Lake Tana is the source of the Blue Nile and is the largest lake in Ethiopia. It is fed by the lower Abay, Reb and Gumara rivers. The surface area ranges from 3,000 km² to 3,500 km² depending on season and rainfall. The lake level has been regulated since the construction of the control weir where the lake discharges into the Blue Nile. This controls the flow to the Blue Nile Falls ("Tis Abbai") and hydro-power station.(Ayalew Wondie et al., 2012).

Lake Tana is located in the Amhara Region in the north-western Ethiopian Highlands. It is geographically located in the north-western part of Ethiopia, between latitude 10°58`–12°47`N and longitude 36°45`-38°14`E. . It is approximately 84 kilometers long and 66 kilometers wide, with a maximum depth of 15 meters, and an elevation of 1,788 meters. It is the largest freshwater body in the country, contributing about 50% of the water resource of the nation. The Lake Tana watershed consists of 347 *Kebele*s (the lowest administrative units) and 21 *Woredas* (districts) in four administrative zones (IFAD, 2007).

Lake Tana's global importance originates not only from the biodiversity perspective but from hydro-politics point of view, being the source of the Blue Nile River. The importance of Lake Tana is not to regionally confine but also nationwide due to the resource potential for hydropower and irrigation development. Some of the hydropower projects (e.g. Tana- Beles) and irrigation (e.g. Koga) are recently completed. Figure 1.1 below presents the map of Lake Tana showing dam construction and water pump sites and the extents of proposed irrigation areas.

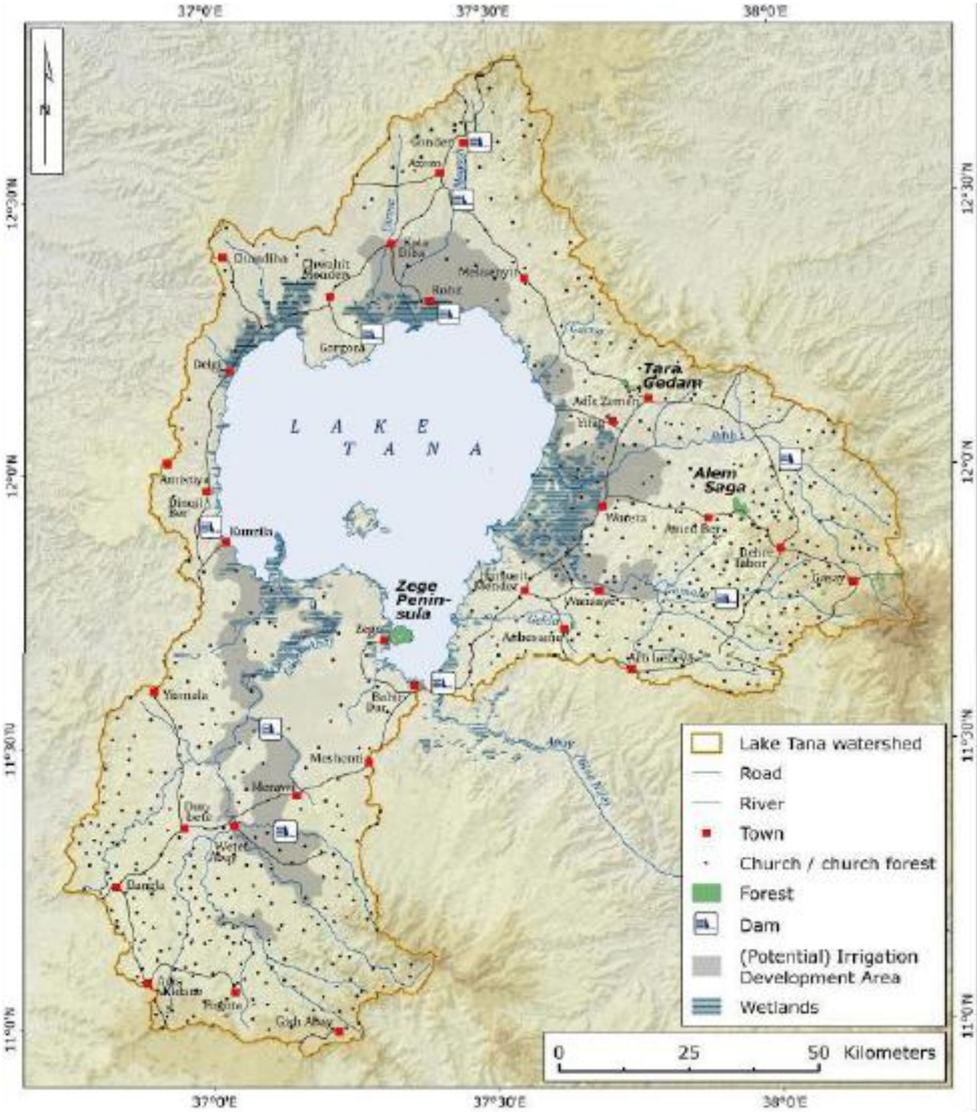


Figure 1.1 Map of Lake Tana showing dam construction sites, water pump sites and the extents of proposed irrigation areas (Heide, 2012).

Water hyacinth is a free-floating perennial (or hydrophyte) plant native to tropical and sub-tropical South America. It has broad, thick, glossy, ovate leaves; it may rise above the surface of the water as much as 1 meter in height and have 80 cm root below the surface of water. The leaves are 10-20 cm across, and float above the water surface. They have long, spongy and bulbous. It is one of the most dangerous aquatic weeds for Lake Tana.(Admas A, et al.,2017). To minimize invasion; biological, chemical and physical control methods can be used. Researchers have been continuing since 2011 but the present removal method is by physical methods.

1.2 Statement of the Problem

Water hyacinth locally known as "emboch" is one of the major problems on Lake Tana. Many people are dependent on this lake for their livelihood. The water hyacinth is damaging the farmers' crops, grazing land and Lake Tana itself. By understanding this basic problem, the regional government has raised awareness of "emboch" to the local people and the people have done a lot to eliminate the weeds.

Though the communities have done a lot to eliminate the weeds, it has now spread to five neighboring woredas. According to the Amhara regional government the water hyacinths and land areas which are covered by weeds have increased from 20,000 hectare to 40,000 hectare .So this re- infestations of the weeds creates a circular closed loop of problems (weed grows→ creates problems→ remove the weed→ re- infestation →weed re grows). Water hyacinth affects navigation, water flow, recreational use of aquatic systems, and poses of mechanical damage to hydroelectric systems. It is also responsible for drastic changes in the plant and animal communities of fresh water environments. As it will be discussed in the literature review part most this weed will destroy the lake in few years. So everyone agrees something must be done.

1.3 Objectives

1.3.1 General Objectives

The prime objective of this study is to make preliminary assessment if water hyacinths can be used to stabilize expansive soils.

1.3.2 Specific objectives

- To determine how the physical characteristics of solid part water hyacinths influence the properties of the expansive soil at different replacement ratios,
- To investigate the possibility of using water hyacinths as an additive (partial replacement) material in stabilization in Ethiopia, and
- To provide a way of looking for future studies on water hyacinths

1.4 Scope of the study

This study investigates the effect of water hyacinths on expansive soils on enhancing geotechnical properties. The results have been compared with different studies that have been studied on expansive soils. But one must consider the limitation of this study to the specific soil being investigated and to the laboratory tests specifically used. Therefore, findings should be considered indicative rather than definitive for field applications.

1.5 Organization of the Thesis

This study has been divided in to five chapters.

Chapter one: Introduction; shows background, statement to the problem and the objective of the study.

Chapter two: literature review; refers to different studies relative to this project.

Chapter three: materials and methodology; shows the way and the materials used for this project.

Chapter four: results and discussions ;engineering properties of the expansive soil and improvements due to addition of water hyacinth is discussed.

Chapter five: conclusion and recommendation; conclusions drawn from the test results are discussed, recommendations on using water hyacinth as a stabilizing agent and future research areas are pointed out.

CHAPTER TWO: LITERATURE REVIEW

2.1 Distribution of Expansive Soil

By definition expansive soils are the type of soils that are prone to large volume changes (swelling and shrinking) which are directly related to changes in water content. Expansive soil shows recurrent volume changes with the changes of moisture content, causing serious problems to the civil engineering structures such as road pavements resting on them.

Expansive soil covers an appreciable part of Ethiopia. It constitutes a real financial risk and disruption to the quality of life. Most of the roads constructed, lightly loaded residential and commercial buildings, airfield and proposed as well as substantial amount of the newly planned railway routes in the country pass through in the heart of expansive soils. Engineering design of such structures in and on this soil must recognize and accept the complexity of the material behavior of the ground (Bin Shi et al., 2002).

Distribution of expansive soil is generally a result of geological history, sedimentation and local climatic conditions. Arid climatic conditions and severe weathering environment prevailing in north eastern part of Africa promote the widespread occurrence of expansive soils in this region (Melik Y., 2015) .In Ethiopia, covering nearly 40% surface area of the country (Meron W., 2013), expansive soils are observed in area such as central Ethiopia, following the major trunk road like Addis Ababa - Ambo, Addis Ababa - Weliso, Addis Ababa - Debere Berehan, Addis Ababa - Gohatsion, Addis Ababa - Mojo. Expansive soil covers also the area like Mekelle, Bahirdar, Gambela, Arba Minch and the most Southern, South-west and south-east part of the capital Addis Ababa area in which the most major recent construction are being carried out. The distribution is shown in Figure 2.5 below. (Meron W., 2013)

Figure 2.5 Distribution of expansive soil in Ethiopia (Meron W., 2013)

Expansive soils are sometimes called black cotton soils, shrink-swell soils, swelling soils, adobe, clay, or caliche soils. They are widely distributed especially in the highlands. Known as vertisols, they are present in the central, north-eastern highlands and western lowlands. They are fertile and used intensively for agriculture. It is estimated that 7.6 million hectares of vertisol area is located in the highlands with a height of greater than 1,500 m above sea level. The remaining area (over 5 million hectares) is located at an elevation below 1,500 m (Meron W., 2013).

The general slope range of the landscape on which vertisols occur is 0 – 8 percent. They are more frequent in 0 -2 percent slope range and are usually found in landscapes of restricted drainage such as seasonal inundated dipressional basins, alluvial and colluvial plains, undulated plateaus, valleys and undulating side slopes (Bin Shi et al., 2002;Eleyas Assefa et al., 2016 and ERA manual, 2013).

2.2 Identification of expansive soils.

In different areas of Gondar, expansive clay soils can be easily recognized in the dry season by the deep cracks, in roughly polygonal patterns, in the ground surface the zone of seasonal moisture content fluctuation can extend from three to forty feet deep. This creates cyclic shrink/swell behavior in the upper portion of the soil column, and cracks can extend too much greater depths than imagined by most engineers. Figure 2.6 below shows the polygonal pattern of surface cracks in dry season.

Figure 2.6 Polygonal pattern of surface cracks in dry season. (Location for the expansive soil Ayra,Gondar)

Arid and semiarid areas are particular trouble spots because of large variations in rainfall and temperature.

2.2.1 Methods of recognizing expansive soils

Grouped into three categories, the following are the methods of recognizing expansive soils: (Meron W., 2013).

- Mineralogical identification

The techniques that can be used are (Chen, 1988; Nelson, and Miller, J.D., 1992):

- X-ray diffraction;
- Differential thermal analysis;
- Dye adsorption;
- Chemical analysis; and
- Electron microscope resolution.

But these methods are not suitable for routine tests because of the following reason;

- They are time consuming;
- They require expensive test equipment; and
- The results can be only interpreted by specially trained technicians.

- Indirect methods, such as soil suction, activity and index properties are:
  - Atterberg Limits;
  - Free Swell Tests;
  - Free Swell Index;
  - Free Swell Ratio test; and
  - Cation Exchange Capacity (CEC).

- Direct measurement.
  - These methods offer the most useful data by direct measurement; and tests are simple to perform and do not require complicated equipment. Testing should be performed on a number of samples to avoid erroneous conclusions.Direct measurement of expansive soils can be achieved by the use of conventional one-dimensional consolidometer (Meron

W., 2013).Impractical and uneconomical in practice, methods of mineralogical identification still hold importance in exploring basic properties of clay minerals. Direct measurement, out of the remaining two categories, offers the most useful data.

By their shattered or fissured condition, or obvious structural damage to existing buildings caused by such soils, potentially expansive soils are usually identified in the field. To classify expansive soil, potential swell, or potential expansion, or the degree of expansion is a favored term used; from this, geotechnical engineers establish how good or bad the expansive soils are (Meron W., 2013).

2.2.2 Classification of soil using general methods

The most widely used general classification systems are:

i. AASHTO Classification

A Soil Classification System was developed by the American Association of State Highway and Transportation Officials(AASHTO), and is used as a guide for the classification of soils and soil-aggregate mixtures for highway construction purposes. The classification system was first developed by Hogentogler and Terzaghi in 1929, but has been revised several times since.
Table 2.2 below provides the AASHTO classification standards (Meron W., 2013).

Table 2.1 AASHTO classifications.

General Classification	*Granular materials (35% or less passing No. 200 Sieve (0.075 mm)*							*Silt-clay Materials More than 35% passing No. 200 Sieve (0.075 mm)*			
Group Classification	*A—1*		*A—3*	*A—2*				*A—4*	*A—5*	*A—6*	*A—7*
	A—1—a	*A—1—b*		*A—2—4*	*A—2—5*	*A—2—6*	*A—2—7*				*A—7—5* *A—7—6*
(*a*) Sieve Analysis: Percent Passing											
(*i*) 2.00 mm (No. 10)	50 max										
(*ii*) 0.425 mm (No. 40)	30 max	50 max	51 min								
(*iii*) 0.075 mm (No. 200)	15 max	25 max	10 max	35 max	35 max	35 max	35 max	36 min	36 min	36 min	36 min
(*b*) Characteristics of fraction passing 0.425 mm (No. 40)											
(*i*) Liquid limit				40 max	41 min	40 max	41 min	40 max	41 min	40 max	41 min
(*ii*) Plasticity index	6 max		N.P.	10 max	10 max	11 min	11 min	10 max	10 max	11 min	11 min*
(*c*) Usual types of significant Constituent materials	Stone Fragments Gravel and sand		Fine Sand	Silty or Clayey Gravel Sand				Silty Soils		Clayey Soils	
(*d*) General rating as subgrade.	Excellent to Good							Fair to Poor			

* If plasticity index is equal to or less than (liquid Limit—30), the soil is A—7—5 (*i.e.* PL > 30%)
If plasticity index is greater than (Liquid Limit—30), the soil is A—7—6 (*i.e.* PL < 30%)

As shown in Table 2.2 above, soils rated A-6 or A-7 by AASHTO can be considered potentially expansive (Nelson, and Miller,1992).

ii. Unified Soil Classification Systems

The Unified Soil Classification System (USCS) is a soil classification system used in engineering and geology to describe the texture and grain size of a soil. The classification system can be applied to most unconsolidated materials, and is represented by a two-letter symbol. Each letter is described below in Table 2.3(with the exception of Pt):

Table 2.2 Unified Soil Classification System (USCS)

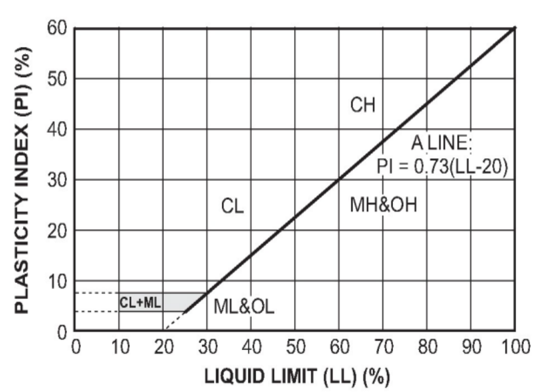
UNIFIED SOIL CLASSIFICATION AND SYMBOL CHART		
COARSE-GRAINED SOILS (more than 50% of material is larger than No. 200 sieve size.)		
GRAVELS More than 50% of coarse fraction larger than No. 4 sieve size	Clean Gravels (Less than 5% fines)	
	GW	Well-graded gravels, gravel-sand mixtures, little or no fines
	GP	Poorly-graded gravels, gravel-sand mixtures, little or no fines
	Gravels with fines (More than 12% fines)	
	GM	Silty gravels, gravel-sand-silt mixtures
	GC	Clayey gravels, gravel-sand-clay mixtures
SANDS 50% or more of coarse fraction smaller than No. 4 sieve size	Clean Sands (Less than 5% fines)	
	SW	Well-graded sands, gravelly sands, little or no fines
	SP	Poorly graded sands, gravelly sands, little or no fines
	Sands with fines (More than 12% fines)	
	SM	Silty sands, sand-silt mixtures
	SC	Clayey sands, sand-clay mixtures
FINE-GRAINED SOILS (50% or more of material is smaller than No. 200 sieve size.)		
SILTS AND CLAYS Liquid limit less than 50%	ML	Inorganic silts and very fine sands, rock flour, silty of clayey fine sands or clayey silts with slight plasticity
	CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays
	OL	Organic silts and organic silty clays of low plasticity
SILTS AND CLAYS Liquid limit 50% or greater	MH	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts
	CH	Inorganic clays of high plasticity, fat clays
	OH	Organic clays of medium to high plasticity, organic silts
HIGHLY ORGANIC SOILS	PT	Peat and other highly organic soils

LABORATORY CLASSIFICATION CRITERIA		
GW	$C_u = \frac{D_{60}}{D_{10}}$ greater than 4; $C_c = \frac{D_{30}}{D_{10} \times D_{60}}$ between 1 and 3	
GP	Not meeting all gradation requirements for GW	
GM	Atterberg limits below "A" line or P.I. less than 4	Above "A" line with P.I. between 4 and 7 are borderline cases requiring use of dual symbols
GC	Atterberg limits above "A" line with P.I. greater than 7	
SW	$C_u = \frac{D_{60}}{D_{10}}$ greater than 4; $C_c = \frac{D_{30}}{D_{10} \times D_{60}}$ between 1 and 3	
SP	Not meeting all gradation requirements for GW	
SM	Atterberg limits below "A" line or P.I. less than 4	Limits plotting in shaded zone with P.I. between 4 and 7 are borderline cases requiring use of dual symbols.
SC	Atterberg limits above "A" line with P.I. greater than 7	

Determine percentages of sand and gravel from grain-size curve. Depending on percentage of fines (fraction smaller than No. 200 sieve size), coarse-grained soils are classified as follows:

Less than 5 percent .... GW, GP, SW, SP
More than 12 percent .... GM, GC, SM, SC
5 to 12 percent .... Borderline cases requiring dual symbols

PLASTICITY CHART



In this classification system a correlation analysis was made between swell potential and unified soil classification as follows:-

- Little or no expansion GW, GP, GM, SW, SP, SM;
- Moderate expansion GW, SC, ML, MH;
- High volume change CL OL, CH, OH; and
- No rating Pt.

The above classification system can be summarized as follow:-

i. All clay soil and organic soils exhibit high volume change;
ii. All clayey gravels and sands and all silts exhibit moderate volume changes; and
iii. All sands and gravels exhibit little or no expansion.

2.2.3 Classification of soil specific to expansive soil

The above classification system may give an initial alert that the soil may have expansive character but it does not provide useful information. A parameter determined from the expansive soil identification tests have been combined in a number of different classification schemes to give qualitative rating on the expansiveness of the soil. But the direct use of such classification systems as a basis for design may lead to an overly conservative construction in some places and inadequate construction in some areas (Nelson, and Miller, 1992).

Some laboratory tests are available for the identification purposes of swelling soils but also by differential thermal analysis, Microscopic examination, and X-ray diffraction. The presence of Montmorillonite in clay minerals allows the judgment of the expansiveness of the soil.
This aspect is however very technical in nature. A simple aspect, as opposed to the aforementioned methods, is the free-swell test, that's done in the laboratory. This test is conducted by adding 10 gm of dry soil, passing through a 425 μ sieve into two separate 100 cc graduated jar – one filled with water, and the other with kerosene. Swelling occurs in the jar containing water. The swelled volume of the soil is then noted (after 24 hours period), and subsequently, the free swell index values, in percentage, are calculated and was followed for free swell index test. The following formula explains the same (IS: 2720 (part 40), 1977).

Free swell value (in %age) = (($Final\ volume - initial\ volume$) / initial $volume$) x 100

There is a small group of soils which can display the characteristics of objectionable volumetric expansion after being compacted and subjected to subsequent saturation. This presents a problem in pavement design as this expansion or swell can damage the structure by means of a "reverse-settlement" mechanism. Experience has shown that the plasticity index (PI) is an excellent indicator of expansive soils.

Hence, it is very important to emphasize that design decision has to be based on predicting testing and analysis, which provide reliable information. An indirect prediction of swell potential includes correlations based on index properties, swell and a combination of them. Some of such classification systems are the following: (Meron W., 2013).

i. Method of Chen

Chen (1988) presented a single index method for identifying expansive soils using only plasticity index and suggested four classes of clays according to their plasticity indices as shown in Table 2.4.[3] Table 2.4 below presents the relation between the swelling potential of clays and the plasticity index.

Table 2.3 Relation between the swelling potential of clays and the plasticity index

Swelling potential	Plasticity index
Low	0-15
Medium	10-35
High	20-55
Very high	Greater than 35 check

ii. **Method of Daksanamurthy and Raman (1973)**

Daksanamurthy and Raman (1973) presented a single index method for identifying expansive soils using only liquid limit. They suggested four classes of clays according to their liquid limits as shown in Table 2.5 below, (Amer, and Mattheus , 2006).

Table 2.4 Relation between the swelling potential of clays and the liquid limit

Swelling potential	Liquid limit
Low	20 < LL ≤ 35
Medium	35 < LL ≤ 50
High	50 < LL ≤ 70
Very high	Very high LL > 70

iii. **USBR Method**

This method is developed by Holtz and Gibbs; it is based on direct correlation of observed volume change with colloid content, plastic index and shrinkage limit. The classification is as given in Table 2.6 below.

Table 2.5 Classification based on bureau of reclamation method (Chen, F.H., 1988; Ranjan, G., and Rao, A.S.R., 2002)

Colloid content (%)	Plasticity index (%)	Shrinkage limit (%)	Probable expansion (%)	Degree of expansion
<15	<18	>15	<10	Low
13-23	15-28	10-16	10-20	Medium
20-31	25-41	7-12	20-30	High
>28	>35	<11	>30	Very high

In general, according to ERA manual a soil with plastic index less than 15 do not generate expansive property.

2.3 Origin and occurrence of water hyacinth around Lake Tana.

There are many weeds that are already found in the Lake Tana Basin. The presence of water hyacinth (Eichornia crassipes) was reported and confirmed in Lake Tana at various times.However in September 2011, it was officially recognized that one of the top ten ecologically dangerous and worst invasive weed, water hyacinth (Eichhornia crassipes), infested Lake Tana.(Ayalew Wondie et al. 2012)

According to the 2012 survey from the Bureau of Environmental Protection Land Use and Administration (BoEPLUA), about 20 ha of the shore on the north-eastern part of Lake Tana was infested. The exact source of water hyacinth infestation of Lake Tana is not well known.

The first infestations were found near the mouth of the Megech River on the northern shores of the lake. From its official identification (September 2011 to June 2012), the team of experts from various institutes worked a lot to bring decision makers on board to help in the mobilization drive and without whom no success was anticipated. The team was composed of members from each of the following institutions: Bureau of Agriculture, Bureau of Water, Bureau of Tourism, Bureau of Environment Land Administration and Use, Bahir Dar University and Agricultural Research Institute of Amhara Region. The team conducted a detailed survey in 2012 estimating the water hyacinth coverage to be 20,000 hectares (BoEPLAU, 2012).

Physical removal to control the proliferation of water hyacinth has been tried in Lake Tana, still being done in a much better scale now days. However, the outcome of this intervention on the control and management of hyacinth are not systematically assessed, documented and shared to the stakeholders. Data about the follow ups and sustainability of the community based water hyacinth removal in Lake Tana was scarce. In addition to scarcity of updated data, some observational reports from various organizations and experts have been seriously alarmed regarding the re-expansion of water hyacinth in Lake Tana. Needless to say, the absences of clear systematically collected information will hinder the implementation of appropriate management measures by policy makers. On the other hand Water hyacinth once established is very difficult to manage and eradication is often impossible. (Wassie A., et.al, August 2014)

The present assessment clearly revealed that Kebeles (shores) which were reported to be infested by water hyacinth during the 2012 survey and cleaned during the removal campaign are almost all now re-infested. Figure 2.7 below is a map showing the present water hyacinth infestation kebeles and woredas. (Wassie A., et.al, August 2014)

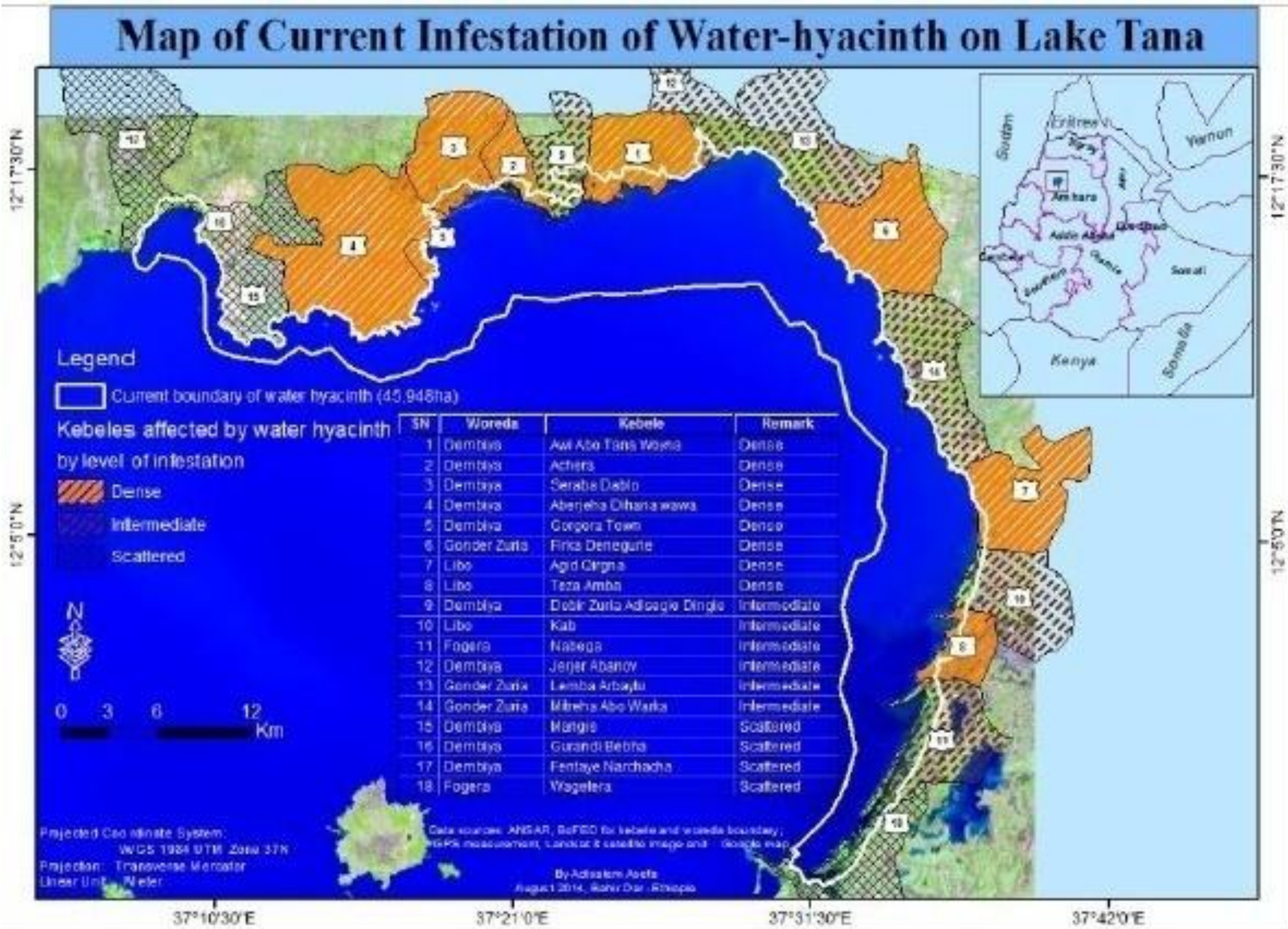


Figure 2.7 A map showing the present water hyacinth infestation kebeles and woredas (Wassie A., et.al, August 2014)

According to the above survey study 18 Kebeles stretching across 4 Woredas have been infested (Figure 2.7).The current 18 estimate of water hyacinth coverage is nearly 40,000 ha shore area of the lake. Lake Tana has a total of 385 km shoreline length.

Close to one-third or more than 30% of the shoreline (128 km distance) of the lake's shoreline is now invaded by water hyacinth. The shoreline length infestation coverage is almost tripled when it is compared with the previous reports; it was estimated to be 40 km during the 2012 assessment. The present assessment clearly revealed that Kebeles (shores) which were reported to be infested by water hyacinth during the 2012 survey and cleaned during the removal campaign are almost all now re-infested (Figure 2.7).

2.4 Chemical and mineral composition of water hyacinth

2.4.1 Chemical composition of water hyacinth

The chemical composition of the WH powder is summarized in Table 2.7.

Table 2.6 Chemical composition of water hyacinth

Components	% of dry weight
Moisture	8.5
Ash	11.2
Crude protein	6.2
Crude fibre	11.5
Cellulose	33.12
Hemicellulose	18.24
Lignin	12.18

2.4.2 Mineral content of water hyacinth

The mineral yield of the WH sample from organic extraction and by ashing method is shown in Table 2.8.

Table 2.7 Mineral content of water hyacinth

Minerals	g/100 g dry weight
Calcium	0.63
Sodium	0.19
Potassium	0.40
Manganese	0.18
Copper	0.12
Zinc	0.37

2.7 Soil stabilization

Soil stabilization is the process of blending and mixing materials with a soil to improve certain properties to make it more stable or is a process that involves the use of stabilizing agents (binder materials) in weak soils to improve its geotechnical properties such as compressibility, strength, permeability and durability. The components of stabilization technology include soils and or soil minerals and stabilizing agent or binders (cementitious materials).

Soil stabilization aims at improving soil strength and increasing resistance to softening by water through bonding the soil particles together, water proofing the particles or combination of the two (Sherwood, 1993) . It is required when the soil available for construction is not suitable for the intended purpose. In its broadest senses, stabilization includes compaction, pre-consolidation, drainage and many other such processes. However, the term stabilization is generally restricted to the processes which alter the soil material itself for improvement of its properties. The process may include the blending of soils to achieve a desired gradation or the mixing of commercially available additive that may alter the gradation, texture or plasticity or act as a binder for cementation of the soil. These can be accomplished by several methods. All these methods fall into two broad categories namely;

A- Mechanical stabilization

Mechanical stabilization is accomplished by mixing or blending soils of two or more gradations to obtain a material meeting the required specification. The soil blending may take place at the construction site, a central plant, or a borrow area. In a broader sense, the soils are subdivided into two categories:

1. Aggregates: These are the soils which have a granular bearing skeleton and have particles of the size larger than 75μ
2. Binders: These are the soils which have particles smaller than 75μ size. They do not possess a bearing skeleton.

B-Chemical stabilization

It involves use of chemical stabilizers (also termed chemical grouting or Additive stabilization). Depends mainly on chemical reactions between stabilizer (cementitious material) and soil minerals (pozzolanic materials) to achieve the desired effect. It is achieved by the addition of proper percentages of cement, lime, fly ash, bitumen, or combinations of these materials to the soil. The selection of type and determination of the percentage of additive to be used is dependent upon the soil classification and the degree of improvement in soil quality desired.

In chemical stabilization the use of pozzolanic materials such as cement, lime, and other waste materials are well established.

2.8 Previous studies on soil stabilization of expansive soils.

Meron w., (2013), Bagasse ash as a Sub-grade Soil Stabilizing Material.

The objective was to evaluate the effect of bagasse ash on the properties of the expansive soil using: Atterberg limits, free swell, free swell index, free swell ratio, compaction and CBR to compare the changes in properties of expansive soil with respect to bagasse ash stabilized soil.

In this investigation, it was concluded that,

- bagasse ash stabilized expansive soil does not bring significant change for use of it as a sub-grade material. Therefore, bagasse ash is not an effective standalone stabilizer for highly plastic expansive soils. However, bagasse ash plus/in combination with lime can effectively stabilize this soil. The expansive soil stabilized with bagasse ash plus/in combination with lime can be used as a good subgrade material. So, combining two local materials (bagasse ash and lime) can effectively improve the poor geotechnical properties of this soil and help in increasing land resources availability for construction projects and reduce the amount of lime needed for the stabilization purpose.

Brook d., (2015), Influence of molding water content on the engineering properties of lime stabilized expansive soil.

The objectives waere to determine the optimum amount of lime that stabilizes the expansive soil, to identify the effect of molding water content on the swelling pressure after treatment by lime and to identify the effect of molding water content on unconfined compressive strength of the soil after treatment by lime.

In this research the final conclusions were:

- Engineering properties of expansive soil can be altered by the addition of small amount of lime;

- As the amount of lime added to the soil increases, the swelling pressure of expansive soil reduces; the UCS of the soil improves; Liquid limit decreases; Plastic limit increases; Plastic index decreases; OMC increases and MDD decreases;
- Variation in molding water content has no effect on the swelling pressure, once optimum amount of lime is added to expansive soil; and
- Variation of molding water content has significant effect on unconfined compressive strength of expansive soil. On the wet side of the OMC, the unconfined compressive strength has increased while on the dry it decreased (The best result is obtained at moisture content slightly larger the OMC).

Reshid m., (2014), Stabilization of expansive soils with lime (A Case Study on the Adura-Burbey DS6 Road Segment).

The objectives were to improve the performance of a material by increasing its strength, stiffness and durability by adding lime as an additive.

Some of the basic final conclusions were:

- ➢ The addition of lime has resulted in an increase of the shrinkage limit of the soil;
- ➢ The optimum lime content in improving the CBR of the soil from its poor subgrade quality to fair class is found out as 12 percent;
- ➢ The addition of lime has resulted in an increase of the unconfined compressive strength of the tested samples; and
- ➢ The addition of lime up to 12% does not bring a significant improvement in CBR which falls in the range of 7-20 percent. But the achievement in Improving the subgrade quality is cost effective because this will reduce the use of borrow materials on the project.

CHAPTER THREE: MATERIALS AND METHODOLOGY

3.1 Materials

3.1.1 Expansive soil

As a part of this investigation, the expansive black cotton soil was acquired from the site Ayira, Gondar, Ethiopia.

The black cotton soil thus obtained was carried to the laboratory in sacks. A small amount of soil was taken, sieved through 4.75 mm sieve, weighed, and air-dried before weighing again to determine the natural moisture content of the same. The various tests to determine the expansiveness of the soil were as follows:

- **Natural Moisture Content (AASHTO DESIGNATION T 265 -93).**

By definition the neutral moisture content is the ratio of the weight of water to the weight of solids in a given mass of soil, expressed in percentage.

$$W = [(\text{mass of moisture})/(\text{mass of oven dry soil})] = [(W_1-W_2)/(W_2-W_c)] \times 100$$

Where:

W=moisture content, percent

W_1=mass of container and moist soil, g.

W_2=mass of container and oven dried soil, g, and

W_c =mass of container, g.

- **Specific Gravity (AASHTO DESIGNATION T 100 -93).**

This test method covers determination of specific gravity of soils by means of pycnometer. The weighted average specific gravity should be calculated using the following equation:

$$G_{svg} = 1/[(R_1/100G_1) + (P_1/100G_2)]$$

Where:

G_{svg}=weighted average specific gravity of soils composed of particles larger and smaller than 4.75mm (no 4) sieve

R_1=percent of soil particles retained on the 4.5 mm sieve

P_1=percent of soil particles passing the 4.75 mm sieve

G_1=apparent specific gravity of soil particles retained on the 4.75mm sieve as determined by AASHTO T 85, and

G_2=specific gravity of soil particles passing the 4.75 mm sieve as determined by this test method.

- **Moisture-Density relations of soils (AASHTO DESIGNATION T 99 -94).**

This test of the soil is intended to determine the relationship between the soil density and moisture content. Calculate the moisture content and the dry unit mass of the soil as compacted for each trial, as follows;

$$w= [(A-B)/(B-C)]\times 100$$

and

$$W= [w_1/ (w+100)] \times 100$$

Where:

w=percentage of moisture in the specimen, based on oven dry mass of soil;

A= mass of container and wet soil;

B=mass of container and dry soil;

C=mass of container;

W=dry mass, in kilograms per cubic meter of compacted soil; and

W_1= wet mass, in kilograms per cubic meter of compacted soil.

The above calculation shall be made to determine the moisture content and corresponding oven-dry unit mass (density) in kilograms per cubic meter. The oven dry densities (Unit mass) of the soil shall be plotted as ordinates and corresponding moisture content as abscissas.

Optimum moisture content: When the densities and corresponding moisture contents for the soil have been determined and plotted, it will be found that by connecting the plotted points with a smooth line, a curve is produced. The moisture content corresponding to the peak of the curve shall be termed "the optimum moisture content".

Maximum density: the oven dry density in kilograms per cubic meter of the optimum moisture content shall be termed "maximum density".

- **Liquid limit (AASHTO DESIGNATION T 89 -96).**

The liquid limit of a soil is that water content, as determined in accordance with AASHTO DESIGNATION T 99 -94 procedures, at which the soil passes from a plastic to a liquid state. The water content of the soil shall be expressed as the moisture content in percentage of the mass of the oven-dried soil and shall be calculated as follows:

Percentage of moisture= (mass of water/ mass of oven dried soil) x 100

- **Plastic limit and plastic index (AASHTO DESIGNATION T 90 -94)**

  The plasic limit of a soil is the lowest water content determined in accordance to AASHTO DESIGNATION T 90 -94 procedure at which the soil remaines plastic.The same calculationfor the water content with liquid limit.

- **Particle Size Analysis of Soils (AASHTO DESIGNATION T 88 -93)**

This method describes a procedure for the quantitative determination of the distribution of particle sizes in soils. The accumulated percentages of grains of different diameters shall be plotted on semi logarithmic paper to obtain a ''grain size accumulation curve.'' It is known that for fine particle sieve analysis is done using a hydrometer but in this paper only aggregate particle sieve analysis was done due to two reasons. One is because of its limited use and the other is there is no equipment in the lab.

- **Free Swell Index (IS:,2720-part 40, 1977)**

Free swell index is also one of the most commonly used simple tests to estimate the swelling potential of expansive clay. The procedure involves in taking two oven dried soil samples passing through 425µm sieve, 10cc each were placed separately in two 100ml graduated soil sample. Distilled water was filled in one cylinder and kerosene in the other cylinder up to 100ml mark. The final volume of soil is computed after 24hours to calculate free swell index.
The free swell index is then calculated using Equation. (Amer, and Mattheus, 2006)

$$\textbf{Free swell Index} = [(v_w - v_k)/v_k] \times 100$$

Where:

V_w= final volume in water

V_k = final volume in kerosene

3.1.2 Water hyacinth

Water hyacinth locally known as ''emboh'' is found on the different shores of Lake Tana. The distribution can be seen in figure 2.7 above. In this particular case the sample for the study was collected around a little village Gorgora which is about 70 km From Gondar. Figure 3.1 below shows water hyacinth located around Lake Tana (Gorgora).

Figure 3.1 Water hyacinth located around Lake Tana (Gorgora)

After locating the sample the following procedures were carried out:

- Sample collection

  Figure 3.2 below shows collection of samples.

Figure 3.2 Collection of sample

- Sundry sample until the natural moisture is fully out before grinding

  Figure 3.3 below shows sun drying sample

Figure 3.3 Sun drying sample

- Crushing until it passes 4.75 mm sieve size

  Figure 3.4 below shows crushed sample passing soil sieve 4.75mm.

Figure 3.4 Crushed sample passing soil sieve 4.75mm.

The samples were dried in the oven for about 24 hours before further usage.

3.2 Methodology Adopted

To evaluate the effect of Water hyacinth ash as a stabilizing additive in expansive soils, series of tests were taken, where the content of water hyacinth ash in the expansive soil was varied in values of 5%, 10% and 15% by weight of the total quantity taken. As a reference the AASHTO manuals were followed during the conduct of the experiments. The basic test done to find the suitability of the stabilizing agent is CBR.

- **California bearing ratio (AASHTO DESIGNATION T 193 -93)**

This test method covers the determination of the CBR of pavement subgrade,subbbase and base coarse materials from laboratory compacted specimenns.the test method is primarly intended ,but not limited to, evaluating the strength of cohesive materials having maximum partcle sizes less than 19mm (3/4 in.). The CBR value obtained in this test formes an integral part of several flexible pavement design methods.

After the test was done the load values for each specimen at 2.54mm and 5.08mm petration must be recorded.CBR values were obtained in percent by dividing the load values of 2.54mm and 5.08 mm by the standard load of 6.9Mpa and 10.3 Mpa respectivelyand multiplying these ratios by 100.

CBR(%)= (load value/standard load) x100

The CBR is generally selected at 2.54mm penetration. If the ratio at 5.08mm penetration is greater the test shall be rerun however if the check test gives similar result,the ratio at 5.08mm penetration shall be used.

This test also gives the swelling charchterstics of the soil sample.after the compaction of the soil the mold will be immersed fully for 96hrs(4 days).The swelling will be measured by the tripodal measuring guge.

Percent of swell=(Change in length in inch during soaking/4.584in.)x 100

The following procedures were followed to determine the correlation between the stabilizing agent (dried and crushed water hyacinth) and the sample material (the identified expansive soil).

- Prepare each sample according to weight;
- Mix each sample accordingly (5%,10% and 15%); and
- Do the following tests:
  - Moisture-Density relations of soils (AASHTO DESIGNATION T 99 -94); and
  - CBR (AASHTO DESIGNATION T 193 -93).

CHAPTER FOUR: RESULTS AND DISCUSSIONS

Introduction

As it has been discussed in the previous chapters the primary objective of this research is to find out the use of water hyacinth as a stabilizing agent to an expansive soil by performing different laboratory tests. In this chapter the result of this laboratory tests are presented.

4.1 Results from Grain Size analysis (sieve Analysis)

This test was performed to determine the percentage of different grain sizes contained within finer particles. The mechanical or sieve analysis was performed to determine the distribution of the coarser, larger-sized particles. Here the result only applies to the natural soil. Figure 4.1 below shows the grain size distribution curve.

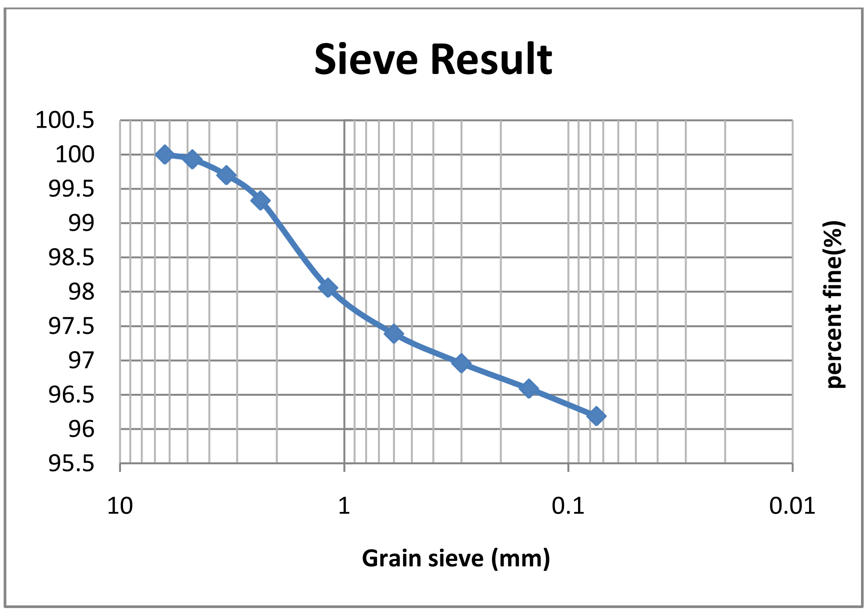


Figure 4.1 Grain size distribution curve

4.2 Test result on identification of sample soil

The results of the tests conducted for identification and/or determination of properties of the natural soil before applying water hyacinth are presented in Table 5.1below.

Table 4.1 Geotechnical properties of the natural soil

Tests	Reference manual	Results
Particle Size Analysis of Soils	AASHTO DESIGNATION T 88 -93	Pass0.075=96.19%
Natural Moisture Content	AASHTO DESIGNATION T 265 -93	14.62%
Specific Gravity	AASHTO DESIGNATION T 100 -93	2.5
Moisture-Density relations of soils	AASHTO DESIGNATION T 99 -94	MDD=1.44 OMC=22.66
Liquid limit	AASHTO DESIGNATION T 89 -96	105
Plastic limit and plastic index	AASHTO DESIGNATION T 90 -94	PL=52.11 PI=52.89
Free Swell Index	IS: 2720(part 40), 1977	109.52

The following interpretations are provided:

- According to Table 2.1, the soil type is A-7-5
- According to method of Chen ,Table 2.3,the soil has very high swelling potential
- According to Method of Daksanamurthy and Raman (1973),Table 2.4,the soil has high risk of swelling
- According to the USBR Method, Table 2.5, the soil has very high swelling potential
- Finally, according to the ERA (Ethiopian Road Authority) standard, a soil having a plastic index of greater than 15 has a risk of swelling potential.

It should be noted that the above results show, without a reasonable doubt, that the soil is an expansive soil.

4.3 Effect of water hyacinth on the identified expansive soil

4.3.1 Effect of water hyacinth on MDD and OMC

The bar graphs below (Figure 4.2 and Figure 4.3) show the effect of water hyacinth on expansive soil according to maximum dry density and optimum moisture content.

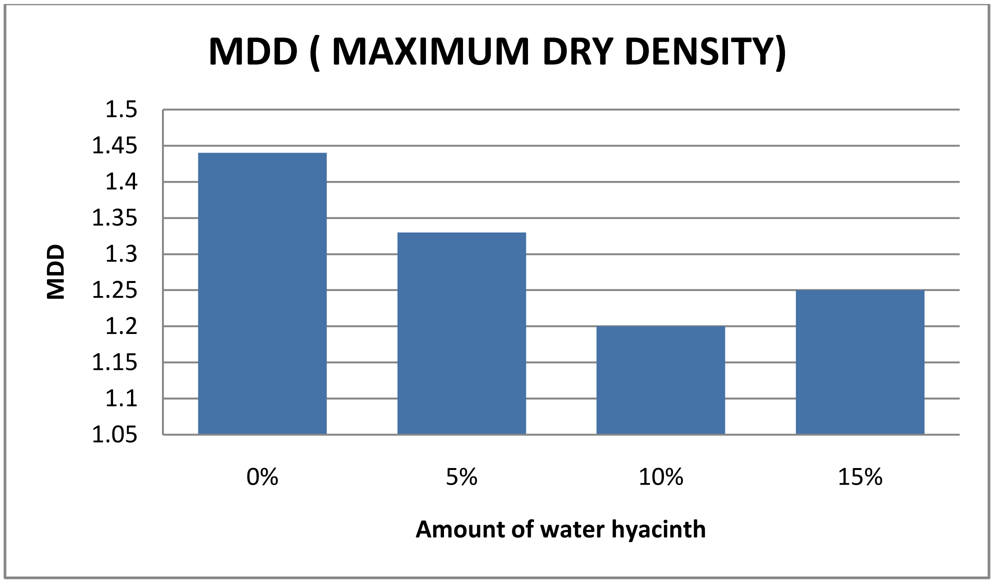


Figure 4.2 Effects on addition of water hyacinth on MDD (maximum dry density)

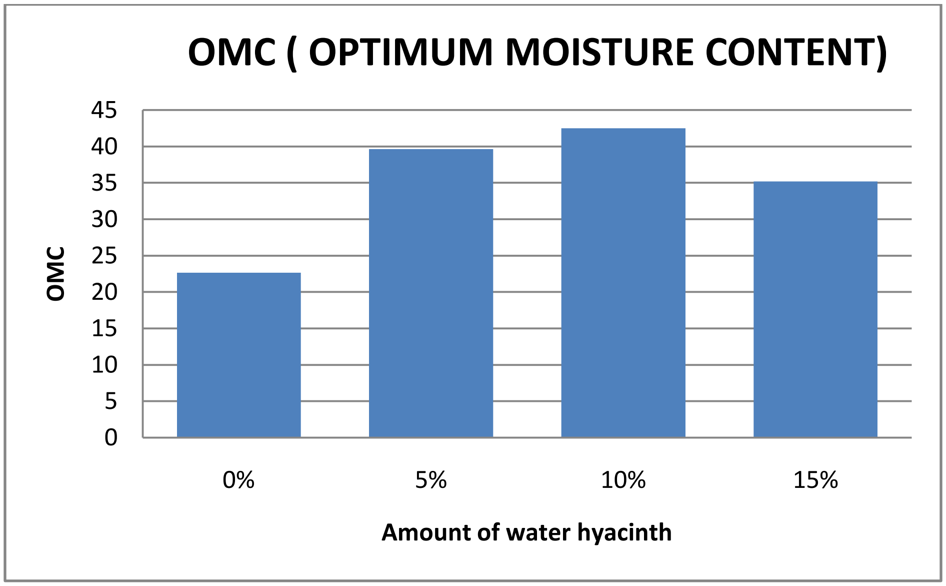


Figure 4.3 Effects on addition of water hyacinth on OMC (optimum moisture content)

4.3.2 Effect of water hyacinth on CBR.

The bar graph below (Figure 4.4) shows the effect of water hyacinth on expansive soil according to CBR test.

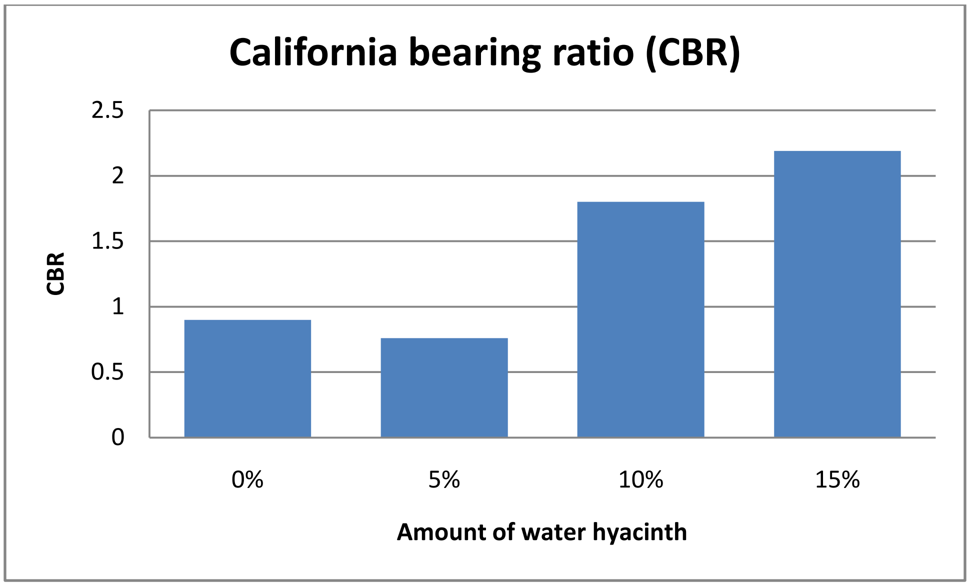


Figure 4.4 Effects on addition of water hyacinth on CBR (California bearing ratio)

The general relationship between CBR values and the quality of the sub grade soils used in pavement applications is as follows (Bowles, J., 1992). Table 4-2 below shows relationships between CBR values and quality of subgrades.

Table 4.2 Relationship between CBR-values and quality of sub grade

CBR-values	Quality of subgrade
(0 – 3) %	Very poor subgrade
(3 – 7) %	Poor to fair subgrade
(7 – 20) %	Fair subgrade
(20 – 50) %	Good subgrade
> 50%	Excellent subgrade

4.3.3 Effect of water hyacinth based on ATTERBERG TESTS (LL AND PI)

The scattered graphs below show the effect of water hyacinth on expansive soil according to atterberg limit test. Figure 4.5 below illustrates the effect on addition of water hyacinth on expansive soil according to LL (liquid limit).

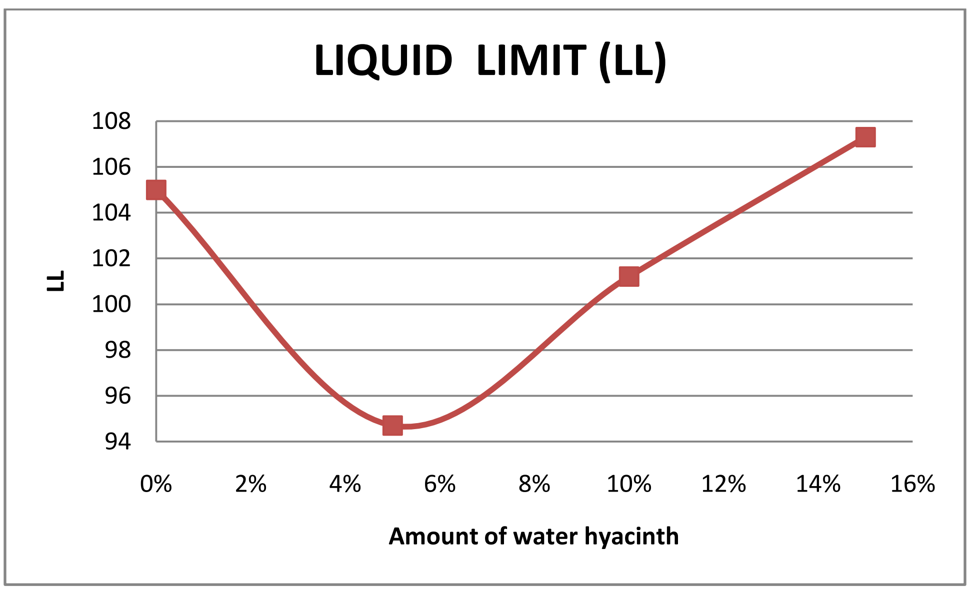


Figure 4.5 Effects on addition of water hyacinth to LL (liquid limit)

Figure 4.6 below illustrates the effect of addition of water hyacinth on expansive soil according to PI (plastic index).

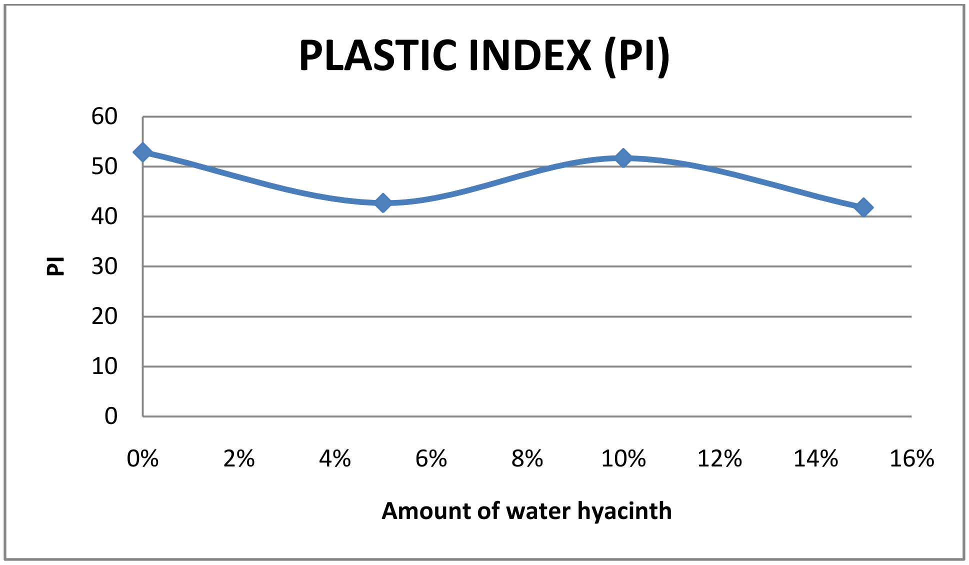


Figure 4.6 Effects on addition of water hyacinth to PI (plastic index)

4.4.4 Effect of water hyacinth on specific gravity (S.G)

Figure 4.7 below shows the effect of water hyacinth on expansive soil according to specific gravity test.

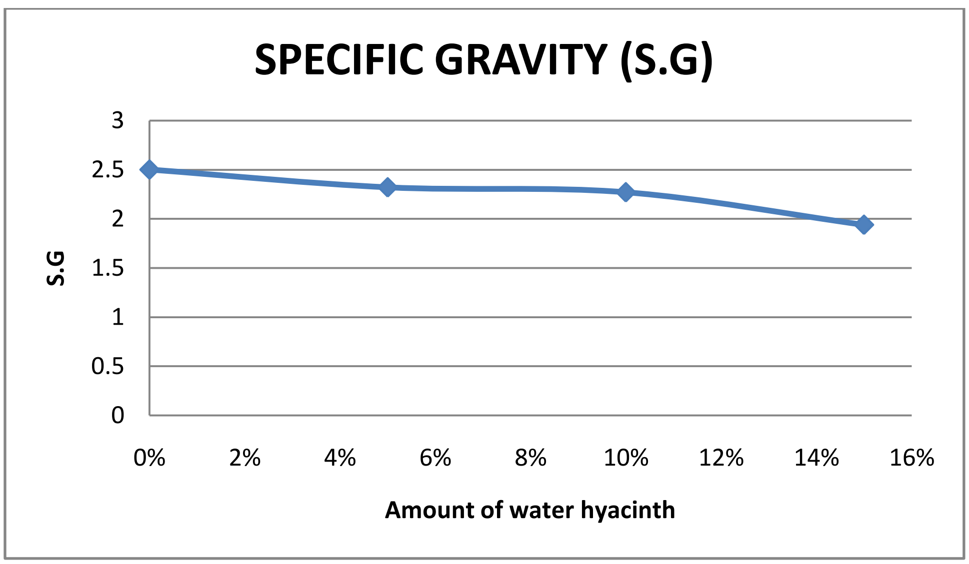


Figure 4.7 Effects for addition of water hyacinth on expansive soil according to specific gravity

4.3.4 Effect of water hyacinth on FREE SWELL

Figure 4.8 below illustrates the effect of water hyacinth on expansive soil according to free swell test.

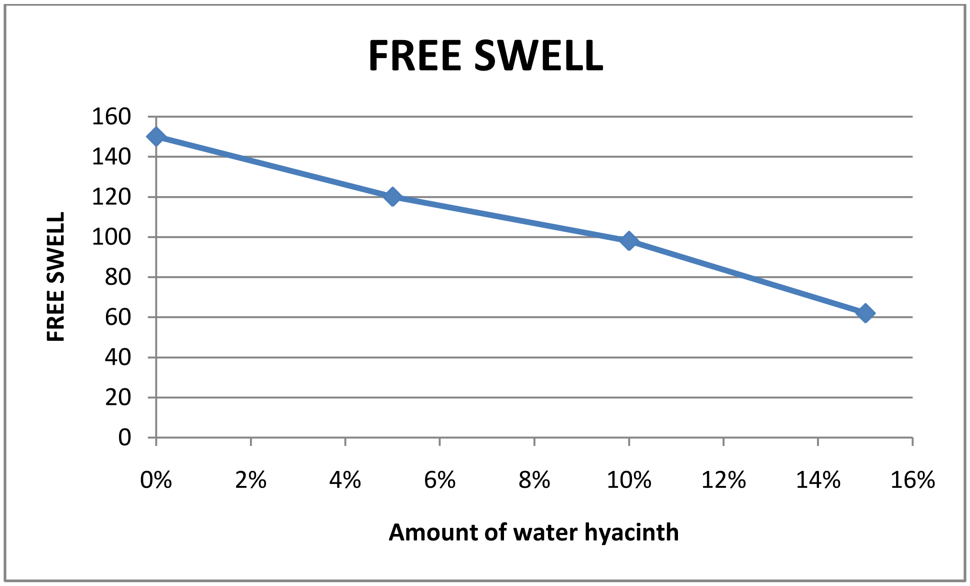


Figure 4.8 Effects for addition of water hyacinth on expansive soil according to free swell

4.4 Comparison with different other studies

Comparisons between previous studies on expansive soil were carried out by Manmay Kumar M., (May 2015), in India under the research title of Stabilization of Expansive Soil Using Fly Ash and by Meron W., (2013), under the title of Bagasse Ash as a Sub-Grade Soil Stabilizing Material. Accordingly, Tables 4.3 and 4.4 below show the respective results of comparison between the two studies at 10% and 15% of stabilizing agent.

Table 4.3 Comparison between the two studies (FLY ASH and Water hyacinth) at 10% of stabilizing agent used.

Comparison on	FLY ASH used		Water hyacinth used	
	0%	10%	0%	10%
Liquid limit	65.6	61.2	105	101.21
Plastic index	29.8	26.6	52.89	51.7
Optimum moisture content	23	22	22.66	42.5
Maximum dry density	1.52	1.5	1.44	1.2
CBR soaked	4.4	4.3	0.9	1.8

Table 4.4 Comparison between the two studies (BAG ASH and Water hyacinth) at 15% of stabilizing agent used

Comparison on	BAG ASH used		Water hyacinth used	
	0%	15%	0%	15%
Specific gravity	2.79	2.57	2.5	1.94
Plastic index	78.1	71.5	52.89	41.8
Optimum moisture content	32.2	43.2	22.66	35.2
Maximum dry density	1.26	1.14	1.44	1.25
Free swell	210	107	150	62
CBR soaked	0.91	1.59	0.9	2.19

Using the results of Manmay Kumar M. (May 2015), correlation coefficients were calculated between FLY ASH and Water hyacinth which were used at 0% and 10% the results were found to be 0.974 and 0.984 respectively. Similarly, corresponding correlation coefficients were calculated using the Meron W. (2013) study results at 0% and 15% and the correlation coefficients were found to be 0.999 and 0.976 respectively. This means that there are high relationships between the results of the two studies using Bagasse ash and Water hyacinth.

When stabilizing any soil consideration must be given to the following factors:

- Type of soil to be stabilized ;
- Purpose for which the stabilized layer will be used ;
- Type of soil quality improvement desired;
- Required strength and durability of the stabilized layer;
- Environmental conditions; and
- Cost.

Next, specific soil which having the following characteristics was considered :(Dallas N. et al, 2009)

- ✓ No 200 sieve pass 4.2;
- ✓ No 4 sieve pass 98.32; and
- ✓ PI = 52.19.

The most compatible option for stabilization is lime (not considering cost and environmental factors). So if the best stabilization for this specific soil is lime, it is good to know the effect of both (water hyacinth and lime stabilization) at the same percent.

Further, Reshid M. of the Addis Ababa University, School of Civil and Environmental Engineering, conducted a study in 2014 under the title of Stabilization of Expansive Soils with Lime (A Case Study on the Adura-Burbey DS6 Road Segment). The results of this study are presented in Table 4.5 below

Table 4.5 Comparison between the two studies (Lime and Water hyacinth) at 10% of stabilizing agent used.

Comparison on	LIME used		Water hyacinth used	
	0%	10%	0%	10%
Specific gravity	2.485	2.632	2.5	2.27
Plastic index	33.11	21.67	52.89	51.7
Optimum moisture content	25	28.5	22.66	42.5
Maximum dry density	1.51	1.47	1.44	1.2
Free swell	70	30	150	98
CBR soaked	2.04	5.94	0.9	1.8

Based on the above results, correlation coefficients were calculated under 0% and 10% between the two tests and the results were found to be 0.955 and 0.815 respectively, indicating that there is strong relationship the results under the two test it was strong at 10%.

4.5 Further discussion on test results

The main chemical stabilizing agent for expansive clay is lime which may be calcium oxide (CaO) or calcium hydroxide Ca $(OH)_2$. Laboratory testing indicates that lime reacts with medium, moderately fine and fine-grained soils to produce decreased plasticity, increased workability and increased strength. Strength gain is primarily due to the chemical reactions that occur between the lime and soil particles. These chemical reactions occur in two phases, with both immediate and long-term benefits. (Patrik K.B, 2016).

This paper is concerned on the immediate effect of the water hyacinth to expansive soils so looking at the first phase of the chemical reaction which involves immediate changes in soil texture and soil properties caused by cation exchange. When calcium comes in contact with the pore water, hydration occurs resulting in the formation of calcium hydroxide. Some of this calcium hydroxide is adsorbed onto the soil particles. Ion exchange takes place and the soil is modified into drier and coarser structure due to slaking process and flocculation of the clay particles that take place. Free calcium from lime exchanges with the adsorbed cations of the clay mineral, resulting in reduction in size of the diffused water layer surrounding the clay particles.

This reduction in the diffused water layer allows the clay particles to come into closer contact with one another, causing flocculation of the clay particles, which transforms the clay into a more silt-like or sand-like material. According to (Little, D.N. 1995) practically all fine-grained soils undergo this rapid cation exchange and flocculation reactions when treated with lime in the presence of water.

The above discussion clearly shows the importance calcium in the first phase or immediate effect of stabilizing an expansive soil. So according to Table 2.8 Water hyacinths has a great amount, 0.63, of calcium. Even though the addition of Water hyacinths up to 15% did not bring a significant improvement in California bearing ratio it has increased it from 0.9% to 2.19 for 0% and 15% water hyctine used respectively the reason probalbaly being the calcium in water hyctine.

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The use of water hyacinth as a potential stabilizing material was studied and after the research work was done and accordingly, the following conclusions are drawn:

- The optimum moisture content increased until 10% and then decreased at 15% whereas, the maximum dry density values decreased until 10% and then increased at15% with increment of water hyacinth ash content.
- Free swell of the stabilized samples decreased with increasing water hyacinth ash content.
- CBR values slightly increased with the addition of water hyacinth. The CBR at 15% almost fall in to the category of fair sub grade as shown in Table 4.2.
- The addition of water hyacinths up to 15% did not result in significant improvement in accordance to California bearing ratio which falls in the range of 2-3 percent.
- The increase in water hyacinths as a stabilizing agent decreases in specific gravity this is due to the decrease in density of dried and crushed water hyacinth.
- The addition of water hyacinth from 0% to 15% decreases the plastic index from 52.89 to 41.8.
- After the test results it can be concluded that water hyacinth can improve the soil properties of an expansive soil. However, to conclude that, it can be used as a standalone stabilizer like lime more studies should be done.

5.2 Recommendations

Based on the results of this study, the following recommendations have been forwarded for use by pertinent policy makers:

- Studies should be made to check the possibility of using water hyacinth with lime.
- Chemical analysis should be used to assess the water hyacinth chemical composition as well as its characteristics;
- Contractors and construction agencies should look forward and conduct researches on the utilization of water hyacinth alone or combined with other materials as a potential stabilizer and lead the path to provide specifications on the material and such materials;
- Studies should be made to check the secondary reaction of the water hyacinth ash using more advanced methods like X-ray Diffraction (XRD) Analysis;
- The use water hyacinth at a higher percentage , more than 15% (up to 30%) ,should be checked for the possibility of a satisfactory results (a higher CBR ,MDD and lower PI).
- As it has been discussed on the literature part water hyacinth is a major problem to the largest lake in Ethiopia. So to lose this lake to the water hyacinth is very dangerous considering the fact that may people depend on this lake for their lively hood. Therefore Studies conserving the reduction and usage of this water hyacinth should be encouraged.

5.2.1 Limitations of the Research

- This thesis is a self sponsored thesis which had cost more than 10,000 birr. This is the reason for the small sample sizes and small number of laboratory tests can be done.
- Chemical analysis and supplementary works weren't conducted due to absence of budget and laboratory equipment's.
- Most of the apparatus that have been used at the laboratory aren't calibrated at a regular basis.

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