EFFECTS OF FLY ASH AND RICE-HUSK ASH ON LIME STABILIZATION OF EXPANSIVE SOILS FROM LOKPAUKWU AND AWGU, NIGERIA

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CERTIFICATION

This is to certify that this project entitled, "EFFECT OF FLY ASH AND RICE-HUSK ASH ON LIME STABILIZATION OF EXPANSIVE SOILS FROM LOKPAUKWU AND AWGU, NIGERIA" was carried out by NNABUIHE, KINGSLEY IKECHUKWU (REG. NO. 20134871378), in partial fulfillment of the requirement for the Award of Degree in Master of Science (M.Sc.) in Environmental Geology, School of Physical Sciences, Federal University of Technology, Owerri.

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DEDICATION

This piece of work is dedicated to God Almighty for His infinite mercy and to my family members.

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ABSTRACT

Soil stabilization refers to the technique of altering the properties of a soil so as to improve its engineering performance. It aims at using chemical additives such as lime as a lone stabilizer or in combination with industrial residues (fly ash, rice husk ash, etc) to achieve this fit. This work investigates the effects of lime alone, lime-fly ash (LFA) and lime-rice husk ash (LRHA) blends in varying percentage mixtures on the engineering properties of expansive soils from Lokpaukwu (Ezeaku Formation) and Awgu (Awgu Formation) in Lower Benue Trough. The soils were stabilized with different percentages of lime (i.e. 2, 4, 6, 8, and 10%) and varying percentage ratio for lime-fly ash and lime-rice husk ash blends (i.e. 2 : 6, 2 : 8, 2.5:7.5, 2.5 : 10, 3 : 9, 3 : 12, 4 : 12, 4 : 16, 5 : 15 and 5:20).Liquid limit, plastic limit, linear shrinkage, compaction characteristics and California Bearing Ratio (CBR) tests were performed on the natural and lime-treated Lokpaukwu and Awgu soil samples while consistency limits and linear shrinkage tests only were performed on the lime-residue treated soil samples. Results of the study indicate that optimum reduction percentage of 24.14% and 30.56% (liquid limits), 72.22% and 74.42% (plasticity indices), 56.14% and 60.12% (linear shrinkages) and maximum percentage increase of 25.60 and 33.70 (Optimum Moisture Content (OMC)), 193.3 and 250 (unsoaked CBR), and 766 and 700 (soaked CBR) for Lokpaukwu and Awgu samples respectively were obtained on stabilizing the soils with 6% lime content. The results from lime-fly ash (LFA) and lime-rice husk ash (LRHA) blends indicate that liquid limits, plasticity indices and Linear Shrinkages decreased from 58 and 72 to 46 and 51, 36 and 43 to 11 and 12, 11.4 and 14.3 to 6.4 and 7.1, and from 58 and 72 to 45 and 51, 36 and 43 to 10 and 11, 11.4 and 14.3 to 6.4 and 7.1 for Lokpaukwu and Awgu samples respectively when treated with Lime-fly ash blend of 3 – 12% and lime-rice husk ash blend of 3 – 9%. It could be concluded that improving the characteristics of expansive soils by lime-fly ash blend or lime-rice husk ash blend is successful and provides immense environmental and economic benefits.

Keywords: ***Expansive Soil, Stabilization, Lime, Fly Ash, Rice-Husk Ash***

CHAPTER ONE

INTRODUCTION

1.1 Background Information

Soil is the fundamental and most economical of construction materials. It bears the loads of structures and pavements transmitted through foundations and subbases respectively. Researchers have shown that the suitability of a soil as a construction material is a function of its geotechnical properties (Bowels, 1984 and 1988; Head, 1984; Venkatramaiah, 2012). The use of the existing soil at a construction site for engineering purpose may be hindered by poor engineering properties including poor bearing capacity, higher compressibility, and the alternate shrink and swell behaviour of expansive soils.

Expansive soils with potentials to change in volume in correspondence to a change in the moisture or suction condition of the soil (shrink or swell) are normally excluded as engineering construction materials because this volume change causes a resultant deformation, cracking and the eventual collapse of lightweight structures. Incidentally, the collapse of civil structures in some prominent towns in southeastern Nigeria have been associated with the occurrence of expansive clays in these towns (Okeke, 2008; Okeke and Okogbue, 2010)

Improvement of sites with weak or high compressible or high swelling or any other such problematic soils is commonly done by removing the problematic soils and replacing them with more competent ones such as compacted gravel, crushed rock, or lightweight aggregates to increase the load bearing capacity (Kukko, 2000). Although this is generally accepted as a good solution, the economic feasibility of an alternative construction material may not be guaranteed due to the excessive cost that may be incurred in long distance hauling of the alternative material, excavation of the in-situ material and as well as refilling with the alternative material.

Also, rise in global population tends to exert pressure on land which is limited in supply (Oramah, 2006), resulting to a very high demand for the available land and consequent rise in its cost (Rama-Subbarao *et al.,* 2011). Considering these factors improving the available soil at a site to meet the desired objective becomes the most viable alternative.

Soil improvement can be realized through several methods including the process of stabilization which aims at using chemical additives to achieve this improvement. Cement and lime are the most widely used stabilizing materials. However, the rise in the cost of these industrially manufactured soil improving additives (cement, lime, etc.) with a corresponding increase in the cost of construction on or with cement or lime stabilized soils has led to investigations and the subsequent adoption and usage of industrial wastes (rice husk ash, fly ash, kiln dust, etc.) as alternative materials for the total replacement (i.e. self cementitious e.g, Class C fly ash) or partial replacement (i.e. pozzolans) of cement and lime in engineering constructions (Uzal *et al.,*; 2007; Sata *et al.,* 2007; Yazici, 2008; Okafor and Okonkwo, 2009; Okeke and Enwelu, 2011; Baldino *et al.,* 2014).

Industrial wastes such as fly ash and rice husk ash that accrues from the processing and, utilization of coal and rice abounds in Southeastern Nigeria due mainly to coal deposits and rice cultivation in the area. Harnessing these industrial wastes as soil treatment materials tend to provide an immense benefit to mankind as it reduces the cost of construction with stabilized soils, and as well as reduction in the environmental hazards caused by these wastes (Muntohar and Hantoro, 2000; Zumrawi and Hamza, 2014). Therefore, the whole process of soil stabilization with pozzolanic materials is invariably an industrial waste management strategy.

1.2 Problem Statement

The long-term performance of any construction project depends on the soundness of the underlying soils (NLA, 2004). Expansive soil has been reported as a threat to engineering structures (Ola, 1987; Gutschick, 1967), and to occur mostly and extensively in tropical countries (Holtz and Gibbs, 1956; Katti, 1979; Ola, 1983; Garrido and Castenada, 1992; O'Connel and Gourley, 1993; Uduji *et al.,* 1994; Okeke, 2008; Lucian, 2008).

Immense damages to civil structures have been attributed to the occurrence of this soil in Nigeria and beyond (Skempton, 1954; Barber, 1956; Youssef *et al.,* 1957; Hammer and Thompson, 1966; Jones and Holtz, 1973, US Army, 1983; Attewell and Taylor, 1984;). Okeke (2008) reported the occurrence of this problem soil in several towns of Southeastern Nigeria.

On the other hand, industrially developed and emergent nations of the world including Nigeria generate enormous industrial wastes, which constitute environmental hazards. The utilization of these industrial wastes for soil improvement has been identified as sustainable and cost effective method compared to the conventional method with lime or cement (Rama-Subbarao *et al.,* 2011). In view of this, this work tends to investigate the stabilization of expansive soils – first with lime and secondly with industrial wastes as percentage substitutes for lime.

1.3 Main Objective

The study aims at utilizing the industrial wastes of Rice-Husk Ash (RHA) and Fly ash (FA) to improve and enhance the geotechnical properties of expansive soils in the study area in relation to their uses in engineering construction, thereby reducing the environmental hazards associated with the wrongful disposal of these wastes.

The specific objectives of the study are to:

i. evaluate the effect of lime on the geotechnical characteristics of the expansive soils from Lopkaukwu and Awgu.
ii. evaluate the influence of rice husk ash on lime stabilization of the expansive soils.
iii. evaluate the influence of fly ash on lime stabilization of the expansive soils.
iv. determine the optimum contents for lime, lime-fly ash and lime-rice husk ash admixtures.

1.4 Justification of Study

There have been cases of structural failures resulting from unstable foundation soils, as well as reports of huge volumes of industrial wastes dumped on open fields, constituting health and environmental hazards. It is against this backdrop that this project was conceived so as to reveal by concrete investigation, the efficacy of these industrial wastes in soil stabilization as an efficient waste management strategy. Hence, this study is design to benefit several entities including individuals, communities, researchers, construction firms, government and policy makers, and the society at large. To individuals and communities, of course, it offers a decent environment, free from vectors, diseases, and pollution. To the construction firms, it provides a cost effective strategy to the design and execution of civil structures by using waste as a resource. To the government and society at large, it provides climate change mitigation and innovative waste management strategies as it ensures a sustainable environment through the reduction in carbon-dioxide emission emanating from both lime production process and unsustainable waste disposal systems. To the researchers, it serves as a reference point as they benefit from the positives in the study, thereby provoking further similar studies.

1.5 Scope of Study

The Study involved the collection of soil samples and soil additives including lime, rice-husk ash and fly ash. It was limited to field sampling observations and laboratory analyses of the soil samples with reference to the various additives by measuring the necessary geotechnical properties (parameters); Attterberg limits (liquid limit, plastic limit and plasticity index), linear shrinkage, compaction characteristics (maximum dry density and optimum moisture content), and California bearing ration (CBR).

CHAPTER TWO
LITERATURE REVIEW

2.1 Review of Previous Studies

Expansive soils are clayey soils that have the tendency to swell or increase in volume when in contact with water and shrink or decrease in volume when the water is removed (Okeke and Okogbue, 2010). Clayey soils as stated above refer to soils with fine [clay (<0.002mm) and silt (0.02mm – 0.002mm) in combination] particles exceeding 50% by weight of the entire soil sample (Legget, 1962). However, Pettijohn (1975) is of the opinion that a soil sample can be termed clay if it indicates the presence of a significant amount of clay minerals (hydrous aluminum silicates), regardless of the percentage of "fines" it contains. Thus, the word clay can be used in geology to denote grain size (<0.002mm) or as an indicator of clay mineralogy including illite, montmorillonite, chlorite, kaolinite, etc. (Plummer *et al.,* 2005).

Clay minerals are capable of absorbing water at different capacities. Consequently, the type of clay mineral present in a soil is a strong determinant of its swelling potential (Okogbue, 1990). However, Kassif and Baker (1971) and Ola (1981) have reported a strong correlation between montmorillonite clay mineral content and the degree of expansion of the clay. Ola (1981) noted that as little as 10% montmorillonite content of a soil sample can strongly indicate a possible expansive soil problem. Montmorillonite clay mineral is invariably the most swelling clay.

The formation of expansive soils depends on a complex interaction of a number of controlling variables, such as weathering and erosion, prevailing climate, parent rock type, local topography and drainage (Russam and Coleman, 1961).

According to Grim (1968), clay particles are products of chemical weathering, and the in-situ weathering of basic igneous, metamorphic and pyroclastic rocks yields residual expansive clay soils (Elueze and Bolarinwa, 1995, 2001; Nton and Elueze, 2005). These residual expansive soils can further be eroded to form areas of transported expansive soils.

On the other hand, the lithification of the transported expansive clayey soils would invariably yield sedimentary mudstones and shales. Shale constitutes a larger proportion of most sedimentary basins and is invariably the most weathered sedimentary rock. Hence, the subsequent re-weathering of these sedimentary rocks tends to release the expansive minerals back into the soil formation (Emofurieta *et al.,* 1994; Elueze *et al.,* 1999; Imeokparia and Onyeobi, 2007; Obrike *et al.,* 2007, 2012).

Expansive soils are distributed throughout the world. Though, they occur extensively in the tropics, they are not climate specific as indicated by findings from South Africa, (Jennings, 1953); England, (Skempton, 1954); Israel, (Kassif and Baker, 1971); Nigeria (Ola, 1981; Okeke, 2008) and Tanzania, (Lucian, 2008).

Expansive soil is a common cause of foundation and pavement problems (Uduji *et al.,* 1994). This is because the moisture-suction condition of the soil in a structure is liable to change after construction. The degree of change is a function of such factors like the availability of active minerals, ground conditions and climatic conditions (Okogbue, 1990).

Okogbue (1990) also stated that expansive foundation soils are bound to swell or shrink resulting to heaving or settlement of structures respectively in response to the moisture-suction condition of the soil. As the soil expands and contracts, it experiences a loss in strength; and the resultant instability creates an enormous force which causes an extensive damage to building foundations, road pavements and other structures. It is believed that expansive soils have caused more damage than earthquake and landslides put together (Plummer *et al.,* 2005).

However, it should be noted that inconsistency in the moisture content of the foundation or subgrade soils is the main cause of foundation or subgrade problems by expansive soils (Lucian, 2008). Hence, stabilizing the moisture content of the foundation or subgrade soils if viable can ensure a proactive and dependable measure to eliminate foundation or subgrade problems caused by expansive soils.

Soil with deficiency or that cannot be safely and economically utilized for the construction of engineering structures without undergoing adequate treatment is termed problem soil. Soil treatment therefore refers to the alteration of any property of a soil to improve its engineering performance. Gidigasu (1976) outlined problem soils to include carbonate rocks which are prone to sinkhole formation, expansive and shrinkable soils, sensitive and highly compressible red clays of high rainfall regions, collapsible soils, dispersive and erosive soils, organic soils including peat, etc. Ola (1987) attributed such problem to instability of the soil which makes it unsuitable as a construction material in foundations, buildings, highways, water retaining structures, dams, etc.

Problem soils have been found to be associated with poor engineering properties, such as low bearing capacity, low stability, low natural densities, high plasticity, high permeability, high moisture retention, difficulty in compaction and high swelling potential (Amadi, 2012; Zumrawi and Hamza, 2014). Expansive clays, one of the known problem soils have been reported to occur extensively in Nigeria (Ibrahim, 1977; Ajayi, 1983; Sadiku, 1985; Adesunloye, 1987; Ola, 1987; Omange *et al.,* 1988; Omange and Aitsebaomo, 1989; Okunade, 2007a; Joel and Agbede, 2008; Okeke, 2008; Okafor and Okonkwo, 2009).

Seed *et al.,* (1962) identified expansive soils with shrinks-swell behavior as one of the most serious challenges confronting the geotechnical engineer. The growing recognition of these soils as environmental hazards have ensured geotechnical engineers remain alert in detecting, monitoring and proffering lasting solutions to this problem. When confronted with such challenges, the engineer tends to seek solution from a number of techniques available to him, which either aims at excavating the problem soils and replacing them with more competent materials (Kuko, 2000; Amadi, 2012) or modifying the existing soil to achieve the desired objective (Yadu *et al.,* 2011). Hence, ground modification techniques have become an integral part of civil engineering in recent time (Haussmann, 1990).

The most common remediation practice among engineers is to excavate the problem soil and replace with a better material (Holtz and Gibbs, 1956; Krynine and Judd, 1957; Katti, 1979; Amadi, 2012).

However, numerous researchers have found stabilization which involves treatment with chemicals or additives to be very effective in controlling the damaging effects of expansive clays (Kassim and Chow, 2000; NLA, 2004; Venkatramaiah, 2012). Nonetheless, the cost implication of the conventional chemical stabilizers necessitated the dire need for intensive and extensive research on the effectiveness and feasibility of using industrial residues as percentage substitutes for the conventional additives in soil stabilization.

Rapid industrialization and agricultural development have resulted in the generation of enormous wastes (Longe and Balogun, 2010; Eni *et al.,* 2011; Nnabuihe *et al.,* 2016). These wastes, both solid and liquid alike are produced in their quantum from industrial processes on daily basis. Myriads of them, termed industrial solid wastes including fly ash, rice husk ash, blast furnace slag, groundnut shell ash, bagasse ash, granite waste, marble waste, steel slag, etc. are dumped on open fields where they occupy huge hectares of arable lands and also constitute environmental hazards (Dahale *et al.,* 2012; Sekar, 2015; Jaglan and Mital, 2015).

The increasing difficulty encountered in the safe and proper disposal of the huge volumes of solid wastes associated with industrialization has continued to be a source of global concern (Akinbinu, 2010; Sekar, 2015). However, Odunola *et al.* (2015) identified effective waste management system as a sure mechanism of eliminating the health risk and environmental hazards associated with indiscriminate waste disposal. This management system should incorporate the recycling or reuse of these wastes aimed at converting them into valuable materials, thereby conserving natural resources and saving the environment (Das *et al.,* 2006; Aguirre *et al.,* 2009; Sharma, 2014).

According to Lim and Chu (2006), factors such as limited waste landfill space, increasing cost of wastes disposal in combustion facilities and landfills, depletion of the natural resources, and the need for sustainable development have necessitated the need to reuse the materials that were once regarded as wastes as substitutes for natural resources. Hence, it has become pertinent to develop suitable scientific, technical and economic solutions for the efficient utilization of these wastes (Sharma, 2014).

However, it should be noted that some of these residues including fly ash and rice husk ash have already been identified and gainfully utilized as substitutes for natural resources or conventional raw materials in engineering construction by numerous researchers including Kamon and Nontananandh (1991), Vazquez *et al.* (1991), Kamon and Katsumi (1994), Kamon (1997), Hartlen *et al.* (1997), Sarsby (2000), Osinubi (2000a, 2000b), Osinubi and Amadi (2003), Osinubi and Eberemu (2006), Osinubi and Edeh (2011), Okeke and Enwelu (2011), Dahale *et al.* (2012), Jaglan and Mital (2015) among many others. This discovery is indeed a landmark achievement as it ensures a cost effective method of engineering construction while providing a pollution-free environment.

One area in which this emergent knowledge and technology has proven to be of high importance or indispensable is soil stabilization. A lot of research works have been carried out in this area. For instance, Poh *et al.* (2006) investigated the stabilization of English China Clay and Mercia mudstone using Basic Oxygen Steel slag fines. They reported an improvement in strength and durability with a corresponding decrease in expansion. Punthutaecha *et al.* (2006) evaluated the changes in volume of sulfate rich expansive soils stabilized using Class F fly ash, bottom ash, polypropylene fibers, and nylon fibers. They concluded that ash stabilizers showed improvements in reducing swelling, shrinkage, and plasticity characteristics by 20 – 80%, while fiber treatment resulted in varied improvement.

In addition, Osinubi *et al.* (2009) investigated the effect of Bagasse Ash (BA) admixture on the engineering properties of lime stabilized black cotton soil and observed an increase in the optimum moisture content with a decreasing maximum dry density. Yadu and Tripathi (2013) reported that stabilization of soft soil can be improved by the addition of blast furnace slag and fly ash. Murthy (2012) reported a successful stabilization of expansive soil using mill waste.

Also, Biradar *et al.* (2014) investigated the influence of steel slag and fly ash on clayey soil and observed significant changes in the compressibility, permeability, plasticity and liquid limit of the soil. Hambirao and Rakaraddi (2014) reported a successful stabilization of soil using shredded rubber tyre chips waste.

However, considering the framework of this study, the focus is on two notable industrial wastes that have been employed in soil stabilization with remarkable success in recent time. They are fly ash (Cokca, 2001; Kolias *et al.,* 2005; Ramadas *et al.,* 2011; Brooks *et al.,* 2011; Modak *et al.,* 2012; Gyanen *et al.,* 2013; Zumrawi and Hamza, 2014) and rice husk ash (Basha *et al.,* 2004; Roy, 2008; 2010; Alhasan, 2008; Sharma *et al.,* 2008; Murthy and Praveen, 2008; Okafor and Okonkwo, 2009; Hossain *et al.,* 2011; Edeh *et al.,* 2012).

According to Ola (1975), stabilization of soil is employed when it is more economical to overcome a deficiency in a readily available material than to bring in one that fully complies with the requirements of specification for the soil. Clay has been reported to occur massively in most towns in eastern Nigeria (Okeke, 1991; 2008). Hence the improvement of its geotechnical properties is of paramount importance.

On the other hand, fly ash and rice husk ash as industrial wastes are known to be generated in very large amount in eastern Nigeria, owing to the abundant coal deposit and its utilization, and the massive rice production in the region. Therefore, the utilization of these readily available waste materials in soil stabilization is crucial and bound to be a double-edge achievement with the view to achieving and maintaining a healthy environment through a cost effective engineering practice. In a nutshell, a sustainable development in the area can be achieved by transforming waste materials to wealthy materials (Aguirre *et al.,* 2009; Rama-Subbarao *et al.,* 2011).

There are several alternatives available to the construction engineers in curbing the problem of expansive soils. However, one of the most common, dependable, and economically feasible option is enhancing the properties of soil on site (Cokca, 2001; Venkatramaiah, 2012), a process known as Soil Stabilization. Soil stabilization therefore, refers to the technique of altering the properties of a soil so as to improve its engineering performance (Attoh-Okine, 1995; IRC, 2008; Venkatramaiah, 2012).

In other words, soil stabilization as the name implies, significantly changes the characteristics of a soil to produce long-term permanent strength and stability with respect to the action of water and frost (NLA, 2004).

A lot of investigations have been carried out on soil stabilization, the use of various additives in soil stabilization, and concrete mixture by numerous scholars and agencies including Gutschick (1967), Holtz (1969), Bell (1989; 1996), Jiang *et al.* (1999), Malhortra *et al.* (2000), ASTM (2001D, 2001E), Parsons *et al.,* (2001), Makaratat *et al.* (2004), Nassif *et al.* (2005), Siddique (2008), Siddique *et al.* (2009), Okeke and Okogbue (2010), Okeke and Enwelu (2011), among so many others.

Stabilization can be used to treat a wide range of problems soils, from expansive clay to collapsible lateritic soils. It can be achieved either by subjecting the soils to mechanical processes or by adding chemical(s) or additive(s) to them. Mechanical stabilization increases the density of the soil by eliminating air from between grains (compaction) or by the addition or removal of soil materials to change the gradation and therefore change the engineering properties (Venkatramaiah, 2012). On the other hand, chemical stabilization involves the addition of cementitious or pozzolanic materials to improve the soil properties (IRC, 2008).

According to Industrial Resources Council (2008), chemical stabilization has traditionally relied on Portland cement and lime as stabilization additives. These traditional stabilizers (Additives) generally rely on pozzolanic reactions to achieve stabilization (Mallella *et al.,* 2004; Little and Nair, 2009; Ramadas *et al.,* 2011; Azadegan *et al.,* 2012). Various pozzolans including, fly ash, silica fume, metakaolin, rice husk ash, blast furnace slag, foundry sand, etc have been found to be suitable cement alternatives (Xu *et al.,* 2012, Kocak and Nas, 2014; Baldino *et al.,* 2014).

A ***"Pozzolan"*** therefore refers to a siliceous or siliceous and aluminous material, which in itself possess little or no cementing property, but will in a finely divided form, and in the presence of moisture, chemically react with calcium hydroxide at ordinary temperatures to form compounds possessing cementitious properties (Malhotra and Mehta, 1996).

The type and amount of additive(s) used is dependent on the nature of the soil and its deficiencies, as the properties of fine-grained soils tend to influence the soil-additive interaction (Little and Nair, 2009). In view of this, Little and Nair (2009) outlined the following parameters to be considered when selecting the appropriate additive(s) for soil stabilization:

i. Soil consistency and gradation
ii. Soil mineralogy and composition
iii. Desired engineering properties
iv. Purpose of treatment
v. Mechanisms of stabilization
vi. Environmental conditions and engineering economics.

Soil stabilization with pozzolanic materials provides cost effective and sustainable methods of improving the engineering properties of problematic soils (IRC, 2008). In addition, stabilization results in strength increase, reductions in compressibility, and shrink-swell potential (associated with decrease in plasticity index) of expansive soils, provided by the cementing action of the additive (Venkatramaiah, 2012), thus improving the load bearing capacity of that soil to support pavement and foundations.

Lime is a general term for calcium-containing inorganic materials in which carbonates, oxides and hydroxides predominate (Kumar and Preethi, 2014). It is produced from natural limestone through the process of calcinations (Zumrawi and Hamza, 2014).

The end product of this process, quicklime (CaO), reacts with water to yield hydrated lime or slacked lime ($Ca[OH]_2$), (NLA, 2004). The reactions on lime production can be clarified using the following chemical equations:

$$CaCO_3 + \text{heat} \longrightarrow CaO + CO_2 \uparrow \tag{2.1}$$

$$CaO + H_2O \longrightarrow Ca(OH)_2 + \text{heat} \uparrow \tag{2.2}$$

The basic constituents of lime are shown in Table 2.1 below

Table 2.1: General Chemical Composition of Hydrated Lime
(After Zumrawi and Hamza, 2014)

Chemical Composition	Percentage (%)
Calcium hydroxide ($Ca(OH)_2$)	65
Active Calcium Oxide (CaO)	48
Silica (SiO_2)	5.2
Alumina and Iron ($Al_2O_3$and Fe_2O_3)	0.7
Magnesium Oxide (MgO)	1.5
Calcium Carbonate ($CaCO_3$)	3.5

The use of lime in the construction industry is an ancient practice from Romans and Egyptians (Rama-Subbarao *et al.,* 2011). It is the oldest traditional chemical additive for soil stabilization (Mallela *et al.,* 2004; Vanlkratramaiah, 2012; Jawad, 2014), and the most routinely used (Little and Nair, 2009). Lime has been used for many years to stabilize road beds and air fields, but now it is also used to stabilize building sites (Gutschick, 1967).

Lime in the form of quicklime (Calcium oxide – CaO), hydrated lime (Calcium hydroxide – $Ca[OH]_2$), or lime slurry can be used to stabilize clay soils (Zumrawi and Hamza, 2014). Though, the most commonly form of lime used in soil stabilization is hydrated lime (Rama-Subbarao *et al.,* 2011), calcium oxide may be more effective in some cases, but will corrosively attack equipment and may cause severe skin burns to personnel (Muntohar and Hantoro, 2000).

Lime either as a sole stabilizer (alone) or as an activator (in combination with other materials), can be used to treat a wide range of soil types (Vankatramaiah, 2012). In general, fine-grained clay soils (with a minimum of 25 percent passing the No. 200 sieve (74mm) and a plasticity index greater than 10) are considered to be suitable for stabilization (NLA, 2004). However, it has been found to react successfully with medium, moderately fine and fine grained soils causing a decrease in plasticity and swell potential of expansive soils, and an increase in their workability and strength properties (Little and Nair, 2009).

According to Little and Nair (2009), the National Lime Association recommends a plasticity index of 10 or greater in order for lime to be considered as a potential stabilizer whereas the U.S. Army Corps of Engineers recommends a plasticity index of 12 or greater for successful lime stabilization. They, however, noted that based on AASHTO classification, soil types A-4, A-5, A-6, A-7 and some of A-2-7 are suitable for stabilization with lime.

When lime is added to moist clay, a number of reactions take place including cation exchange, pozzolanic reaction and carbonation (O' Flaherty, 2002). The cation exchange of calcium ions (Ca^{2+}) is responsible for the aggregation of soil particles and changes in the plasticity properties of clay, leading to early strength development (Boardman *et al.,* 2001). The pozzolanic reaction takes place slowly and is responsible for late strength development (Zumrawi and Hamza, 2014).

According to Eades and Grim (1960), and the National Lime Association (2004), the degree of reactivity of soil with lime and the strength of soils is dependent on the mineralogical constituents and surrounding environment. The properties of soil-lime mixtures are dependent on many variables such as soil type, lime type, lime percentage and curing conditions, including time, temperature, and moisture (Little, 1995).

When adequate quantities of lime and water are added, the pH of the soil quickly increases to above 10.5 which enables the clay particles to break down (NLA, 2004). The silica and alumina that exist in the soil minerals become soluble and free from the soil when pH exceeds 12.4 (Jawad *et al.,* 2014).

According to Gutschick (1967), lime stabilization is used especially when expansive clays, including heavy clay and silty clay soils are encountered. Expansive clays can be stabilized by the addition of small percentages, by weight of lime, thereby enhancing many of the engineering properties of the soil and producing an improved construction material (Bell, 1989, 1996).

The addition of lime to unstable clay soils initiates and accelerates a chemical reaction that occur in two phases resulting to the production of coarse grains and cementitious materials such as Calcium-Silicate-Hydrates (C-S-H) and Calcium Aluminate Hydrates (C-A-H) in phases one and two respectively (Eades and Grim, 1960; Gutschick, 1967; NLA, 2004; Little and Nair, 2009; Eisazadeh *et al.,* 2012a). It should be noted that the level of reactivity depends on the type and amount of clay minerals present in the soil (Little and Nair, 2009).

Phase one, which is known as immediate or short-term treatment, occur within a few hours or days after lime addition (Locat *et al.,* 1990; Abdi and Wild, 1993). As noted earlier, this phase is characterized by three main chemical reactions – cation exchange, flocculation-agglomeration and carbonation. Phase two which is known as the long-term treatment as it requires several months or even years to be completed is characterized by pozzolanic reactions.

Pozzolanic reactions are functions of temperature, calcium quantity, pH value and the percentage of silica and alumina in the soil minerals (Eades and Grim, 1960; Kassim *et al.,* 2005). These pozzolanic reactions can be illustrated by the following chemical equations (Mallela *et al.,* 2004; Yong and Ouhadi, 2007; Chen and Lin, 2009):

$$Ca(OH)_2 + SiO_2 \longrightarrow CaO - SiO_2 - H_2O \qquad (2.3)$$

$$Ca(OH)_2 + Al_2O_3 \longrightarrow CaO - Al_2O_3 - H_2O \qquad (2.4)$$

The use of lime in soil stabilization has been investigated by several researchers who critically outlined the various benefits and effects of lime in soil-lime stabilization or in combination with pozzolans (Eades and Grim, 1960; Locat *et al.,* 1990; George *et al.,* 1992; Abdi and Wild, 1993; Wild *et al.,* 1996; Kassim and Chow, 2000; Milburn and Parsons, 2004; Geiman, 2005; Kassim *et al.,* 2005; Alhasan, 2008; Singh *et al.,* 2008; Okeke and Okogbue, 2010; Jawad *et al.,* 2014, and host of others).

Bell (1996) investigated lime stabilization of clay minerals and soils using the three most frequently occurring minerals in clay deposits – kaolinite, montmorillonite and quartze, which were subjected to series of tests. Till and laminated clay were treated in similar fashion. With the addition of lime, the plasticity of montmorillonite was reduced while that of kaolinite and quartz was increased somewhat. However, the addition of lime to the till had little influence in its plasticity but a significant reduction occurred in that of the laminated clay. All materials experienced an increase in the Optimum Moisture Content (OMC) and a decrease in the maximum dry density (MDD), as well as enhanced California Bearing Ratio on addition of lime.

Okeke and Okogbue (2010) investigated the effects of lime-stabilization on the geotechnical properties of an expansive soil from Akaeze, Southeastern Nigeria. The geotechnical properties investigated include liquid limit, plasticity index, linear shrinkage, compaction characteristics and California Bearing Ratio. The results show that liquid limit, plasticity index, linear shrinkage and maximum dry density values of the treated soil were reduced while the California bearing ratio values were increased.

Little (1995) observed that lime reduces plasticity index and makes the soil more workable. He demonstrated that the reaction between lime and soil causes an alternation of the moisture-density relationship that is soil dependent and is also dependent on amount of lime added. He found that the compaction curve peaks at a higher value of density and a lower moisture content with lime than without.

Eades *et al.,* (1963) evaluated three different Virginia soils. 3% to 5% hydrated lime was added which significantly improved the soaked CBR from less than 5% to near 100%. Al-Rawas *et al.,* (2005) observed a reduction in swell percent and swelling pressure from 9.5 to 0 and 250kPa to 0 respectively by addition of 6% lime to Oman expansive soil. They concluded that the addition of lime reduces the swelling characteristics of stabilized clayed soils. Also, as reported by Basma and Tuncer (1991), the swelling pressure of highly plastic clay 2600kPa was reduced to 1700kPa with 10% hydrated lime (immediately) and was further reduced to 0kPa with 28days of cure at only 4% hydrated lime.

Ismail (2004) studied materials and soils derived from Feuerletten (Keuper) and Amaltheenton (Jura) formations in Germany. He determined consistency limits, compaction properties, and shear – and uniaxial strengths by treating and stabilizing these materials using lime (10%), cement (10%), and lime/cement

(2.5%/7.5%). He concluded that by increasing the optimum moisture content of the treated-materials, the maximum dry density decreased. The cohesion and the friction angle of the treated materials increased for all the mixtures. In the case of the lime-treated materials, the cohesion decreased by curing time. For Feuerletten materials, uniaxial strength increased strongly using lime and cement together. For Amultheenton, uniaxial strength increased strongly with cement alone.

Ampere and Aydogmust (2005) performed stabilization on Chemnitz clayed soil (A-7-6 Group) (according to American Association of State Highway and Transportation Officials (AASHTO)) using lime (2, 4, and 6%) and Cement (3, 6, and 9%), they conducted compaction–unconfined compressive strength, and direct shear–tests on untreated and treated specimens. They concluded that the strength of cement-treated soil was generally greater than the strength of lime-treated soils. They also reported that lime-stabilization is (in general, more tolerant of construction delay than cement-stabilization) more suitable for the clayed soils.

Bell (1989) evaluated lime stabilization of clay soils. He concluded that the addition of lime to clay soils results to an increase in the plastic limit but a decrease in liquid limit, which is associated with workability of the soil. He further stated that addition of lime in excess is utilized in cementation process, which gives rise to an increase in soil strength.

Parsons *et al.* (2001) used five types of soils to evaluate the mixing procedure of soil modification using lime. In their study, the soil was mixed with 2.5 and 5.0% lime and the results showed that the liquid limit decreased with increasing lime content, together with the decrease in plastic limit and plasticity index.

A number of authors (Little *et al.,* 1995; Mallela *et al.,* 2004) reported that a lime-treated soil would experience a reduction in liquid limit while the plastic limit is increased, with a corresponding decrease in plasticity index. Jan and Walker (1963) and Wang *et al.* (1963), also reported a corresponding decrease with increasing lime content.

However, Zolkov (1962) reported that lime contents rather increased the liquid limit of the soil. In addition, Lund and Ramsey (1958), and Taylor and Arman (1960) are of the view that increase or decrease in the liquid limit of lime-treated soil is a function of the soil types.

Thus, in whichever case, lime stabilization aims at reducing the plasticity and swell potential of expansive soils, and increasing their workability and strength properties (Gutschick, 1976; Locat *et al.,* 1990; Greaves, 1996; Wild *et al.,* 1996; Okogbue and Yakubu, 2000; Mallela *et al.,* 2004; NLA, 2004; Geiman, 2005; Little and Nair, 2009).

Consequently, the soil is converted into a suitable construction material attributed to a significant reduction in the sensitivity of the soil to moisture.

Fly ash refers to the waste material produced primarily from the combustion of coal in coal-fired power plants. It is otherwise known as fuel ash and consists mainly of fine powdery materials composed mostly of silicon dioxide (SiO_2), Aluminum oxide (Al_2O_3) and iron oxide (Fe_2O_3), which is carried up the smoke stack and captured by pollution control devices in coal based electric generating plants (Ismail *et al.,* 2007).

According to Sue (2013), coal which currently provides 40% of the world's electricity need is the second source of primary energy in the world after oil, and the first source of electricity generation. He noted that coal has been the fastest growing global energy source since the beginning of the 21st century, and that the growth in coal utilization in the last decade is been driven by the economic growth of developing economies. For instance, in India, 75% of the total power generated is from coal-based thermal power plants (Senapati, 2011).

On the contrary, in Nigeria, a sister developing nation, coal production and utilization has been on the decline since the advent of petroleum in 1958. According to Kayode Fayemi in Vanguard Newspaper of March 20, 2016, "Coal production started in Nigeria in 1902 and it was the main energy source for our country until 1960, and coal is in about 19 states of the federation stretching for about 800 kilometres". Several factors contributed to the demise of the coal industry in Nigeria; general decline in global and local demand of coal, constant flooding of Nigerian coal mines, including Onyema and Okpara mines – the two notable coal mines in Enugu (coal city), Southeastern Nigeria; and the eventual demise of the Nigerian Coal Corporation in the last few decades.

However, with the revitalization of the Nigerian coal industry in view, coupled with the current increase in the global demand of coal, a huge potential exists for the Nigerian coal, especially in electricity generation. Coal exploration offers a significant opportunity for power generation and we believe that about 1000 megawatts of electricity can be generated from coal by the year 2020 (Fayemi: Vanguard Newspaper, March 20, 2016).

With the increasing demand for power, a corresponding increase in fly ash generation is expected in Nigeria and beyond. In India for instance, Kumar *et al.* (2005) estimated fly ash generation at 225 million tons by the year 2017. Considering the trend, Nigeria would not be left out in contributing to the global generation of fly ash in the near future, especially as her revitalization process gathers momentum.

Notably, two classes of fly ash have been defined by ASTM C 618 based on their chemical composition which is dependent on the type of coal burned: Class F fly ash and Class C fly ash. Class F fly ash is a by-product of anthracite and bituminous coals combustion and contains little amount of lime (CaO). This class of fly ash possesses siliceous and aluminous materials (Pozzolans), which in their own possess little or no cemetitious value but reacts chemically with lime in the presence of water and at ordinary temperature to form cementitious compounds (Chu and Kao, 1993; Dahale *et al.,* 2012; Nadaf and Mandal, 2013; Zumrawi and Hamza, 2014).

On the other hand, class C fly ash is a by-product of lignite and sub-bituminous coals combustion, possessing significant amount of lime along with pozzolanic materials (Cockrell and Leonard, 1970; Ismail *et al.,* 2007; Dahale *et al.,* 2012; Nadaf and Mandal, 2013; Zumrawi and Hamza, 2014). The Enugu Coal is sub-bitumunous (Okeke, 1991). The Nkalagu Cement factory gets its fuel supply from the Enugu Coal (Okeke 1991). By ASTM C 618 classification, the Nkalagu coal ashes fall in the category of Class C.

However, it should be noted that there is no strict requirement that a given class of ash must come from a specific type of coal (Ismail *et al.,* 2007). They concluded that class F fly ash can be produced from coal that is not bituminous, and bituminous coal can produce fly ash that is not class F. The chemical composition of fly ash is shown in Table 2.2 below.

One of the greatest challenges arising from industrialization, urbanization and development in general, including coal production and utilization is the huge amount of wastes that is associated with these processes. According to Sharma *et al.* (2012), the world's largest quantity of industrial solidwastes is generated by coal-fired power plants as fly ash, which creates severe waste disposal problems. Hence, the increasing trend towards electrical power generation through coal combustion has and would continue to aggravate the problems associated with the disposal of the fly ash "byproduct" (Nablantolu, 2001), until bulk utilization of fly ash is factored into the waste or environmental management plan.

Although, coal production and utilization is temporarily out of favour in the country, including the Nigerian Cement Factory Nkalagu, that depends solely on coal (Enugu coal) for its fuel supply, the relics of disposed fly ash that stand like mountains around the vicinity of this cement factory is a clear indicator of what to expect as soon as the revitalization process is completed. Hence, there is dire need to resolve the clash between development and environment by establishing an efficient fly ash management system that would seek to adopt proactive measures rather than reactive measures.

Considering the increasing global concern for human and environmental health, efficient utilization and disposal of fly ash remains paramount in a developing country like Nigeria. The U.S Congress Office of Technology Assessment (1992) stated that the coal industry sees utilization, or recycling of fly ash as the most realistic ways to lower the volume of waste requiring disposal.

Fly ash has become the earth's largest industrial waste by-product, but fortunately some of it is diverted for a good purpose (Sue, 2013). According to U.S. Congress Office of Technology Assessment (1992), the coal industry estimates that between 20 and 28 percent of coal ash being generated today is recycled annually, and 17 percent of fly ash is used as a concrete or cement additive, among other uses.

Table 2.2: General Chemical Composition of Fly Ash
(After Nadaf and Mandal, 2013)

CHEMICAL CONSTITUENTS	VALUE (%)
Al_2O_3	26.822
BaO	0.067
CaO	1.128
Fe_2O_3	5.487
K_2O	0.936
MgO	0.955
MnO	0.031
P_2O_5	0.246
SiO_2	61.321
SO_3	0.073
SrO	0.059
TiO_2	1.646
LOI*	1.229
LOI Loss on ignition	

Many researchers have attempted to convert fly ash into useful construction materials (Singh *et al.,* 1996; Singh *et al.,* 2008; Kaniraj and Havanagi, 2001; Pandian *et al.,* 2002; Phanikumar and Sharma, 2004; Kolias *et al.,* 2005; Brooks *et al.,* 2011; Udayshankar *et al.,* 2012). According to the statistics reported for years 1987 - 1989, 415 million tons of flyash was produced all over the world. Of this 415 million, only 16% was utilized in construction sector (Baykal and Doven, 2000).

However, recent investigations have indicated that bulk utilization of this waste is possible only through geotechnical applications (Pandian, 2004; Nadaf and Mandal, 2013). Its world wide availability, outstanding structural contributions (strength and durability) and relatively economical cost create a constant demand for this by-product in the construction industry (Sue, 2013).

The American Coal Ash Association (2003) enumerated the applications of fly ash to include: soil stabilization, soil drying, and control of shrink-swell behavior of soil. Its usage in geotechnical applications is made possible through the possession of such properties like low unit weight, low compressibility and pozzolanic reactivity (Amadi, 2002). Of these properties, pozzolanic reactivity makes fly ash a valuable soil stabilizing agent (Amadi, 2012).

Through the possession of pozzolanic properties, or self-cementing properties, or both, fly ash can and has been successfully used as part of the binder in stabilized based construction applications (American Coal Ash Association, 2016). The use of fly ash in soil stabilization dates back in history as early as 1950s (American Coal Ash Association, 2003; Ismail *et al.,* 2007; Nadaf and Mandal, 2013; IRC, 2014).

The American Coal Ash Association (2003) confirmed the efficacy of fly ash in chemical and/or mechanical stabilization of soils, and outlined the benefits of this waste as a stabilizing agent to include: elimination of the need for expensive burrow materials; expedites construction by improving excessively wet or unstable soil; by improving subgrade conditions, promotes cost savings; can reduce or eliminate the need for more expensive natural aggregates. Besides improving performance and lowering cost of construction, stabilization with fly ash offers a solution to an environmental problem, as it reduces to the bare minimum, the volume of wastes that would have occupied arable and more useful lands, and constituted environmental health hazards.

According to Amadi (2012), fly ash treatment has shown to be effective in improving the gradation characteristics, plasticity, workability, strength, shrinkage, as well as reducing the hydraulic conductivity and swell potential of highly plastic clays, and preventing the swell beneath small foundation pressures. Class C fly ash has been used alone to stabilize moderately plastic soils (Little and Nair, 2009). According to the Industrial Resources Council (2014), self-cementing (Class C) fly ash has been used successfully to stabilize fine-grained soils. The Council observed that rapid reactions of Class C fly ash reduced the plasticity of the soil, lowered the water content and increased the strength of the soil.

Choudhary *et al.* (2009) investigated the use of fly ash in stabilizing and modifying the undesirable characteristics of fine grained soil and reported that the addition of fly ash resulted in the decrease of plasticity, maximum dry density, cohesion and swelling properties of the soil while optimum moisture content and angle of internal friction increased with increasing fly ash content in the mix. These can be attributed to a cation exchange process (immediate reaction) provided by fly ash (Zumrawi and Hamza, 2014). Kate 1998 reported reduction in free swell index by 60% and 63% for two expansive soils A and B respectively with 15% class C fly ash. He also reported a decrease in swelling pressure from 120kPA to 90kPa of expansive soil A and from 160kPa to 105kPa of expansive soil B by treating with 12% fly ash.

Okunade (2010) investigated the effects of self-cementing coal fly ash on the engineering properties of three lateritic soils from Southwestern Nigeria. He observed that increasing coal fly ash contents led to decrease in liquid limits, plasticity indices, optimum moisture contents with a corresponding increase in the maximum dry densities and the unsoaked CBR values for all the soils.

Cokca (1999) observed that the percentage reduction in swelling potential of expansive soil composed of 85% Na-bentonite and 15% kaolinite was 52.6% and 58.3% treating with 25% of fly ash-1 and fly ash -2 (both class - C), respectively. Still on that note, Cokca (2001) found a reduction of 65% in swelling potential by addition of 20% fly ash which was nearly same as that shown by 8% lime.

Edil *et al.* (2002) conducted a field evaluation of several alternatives for construction over soft sub-grade soils using class C fly ash, and reported significant improvements in the unconfined compression test and CBR test of the soil. Acosta *et al.* (2003) estimated the self-cementing fly ash as a subgrade stabilizer and observed significant improvements in the California Bearing Ration (CBR), resilient modulus, and unconfined compressive strength at 18% fly ash.

Senol *et al.* (2006) investigated the use of self-cementing class C fly ash for the stabilization of a soft sub-grade. They observed that the engineering properties, such as unconfined compressive strength, CBR, and resilient modulus increased substantially after fly ash stabilization. Thomas and White (2003) used self-cementing fly ashes (from eight different fly ash sources) to treat and stabilize five different soil types (ranging from ML to CH) in Iowa for road construction applications. They reported that the geotechnical properties of these soils such as unconfined compressive strength, strength gain, and California Bearing Ratio showed remarkable improvements.

Parson and Milburn (2003) conducted a series of test to evaluate the stabilization process of seven different soils (CH, CH, CH, CL, CL, ML, and SM) using lime, cement, class C fly ash, and enzymatic stabilizer. It was aimed at determining the Atterberg limits and unconfined compressive strengths of the stabilized soils. They however reported that lime- and cement-stabilized soils showed better improvement compared to fly ash-treated soils.

As noted earlier, one outstanding property of fly ash in geotechnical application is its pozzolanic reactivity. The self-cementing fly ash has been used in soil stabilization as a lone stabilizer in soil treatments (Cokca, 1999; Edil *et al.,* 2002; Senol *et al.,* 2006) with varying degrees of success. However, when pozzolanic-type fly ash is used, an activator must be added to initiate the pozzolanic reaction (FHWA/ACAA, 2016). The most commonly used activators are lime and Portland cement (Little and Nair, 2009; FHWA/ACAA, 2016).

According to Little and Nair (2009), fly ash is typically used in conjunction with lime or cement to enhance the reactivity of the fine-grained soil with lime or cement and this substantially increases strength in clay stabilization due to the reactive pozzolans provided by the ash. The Industrial Resources Council

(2014), stated that class F fly ash is typically added to both cement and lime stabilized soils because the pozzolanic reactions provided improved strength and increased density and durability.

According to Kezdi (1979), the hydration of cement in fine-grained silts and clays would result in strong bonds between various mineral substances and the matrix formed encloses the non-bonded soil particles, resulting in reduction of plasticity and increase of shear strength of the mixture. Kate (1998) reported that pozzolanic reaction resulted in cemented compounds characterized by high strength and low volume change.

On that note, several researchers have attempted to treat and stabilize various types of problem soils using lime in combination with fly ash (Nalbantoglu and Gucbilmez, 2002; Zhang and Cao, 2002; Beeghly, 2003; Modak *et al.,* 2012; Zumrawi and Hamza, 2014). Nalbantoglu and Gucbilmez (2002) studied the utilization of an industrial waste in calcareous expansive clay stabilization, where the calcareous expansive clay in Cyprus had caused serious damage to structures. They reported that fly ash and lime-fly ash admixtures reduced the water absorption capacity and the compressibility of the treated soils. There was also an increase in hydraulic conductivity of the treated soils as fly ash percentage and curing time increased.

Zhang and Cao (2002) investigated the individual and admixed effects of lime and fly ash on the geotechnical characteristics of expansive soil, including chemical composition, grain size distribution, consistency limits, compaction, CBR, free swell and swell capacity. Lime and fly ash were added to the expansive soil at 4-6% and 40-50% by dry weight of soil, respectively. They reported a change of expansive soil texture when lime and fly ash were mixed with expansive soil. Mixing with lime led to an increase in plastic limit while mixing with fly ash led to a decrease in liquid limit, thereby decreasing the plasticity index. There was an obvious reduction in maximum dry density, free swell, and swelling capacity with a corresponding increase in the percentage of coarse particles, optimum moisture content, and CBR value as the percentage of lime and fly ash increased. They concluded that the expansive soil can be successfully stabilized with lime and fly ash.

Modak *et al.* (2012) performed stabilization on a black cotton soil using admixtures. They observed that the improved CBR value is due to addition of lime and fly ash as admixtures to the expansive soil. Zumrawi and Hamza (2014) investigated on the effect of lime-fly ash mixture on the characteristics of expansive sub-grade soils. They reported that CBR and UCS of the treated samples increased significantly, coupled with a reduction in swelling potential, as well as hydraulic conductivity. However, they concluded that in combination, the admixtures are beneficial for lower plasticity and higher silt content soils.

Beeghly (2003) evaluated the use of lime in combination with fly ash in stabilization of sub-grade soil (silty and clayey soils) and granular aggregate base course beneath the flexible asphalt layer or rigid concrete layer. He reported that lime alone works well to stabilize clay soils but a combination of lime and fly ash is beneficial for lower plasticity (higher silt content) soils.

He noticed that both unconfined compressive strength and CBR-values of treated stabilized soils (Moderate plasticity "P1 < 20" and high silt content "i.e. >50%") with lime and fly ash together are higher than the value with lime alone. He also observed that the capillary soak of the stabilized specimens led to a loss of unconfined compressive strength (15 – 25%). Beeghly (2003) concluded that lime/fly ash admixtures resulted in cost savings by increment material cost by up to 50% as compared to Portland cement stabilization.

Rice is a primary source of food for billions of people around the world (Rama-Subbarao *et al.,* 2011). This can serve as an insight to its high global production and consumption. In Nigeria for instance, about two (2) million tonnes of rice is produced annually (Okafor and Okonkwo, 2009).

Processing of rice generates an agricultural waste known as rice husk. Rice husk contains about 50% cellulose, 25 – 30% lignin, 15 – 20% silica (Siddique, 2008), and constitutes about 22% by weight of rice paddy (Okeke and Enwelu, 2011; Nagrale *et al.,* 2012). The global generation of this waste (rice husk) stands at one hundred and eight (108) tones per annum (Okafor and Okonwko, 2009; Kumar and Preethi, 2014).

Rice husk is used as fuel in the parboiling process of rice milling. The combustion of rice husk yields a residue known as rice-husk ash, which constitute 25% of the husk while 75% of the bulk escapes as organic volatiles (Okeke and Enwelu, 2011; Nagrale *et al.,* 2012). According to Nagrale *et al.,* (2012), rice husk production is likely to have more than doubled in most of the rice growing countries of the world by 2004 with estimation that some 120 million tonnes of it could be available annually on a global scale.

Considering the fact that about 25% by weight of rice husk constitutes the ash content, there are potentially 30 million tonnes of rice husk ash to be generated annually on a global basis. Nigeria with her teeming and increasing population as well as her ever-growing rice industry is a major contributor in the global production of rice husk and the subsequent generation of rice husk ash.

The disposal of this ash tends to pose a great environmental and health challenges and threats in poor and developing countries, especially the rice producing countries of the world including India, Indonesia, China and Nigeria (Okeke and Enwelu, 2011; Dahale *et al.,* 2012; Mohamed *et al.,* 2015) owing to the fact that much of the husk generated from rice processing is either burnt or dumped on the surroundings. A lasting solution of this problem would be to incorporate this by-product into a technology that would make an efficient utilization of the ash, converting it into a beneficial resource, forming part of the waste and environmental management system.

Research studies have shown that the oxide composition of rice-husk ash constitutes about 70% silica, 4.9% alumina and 0.95% iron oxide (Oyetola and Abdullahi, 2006), as seen in Table 2.3 below. The high silica content of rice-husk ash is an indication of its good pozzolanic value that promote the formation of cementitious compounds (such as Ca(SiO_3), a bonded gel) when mixed with lime or cement (Muntohar and Hantoro, 2000; Deodhar, 2009; Dahale *et al.,* 2012). Hence, as noted earlier, the use of this pozzolan (RHA) as a construction material will reduce the above mentioned environmental hazard associated with its disposal, as well as reduce the cost of construction (Okeke and Enwelu, 2011).

Table 2.3: Oxide composition of RHA
(After Oyetola and Abdullahi, 2006)

Constituent	**Composition (%)**
SiO_2	67.3
Al_2O_3	4.9
Fe_2O_3	0.95
CaO	1.36
MgO	1.81
Loss on Ignition	17.78

While trying to ensure that the aforementioned objective (environmental sustainability and cost) is achieved attempts have been made investigating the viability of rice-husk ash in geotechnical application (Dashan and Kamang, 1999; Makaratat *et al.,* 2004; Jha and Gill, 2006; Yin *et al.,* 2006; Muthadhi *et al.,* 2007; Alhassan, 2008; Phani Kumar *et al.,* 2008; Siddique, 2008; Roy *et al.,* 2009; Brooks, 2009).

Traditionally, rice husk has been considered a waste material and has generally been disposed off by dumping or burning, even though it has been used on a low scale as a low-grade fuel, which invariably ends in ash generation (Nagrale *et al.,* 2012). However, they reported that rice-husk ash has been successfully used as a pozzolanain commercial production in a number of countries including Columbia, Thailand and India. Undoubtedly, this geo-technology can be replicated in Nigeria, a co-developing and rice producing nation, considering the sufficient availability of the by-product.

According to Siddique (2008), the utilization of rice husk ash as a pozzolanic material in engineering construction provides several advantages such as improved strength and durability properties, reduced material costs, as well as environmental sustainability. It is therefore commonly used in production of special cements, concrete mixes, soil stabilization and partial replacement for cement in the production of sandcrete blocks (Al-khalif and Yousif, 1984; Dashan and Kamang, 1999; Deodhar, 2009).

For instance, Okeke and Enwelu (2011) investigated the use of rice husk ash as a partial replacement for cement in the production of sandcrete blocks. A proportion of cement was replaced with varying percentage of rice husk ash (10%, 20%, 30%, 40% and 50%) to determine the compressive strength and bulk density of the sandcrete blocks. They reported that compressive strength of the sandcrete for all mix proportions increased with age (curing age) but decreases with increase in the proportions (percent replacement) of the rice husk ash. The bulk density of the sandcrete block also decreased with increase in the proportion of rice husk ash.

Nagrale *et al.* (2012) investigated the utilization of rice husk ash for economical concrete. They observed a reduction in density of concrete, water absorption of concrete, as well as material cost with a corresponding increase in compressive strength on the addition of RHA. However, research has shown that one of the prominent uses of rice-husk ash is in improvement of soil performance (Haji Ali *et al.,* 1992; Muntohar, 2002, 2005 and 2009; Basha *et al.,* 2004; Yin, *et al.,* 2006; Oyetola and Abdullahi, 2006; Roy, 2008, 2010; Alhasan, 2008; Sharma *et al.,* 2008; Ramanamurty *et al.,* 2008; Okafor and Okonkwo, 2009; Hossain *et al.,* 2011; Edeh *et al.,* 2012).

Several of these researchers studied the influence of rice-husk ash in soil stabilization (Muntohar, 2002; Alhassan, 2008; Okafor and Okonkwo, 2009). Okafor and Okonkwo, (2009) investigated the effect of RHA on some geotechnical properties of a lateritic soil classified as A-2-6(o) or SW for sub-grade purposes. The results obtained show that increase in RHA content increased the OMC, volume stability, as well as strength of the soil but decreased the MDD and plasticity index.

Yadu *et al.* (2011) carried out an investigation to compare rice husk ash and fly ash stabilized black cotton soil with respect to Atterberg limits specific gravity, California bearing ratio (CBR), and unconfined compressive strength (UCS). The results indicate that the addition of RHA and FA reduces the plasticity index and specific gravity of the soil but increases UCS and CBR. However, the addition of RHA results in an increase in OMC and decrease in MDD, while these values decreased with addition of FA.

Nevertheless, findings by Rama-Subbarao *et al.* (2011) indicated that the effect of both RHA and FA in the geotechnical properties of soil replaced by these industrial residues proved to be modifying properties of the soil rather than enhancement.

Though, silica produced from rice husk ash has been successfully investigated as a pozzolanic material in soil stabilization, findings on the physical and chemical properties of rice husk ash suggest that RHA cannot be used solely for soil stabilization due to the possession of insignificant amount of cementitious properties (calcium element) (Dahale *et al.,* 2012; Kumar and Preethi, 2014).

As a result, ASTM (1993) stated that RHA can only be used as a partial replacement for the more expensive stabilizing agents (cement/lime) due to inadequate cementitious property required to bind the material to a satisfactory durability. Kumar and Preethi (2014) supported this view by recommending that rice husk ash be mixed with other cementitious materials such as lime and cement to have a solid chemical reaction in stabilization process.

Stabilization of expansive soil using rice husk ash as pozzolanic material along with a binder has engendered series of research studies. Some of the researchers studied the effect of RHA-FA on soil properties (Brooks, 2009), (Rama-Subbarao *et al.,* 2011), effect of RHA – Marble dust (Sabat and Nanda, 2011), effect of RHA-Calcium carbide residue (Jaturapitakkul and Roongreung, 2003), effect of RHA-lime sludge (Chandra *et al.,* 2005), (Akshaya, 2014), etc.

Brooks (2009) studied the potential of rice husk ash (RHA) and fly ash (FA) blended soil as a swell reduction layer between the footing of a foundation and subgrade. He recommended 12% and 25%, RHA and FA, respectively, for modifying the expansive subgrade soil.

Rama-Subbarao *et al.* (2011) investigated the effects of industrial wastes (FA and RHA) in soil improvement. The results showed that the addition of RHA to the soil led to a decrease in liquid limit, plasticity index and DFSI, with increasing unconfined compressive strength (UCS). They also observed that the addition of RHA in combination with FA produced a greater UCS. Hence, they concluded that fly ash has a significant influence on improvement of strength.

Chandra *et al.* (2005) stabilized a non-expansive clay soil with RHA and lime sludge. RHA added to soil was from 5 to 20% in steps of 5% and lime sludge from 4 to 16% in steps of 4%. Properties of the stabilized soil studied were Atterberg's limits, maximum dry density (MDD), optimum moisture content (OMC), unconfined compressive strength (UCS) and soaked California bearing ratio (CBR) of soil.

Akshaya (2014) studied the effect of rice husk ash (RHA) and lime sludge on the engineering properties of an expansive soil, including compaction characteristics, California bearing ratio, shear strength parameters, compression index, swelling pressure and durability. He reported an increase in OMC, CBR, cohesion and angle of internal friction with increasing RHA and lime sludge up to their optimum percentages. However, MDD, coefficient of compression and swelling pressure decreased with increasing RHA and lime sludge up to their optimum percentages.

Jaturapitakkul and Roongreung (2003) investigated the efficacy of a pozzolanic reaction between rice husk ash and calcium carbide residue to produce a cementitious material with respect to setting times of pastes, flow, and compression strength of mortars. The results show that the setting times of the new cementing pastes are longer than that of Portland cement paste. The ratio of calcium carbide residue to rice husk ash of 50:50 by weight obtains the highest compressive strength of mortar. On the basis of the compressive strength obtained, they concluded that calcium carbide residue – rice husk ash mixture has a high potential to be used as a cementing material.

Similarly, the effect of rice husk ash in combination with Portland cement on the characteristics of soil has been extensively studied (Rahman, 1987; Basha *et al.,* 2003; Ramakrishna and Pradeep Kumar, 2006; Mustapha, 2007; Alhassan and Mustapha, 2007; Montgomery and Chmeisse, 2012). Rahman (1987) investigated the effects of various cement-rice husk ash proportions on the geotechnical properties of lateritic soils including Atterberg limits, compaction characteristics, unconfined compressive strength, California bearing ratio and swelling potential. The test results show that these lateritic soils stabilized with cement – RHA mixtures can be used in highway construction.

Alhassan and Mustapha (2007) investigated the effect of rice husk ash on lateritic soil classified as A-7-6 and stabilized with 2-8% cement by weight of the dry soil, with respect to compaction characteristics, California bearing ratio (CBR) and unconfined compressive strength (UCS). They reported a general decrease in maximum dry density (MDD) with a corresponding increase in optimum moisture content (OMC), as the RHA content increased at specified cement contents.

Montgomery and Chmeisse (2012) investigated the effect of RHA on the engineering properties of three types of soil treated with varying quantities of lime, cement, RHA and combinations of RHA with lime or cement, with respect to unconfined compressive strength (UCS), plasticity index and linear shrinkage. They reported that RHA alone showed to be unsuitable for modifying soil properties, but produced significant results when in combination with lime or cement.

There exist several agents that can be used as an activator in a pozzoloanic reaction to form a cementitious substance, however, lime and cement remain the most commonly used activators (Little and Nair, 2009; FHWA/ACAA, 2016). ASTM (1993) reported a case history where rice husk ash was used on a

Malaysian soil with lime and cement as activators. On the basis of strength development as indicated by the results, it was concluded that lime is more effective than cement as an activator or stabilizing agent.

It should be noted that various attempts have been made by numerous researchers especially within the last two decades investigating the efficacy of rice husk ash in combination with lime as admixtures in soil stabilization (Muntohar and Hantoro, 2000; Jha and Gill, 2006; Ali and Sreenivasulu, 2004; Alhassan, 2008; Phani Kumar *et al.,* 2008; Lazaro and Moh, 1970; Balasubramanian *et al.,* 1999; Choobbasti *et al.,* 2010; Kumar and Preethi, 2014; Jha and Tiwari, 2016).

Muntohar and Hantoro (2000) investigated the influence of rice husk ash and lime on the engineering properties of a clayey subgrade. The results showed that the addition of lime and rice husk ash to the soil led to a decrease in specific gravity, plasticity index, swell potential and maximum dry density, with a corresponding increase in optimum moisture content, shear strength and California bearing ratio (CBR).

Choobbasti *et al.* (2010) evaluated the influence of using rice husk ash in soil stabilization method with lime. The geotechnical properties investigated include Atterberg limits, compaction, California bearing ratio (CBR), and shear strength. They reported a decrease in dry density, liquid limit, plastic limit, and deformability, with a corresponding increase in optimum moisture content

(OMC), shear strength and California bearing ratio (CBR) on the addition of lime and rice husk ash (RHA).

Kumar and Preethi (2014) evaluated the behaviour of clayey soil stabilized with rice husk ash and lime. The results show improvement in unconfined compressive strength (UCS) and California bearing ratio (CBR). It was observed that the addition of RHA alone gave an average improvement when compared with the untreated sample whereas the addition of lime to the mix raised the improvement to a greater extent.

Jha and Tiwari (2016) studied the effect of lime and rice husk ash on the engineering properties of black cotton soil. There was improvement in the index properties, as well as the strength characteristics of the soil. Hence, they concluded that rice husk ash is an important material to stabilize the black cotton soil and make it suitable for construction purpose. Similarly, Ali *et al.,* (2004) studied the effect of rice husk ash (RHA) and lime on characteristics of bentonite. They reported a successful improvement in the engineering properties of the stabilized soil.

However, varying conclusions have been deduced by these researchers concerning the viability of blended rice husk ash with lime or cement. For instance, Lazaro and Moh (1970) concluded that the addition of RHA in combination with lime to both Thai and Philippine soils does not produce any significant increasing of strength as compared to the use of lime alone.

On the same note, Balasubramaniam *et al.* (1999), and Muntohar and Hantoro (2000) showed that addition of rice husk ash to lime-stabilized soils exhibits ductile behaviour associated with high strain and low strength. Whereas, Haji Ali *et al.,* (1992) pointed out that both the lime-stabilized and cement-stabilized residual soils from Malaysia enhance the strength and durability by adding rice husk ash.

Nonetheless, it should be noted that all the researchers examined above focused on either the effects of some additives or admixtures on a particular soil, or the effect of a particular additive or admixture on different soils. Yet, this particular investigation focused on the effects of two admixtures (lime-fly ash and lime-rice husk ash) simultaneously on two different Formations (Ezeaku Shale and Awgu Shale).

2.2 The Study Area

2.2.1 Location and Accessibility

The study area, comprising Lokpaukwu and Awgu in Southeastern Nigeria, lie between latitude $5^{0}54^{1}$ – $6^{0}10^{1}$ and longitude $7^{0}21^{1}$ – $7^{0}33^{1}$. Though, the two communities may share proximity, Lopkaukwu is located in Umuneochi Local Government Area of Abia State and bounded in the North by Lekwesi, in the West by Uhuda Ngodo, and in the South by Eluama. Awgu is located in Awgu Local Government Area of Enugu State. It is bounded in the North by Maku and Mgbowo Communities, in the West by Mgbidi, in the South by Ohaja Awgu, and in the East by Ndeaboh.

The ever busy Enugu-Port-Harcourt Expressway that runs from North to South of the region, transversing the study area, places it at a very strategic location. Other roads including the Awgu-Ndeaboh road, Ishiagu road, Ihube road, and foot paths contribute to make the area very accessible (Fig. 2.1).

2.2.2 Climate

The climate of the study area has been described by Inyang (1975), Nigerian Meteorological Agency (2007), and Geographical Alliance of Iowa (2007). The area lies within the tropical rainforest, experiencing two distinct seasons a year – the wet and the dry seasons. The wet season begins in April and lasts until October with a break (little dry season) in August usually referred to as "August break". The dry season lasts from November to March, experiencing two months of harmattan from late December to February.

The climate is humid and this humidity is usually high (about 75%) throughout the year, reaching a maximum value of about 90% in the rainy season. The average annual rainfall in the area is 1800mm (Nigerian Meteorological Agency, 2007). The hottest months are between January and March with mean annual temperature of over 27^0C and long hours of sunshine, resulting in high evapotranspiration as against the lower values recorded during the rainy months.

Generally, the climate type is the controlling factor in the weathering of the shale deposited in the study area to expansive clay, and in the moisture-suction condition of the derived soil.

2.2.3 Vegetation

The vegetation of the area is the evergreen and luxuriant vegetation of the tropical rainforest prevalent in the Eastern States of Nigeria. It is characterized by scattered trees and bushes. The trees exist in different heights or layers, possessing robust branches, and forming a dense canopy.

Economically exploitable flora like the iroko, mahogany, obeche, bamboo, coconut, native pear, mango, and oil palm predominate the area, while dependent species such as parasitic plants, saprophytes, climbers, creepers, and epiphytes are also common.

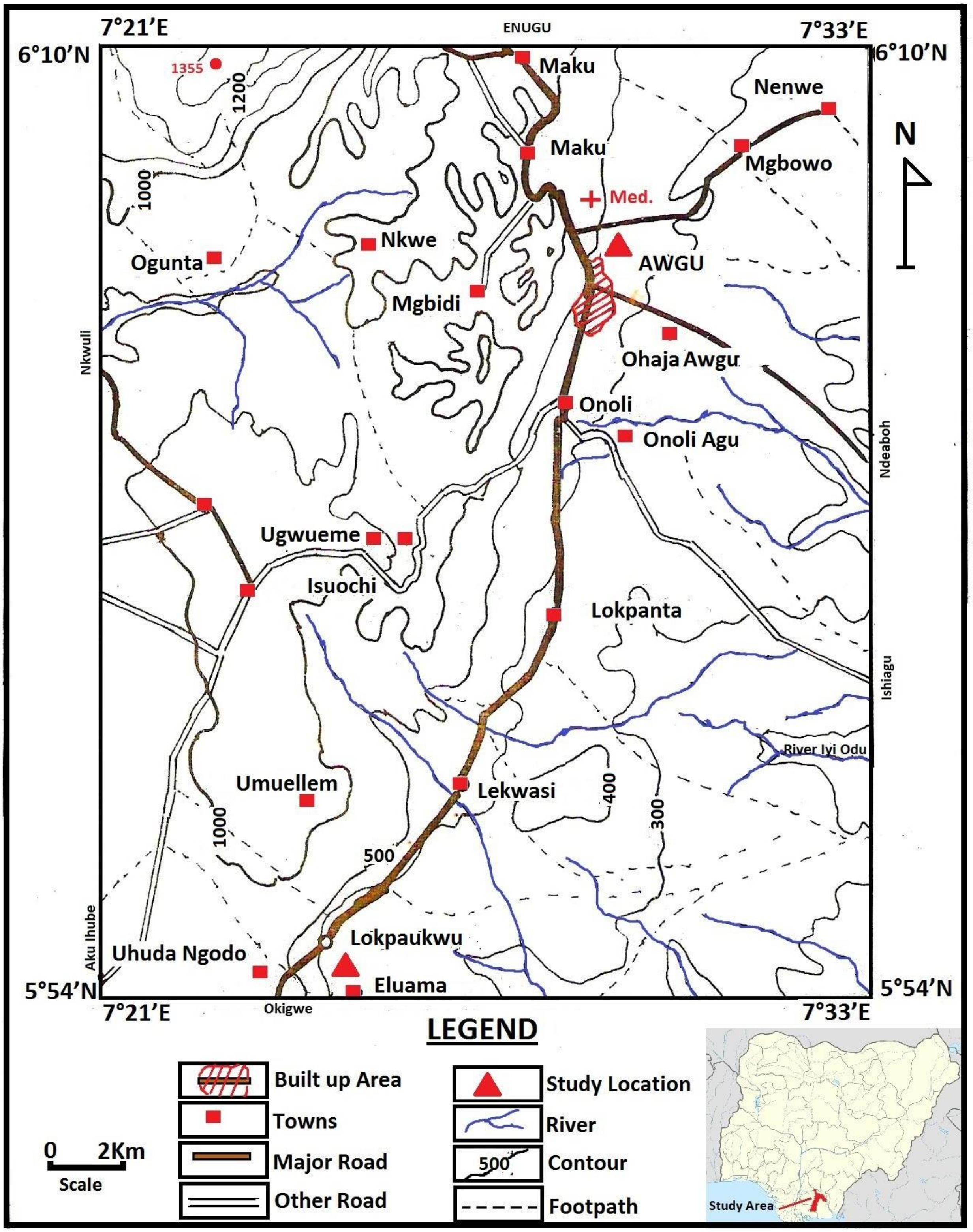

Fig. 2.1: Location/Topographic map of the study area (Modified from Zaborski, 1998)

2.3 Geology of the Study area

The geology of the Lower Benue Trough has been extensively studied and described by numerous scholars including Wilson and Bain (1928), Simpson (1954), Deswardt and Casey (1961), Reyment (1965), Short and Stauble (1967), Burke *et al.,* (1970), Murat (1972), Nwachukwu (1972), Hoque (1977), Agagu and Adighije (1983), Ofoegbu (1985), Agumanu (1986, 2011), and Umeji (2006), among many others.

2.3.1 Geologic Setting

The study areas (Lopkaukwu and Awgu) lie within the Abakiliki Basin which constitute the southern border of the Pre-Santonian Lower Benue Trough Sediments (Reyment, 1965). According to Murat (1972), the Southern part of Benue Trough was associated with a NE-SW trending fault, with the eastern half subsiding to give rise to the Abakiliki depression (Abakiliki trough). Host of other authors including Olade (1975), Burke (1996), Onyekuru and Iwuagwu (2010), and Chiaghanam *et al.* (2012) designated the Lower Benue Trough as an Aulacogen, a failed Arm of an RRR Triple junction that resulted from the Megatectonic-related opening of the South Atlantic in the Early Cretaceous Period.

Sedimentation in the Benue Trough was mainly during the Cretaceous Period, controlled by tectonic forces that engendered series of marine transgression and regression (Reyment, 1965; Reyment and Morner, 1977; and Zaborski, 2000). The Upper Cretaceous, precisely the Santonian Period, witnessed the deformation (folding and tectonic upliftment) and redefinition of the lower

Benue Trough (Kogbe, 1989). Thus, in describing the cretaceous history of the Lower Benue Trough, Murat (1972) and Kogbe (1974; 1989) noted two main sedimentary phases separated by the Santoniain deformation; the Pre-Santonian Lower Benue Trough (Abakiliki-Benue Troughs) and the Post-Santonian Lower Benue Trough (comprising the Abakiliki Anticlinorium, the Anambra Basin and the Afikpo Syncline).

Reyment (1965), Short and Stauble (1967), Murat (1972) and Obi *et al.* (2001) recognized three main depositional phases in the Lower Benue Trough; Abakiliki-Benue Phase (Albian-Santonian), Anambra-Afikpo phase (Companian-Maastrichtian), and the Niger-Delta phase (Paleogene) as seen in Table 2.4. The Abakiliki Trough was the main depocenter of the Pre-deformation Era, with its sediments including the Asu River Group, Ezeaku Formation and Awgu Formation (Ojoh, 1992), and represents the first sedimentary phase.

However, the initiation of the Anambra Basin during the Coniancian-Early Santonian and the subsequent Santonian deformation resulted to the dislocation of the depocenter from the Abakiliki-Benue rifts to the Anambra Basin (Murat, 1972; Hoque and Nwajide, 1985; Amajor, 1987; Kogbe, 1989) thereby marking the second sedimentary phase. According to Obi *et al.* (2001), tectonic inversion of the Abakiliki region which led to the displacement of the depositional axis further south of the Anambra Basin, initiated the Niger-Delta Basin that marked the third sedimentary phase (Paleogene sedminents).

2.3.2 Stratigraphy

The lithostratigraphy or depositional framework of the Lower Benue Trough Southeastern Nigeria has been documented through the sedimentary studies of Simpson (1954), Reyment (1965), Murat (1972), Offodile (1975), Petters and Ekweozor (1982), and Ojoh (1990). The stratigraphy of Lokpaukwu and Awgu, Southeastern Nigeria, developed during the first sedimentary phase (Albian-Santonian) of the Lower Benue Trough that produced the Asu river Group, Ezeaku and Awgu Formations, Collectively known as the Abakiliki Basin as accounted by Murat (1972), Fig.2.2. However, the study areas are particularly underlain by Ezeaku and Awgu Shales.

Table 2.4: Regional Stratigraphic Sequence of Southeastern Nigeria

(Modified from Reyment (1965), Murat (1972) and Offodile (1975))

	AGE	FORMATION	LITHOLOGY	SEDIMENTARY CYCLE
Tertiary	Recent	Recent	Alluvium/Deltaic Plains	Niger-Delta Basin (Third Tectonic Phase)
	Pliocene	Benin Formation	Unconsolidated Sandstone with Lenses of Clay	
	Pleistocene	Ogwash-Asaba Formation	Unconsolidated Sandstones, Mudstone, Clays and Lignite Seams	
Upper Cretaceous	Eocene	Ameki Formation	Grey to Green Argillaceous Standstone, Shale and Limestone Units	
	Paleocene	Imo Shale	Blue to Dark Grey Shales and Subordinate Members (Umuna and Ebenebe)	
	Maastrichtian	Nsukka Formation	Alternating Sequence of Shale, Sandstone and Coal Seams	Anambra-Afikpo Basin (Second Sedimentary Cycle).
		Ajali Sandstone	Friable Sandstones with Iron Stains	
		Mamu Formation	Sandstones, Shale, Siltstone with Coal Seams	
	Campanian	Nkporo Formation/Enugu Shale (including Afikpo Sandstone and Owelli Sandstones)	Mudstone and shale with thin Beds of Sandstone	
	Santonian Coniacian	Awgu Formation (Awgu Shale)	Shale with interrelations of Sandstones an Shelly Limestones	Abakiliki-Benue Basin (First Sedimentary Cycle).
	Turonian	Ezeaku Formation (Ezeaku Shale)	Siltstone and shale with Sandstone Lenses	
	Cenomanian	Odukpani Formation	Alternating Sequence of Sandstone, Shale and Limestone	
Lower Cretaceous	Albian	Asu-River Group	Sandy Shales, Sandstone and Sandy Limestone Lenses	
	Precambrian	Basement Complex	Older Granite and Gneisses	

2.3.2.1 Ezeaku Formation (Ezeaku Shale)

Lokpaukwu area is underlain by the Turonian Ezeaku Shale Formation that resulted from the second major marine transgression, and overlies the Asu River Group as noted by Murat (1972). This formation was first described by Simpson (1954). Its type section, along the Ezeaku River was identified by Reyment (1965), and its lithology was noted to consist essentially of calcareous shales, micaceous fine to medium-grained friable sandstones and occasional beds of a shelly limestones (Reyment, 1965; Kogbe, 1989). This formation varies in thickness but however attains up to the thickness of 1200m in some places (Dessauvagie, 1975). Kogbe (1989) also noted the grading of the shale into sandstone units; the Amasiri Sandstone near Afikpo and the Makurdi Sandstone around Makurdi.

2.3.2.2 Awgu Formation (Awgu Shale)

Awgu area is underlain by Awgu Formation of the Coniacian Age. It overlies the Ezeaku Formation, having a thickness of about 900m (Kogbe, 1989). The lithology consists of bluish grey, well bedded shales with occasional intercalations of fine-grained, pale yellow calcareous sandstones and shelly limestone (Reyment, 1965; Kogbe, 1989). Its type locality occurred between the towns of Awgu and Ndeaboh in Enugu State (Reyment, 1965), where the formation consists mainly of marine shales and limestones (Najime, 2011).

The Awgu Shale is overlain by a sandstone unit (Agbani Sandstone) composed of white, medium to coarse grained, poor to moderately sorted and cross laminated facie, depicting a fluviatile environment as a result of regression during Coniacian to Lower Santonian (Agumanu, 2011).

Agumanu (1986, 2011) and Uduji *et al.* (1994) also noted the presence of abundant clay minerals including smectite, illite, kaolinite and chlorite in the Shale of Awgu Formation.

Thus, the shale-derived soils in the study area have significant amounts of expansive smectite (Montmorillonite) minerals, resulting in shrink/swell potential.

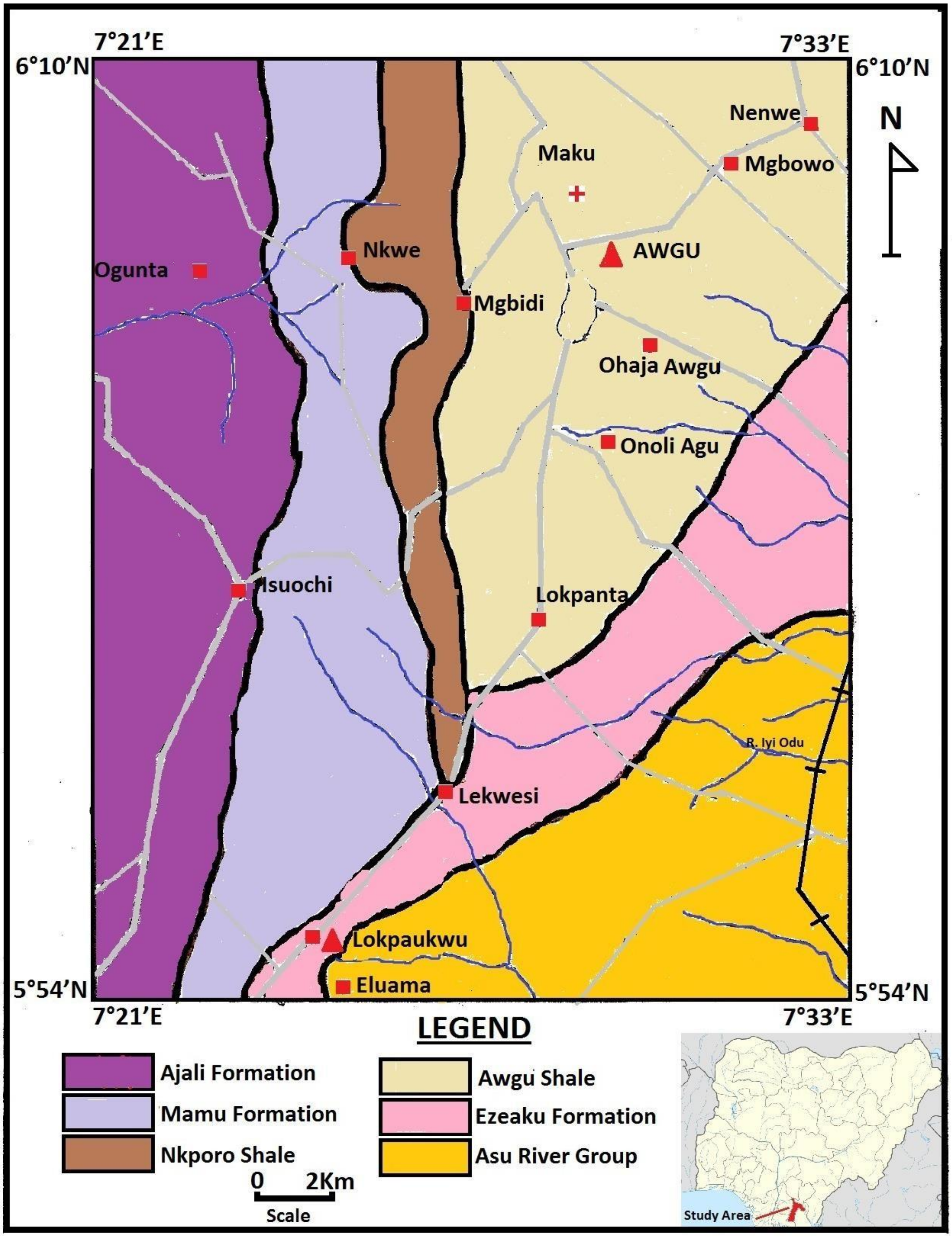

Fig. 2.2: Geologic map of the study area (Modified from Zaborski, 1998)

CHAPTER THREE

MATERIALS AND METHODS

3.1 Materials

The materials used for the laboratory investigation of the study include the expansive soil, lime, fly ash and rice-husk ash.

3.1.1 Soil

Three soil samples each were collected from outcrops of the expansive soils (Ezeaku and Awgu shales) at the two study locations (Lokpaukwu and Awgu). The sampled sites as shown in Fig. 1.1 are located beside Lokpaukwu Quarry, along Enugu-Port-Harcourt Expressway (Location 1), and at the junction of Awgu-Ndeaboh road and the Enugu-Port-Harcourt dual carriage way (location 2).

3.1.2 Lime

Lime is a traditional soil stabilizer in the construction industry, as indicated by numerous scholars. The Romans and Egyptians blazed the trail in the art of lime stabilization (Rama-Subbarao *et al.,* 2011). There are various forms of lime but the most commonly used form in soil stabilization is hydrated lime ($Ca(OH)_2$, otherwise known as Calcium hydroxide or slacked lime. In this investigation, a high quality hydrated lime bought from the open market and which satisfies the general requirements for construction purposes was used. The basic constituents of lime are shown in Table 2.1.

3.1.3 Fly Ash

Fly ash is the waste that is left after coal is combusted. The fly ash used in this investigation was obtained from the coal-fired power plant of the Nigerian Cement Company (Nigercem), Nkalagu, Southeastern Nigeria. In the course of this investigation, only fractions of the ash passing BS sieve No. 200[75µm] was used throughout, and without additional treatment. Table 2.2 shows the general chemical compositions of fly ash as provided by Nadaf and Mandal (2013).

3.1.4 Rice Husk Ash

Rice husk is a common agricultural waste in rice producing countries, generated as a by-product of rice milling. Rice Husk Ash (RHA) is obtained from the combustion of rice husk used as fuel in the parboiling process of rice processing. The RHA used in this investigation was obtained from Abakiliki Rice Mill, Southeastern Nigeria. The ash was screened with sieve 36 (0.425 mm sieve opening) using a mechanical vibrator to obtain the desired texture.

Table 2.3 shows the chemical composition of rice husk ash as provided by Oyetola and Abdullahi (2006), based on the fact that the chemical composition of RHA is always the same irrespective of where it is produced.

3.2 Methods

3.2.1 Field Work

The field work involved collection of sample from outcrop sections of Ezeaku Shale and Awgu Shale (Plates 3 and 4), and observations of cracks on the walls of buildings and other civil structures in the study area.

The sample collection was by open excavation, using a shovel, from a depth of 0.5m below natural ground level in accordance with British Standard (BS), 1377 (1975). Coordinates and elevations were taken using GPS. Thereafter, the collected samples (bagged in bagco bags) were transported to Hardel & Enic Nigeria Limited, Laboratory, Owerri, Nigeria, for testing.

Plate 3a: Clearing of sample collection point at one of the study locations

Plate 3b: Collection of sample at one of the study locations

3.2.2 Tests Conducted

In order to meet the objectives of this investigation, some geotechnical tests including liquid limit, plastic limit, linear shrinkage, compaction characteristics as California Bearing Ratio were carried out on the soil samples as detailed below.

3.2.2.1 Atterberg Limits

The plasticity characteristics (i.e. Liquid Limit (LL), Plastic Limit (PL), Plasticity Index (PI), and Linear Shrinkage (LS)) of the natural soil were determined with about 160g each of air-dried soil samples passing through 425µmBS sieve in accordance with procedures outlined in the British Standards (BS 1377 (1990a, 1990b)).

a. Liquid Limit Test

A Casagrande liquid limit device was used. Prior to the commencement of the test, the sample was air-dried, pulverized and sieved. With reference to the above standard, a representative sample was mixed with small amount of water at the start of the test and a part of the moist soil sample was placed in the brass cup using a knife-edge. The groove opening was made using the grooving tool. This test was carried out for groove closuresat different number of blows. After each of the groove closures was obtained, moisture content samples were taken from the point of groove closure. The moisture cans containing the samples were weighted and kept in the oven and after 24 hours; the moisture cans were removed and reweighed.

The moisture contents (%) for each number of blows were computed and the moisture content was plotted against the number of blows. The liquid limit of the sample is the moisture content (%) corresponding to 25 blows as obtained from the graphical plot.

b. Plastic Limit Test

The thoroughly mixed moist soil sample used for the liquid limit determination was spread on a glass plate and left for about 30 minutes. The moist sample was then rolled with the palm at a sufficient pressure to form a thread of uniform diameter using about 80 - 90 rolling strokes per minute.

When the diameter of the rolled sample became about 3mm, the thread was broken into several pieces, re-formed into a ball and re-rolled. The rolling and re-balling was continued until the thread crumbled under the pressure of rolling and the sample could no longer be rolled into a thread. The crumbled sample was taken for moisture content determination. Two moisture content samples were taken and their average (in percent) was computed as the plastic limit of the soil. The plasticity index was obtained by determining the difference between the plastic limit and the Liquid Limit.

c. Linear Shrinkage Test

The homogeneous mixture used for Liquid Limit determination was put into a mould with its inner wall lightly oiled to prevent the adhesion of the mixed sample on the walls. The specimen was oven-dried at a temperature range of

60^0 -65^0C for about 3 - 4 hours. Thereafter, the oven was adjusted to a temperature of 105^0C for 20 hours, totaling 24 hours period. The final length of the specimen was measured using a tape. The linear shrinkage of a sample is reported as the percentage of its original length. This can be represented mathematically as:

$$\text{L. S.} = \frac{L_D}{L_O} \times \frac{100}{1}$$

Where,

L_D = final length of specimen

L_O = initial length of specimen

Thereafter, the soil samples were treated or stabilized with varying percentages of lime (2, 4, 6, 8 and 10) in accordance with Greaves (1996), and Ingles and Metcalf (1972). The geotechnical tests earlier performed on the natural soil samples were carried out on the lime-treated samples so as to evaluate the effects of the lime treatment on the geotechnical characteristics of the expansive soils.

The soil samples were also treated with varying proportions of lime-rice husk ash and lime-fly ash admixtures in the combining ratio of 1 :3 or 1:4 (i.e. 2:6, 2:8, 2.5:7.5, 2.5:10, 3:9, 3:12, 4:12, 4:16, 5:15, and 5:20) in accordance with Singh (1992). The geotechnical test performed for the soil-lime stabilization were repeated on the soil-lime-rice husk ash and soil-lime-fly ash mixtures so as to evaluate the influence of rice husk ash and fly ash on lime stabilization.

3.2.2.2 Compaction Characteristics

Compaction test was conducted using the standard proctor mould. The soil was air-dried and pulverized sufficiently to run through BS No. 4 sieve (4.75mm). Test specimens were prepared by mixing the relevant percentages of air-dried soil and lime (0, 2, 4, 6, 8 and 10%).

The various specimens were compacted in the cylinder having three equal layers, with each layer receiving 27 blows from the tampers dropped through a height of 305mm.

Each time a specimen is removed from the mould after compaction, a 100g sample of the compacted specimen is taken from near the centre of the cylinder for moisture content determination. Thereafter, the specimen was broken after each compaction, and 30, 60 and 90% water were added successively as the whole process was repeated. This process was repeated until two to five tests showed a decreasing total mass of specimen or until the compacted sample started falling.

At this stage, the bulk density of each compaction segment was computed, and used to derive the dry density. Plotting the dry density obtained against the corresponding moisture content, a smooth curve was drawn through the line of best fit. The dry density corresponding to the maximum point on the moisture content-dry density curve is referred to as the maximum dry density (MDD) while the moisture content corresponding to the maximum moisture content on the same curve is referred to as the optimum moisture content (OMC).

3.2.2.3 California Bearing Ratio (CBR)

The CBR tests were performed as unsoaked and soaked for 2 days in accordance with the West African Standard (WAS) which involves energy derived from a 4.5kg rammer falling through 450mm onto five equal layers in a mould, and each layer receiving 27 evenly distributed number of blows. These tests were carried out on samples at their optimum moisture content (OMC) and maximum dry density (MDD). Two identical compacted soil samples were prepared for the measurement of CBR. A direct CBR penetration test (unsoaked CBR) was carried out on the first sample while the second sample was subjected to soaking condition before placing on the CBR penetration machine to measure the soaked CBR.

CBR values at 2.5mm and 5.00mm penetrations were computed using Dial Reading, machine factor and plunger force as parameters. The highest value at these two points (2.5mm and 5.00mm penetrations) was recorded as the CBR value. However, it should be noted that Dial Readings and Plunger Forces are different for the respective penetrations while Machine Factor is a constant based on the machine used which in this case is 0.0434.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Results

4.1.1 Field Observations

Cracks (horizontal, vertical and diagonal) were observed on the walls of the buildings during the field investigation as shown below. These are typical types of damage done by swelling soils. These cracks usually run from corner towards adjacent opening (Mokhtari and Dehghani, 2012). They also increase in width as they advance forward (i.e. wider at the top than the foundation wall), with the roof leaning outward.

Plate 4a: Cracked buildings within Lokpaukwu area (study location)

Plate 4b: Cracked buildings within Awgu area (study location)

Plate 4c: Cracked buildings within Awgu area (study location)

4.1.2 Basic Geotechnical Properties of the Soils

Table 4.1: Geotechnical properties of Expansive soils from Lokpaukwu and Awgu (Abakaliki Basin), Southeastern Nigeria.

Parameters	Lokpaukwu Values	Awgu Values
Liquid Limit, LL (%)	58	72
Plastic Limit, PL (%)	22	29
Plasticity Index, PI (%)	36	43
Linear Shrinkage, LS (%)	11.4	14.3
Maximum Dry Density (Mg/m^3)	1.61	1.56
Optimum Moisture Content (%)	18.00	20.20
California Bearing Ratio, Unsoaked	15	12
California Bearing Ratio, Soaked	3	3

4.1.3 Effects of Stabilization

4.1.3.1 Effects of Lime Stabilization

Table 4.2: Effect of lime stabilization on geotechnical properties of an expansive soil from Lokpaukwu (Abakaliki Basin) Southeastern Nigeria.

% Soil	% Lime	LL (%)	PL (%)	PI (%)	LS (%)	MDD (Mg/m^3)	OMC (%)	CBR (%) Unsoaked	CBR (%) Soaked
100	0	58	22	36	11.4	1.61	18.00	15	3
98	2	51	32	19	8.6	1.56	20.10	32	16
96	4	48	33	15	6.4	1.51	22.00	38	20
94	6	44	34	10	5.0	1.44	22.60	44	26
92	8	49	35	14	4.3	1.46	23.00	37	23
90	10	50	36	14	2.9	1.47	25.00	30	19

Table 4.3: Effects of lime-stabilization on geotechnical properties of expansive soil from Awgu (Abakaliki Basin) Southeastern Nigeria.

% Soil	% Lime	LL (%)	PL (%)	PI (%)	LS (%)	MDD (Mg/m^3)	OMC (%)	CBR (%) Unsoaked	CBR (%) Soaked
100	0	72	29	43	14.3	1.56	20.20	12	3
98	2	55	37	18	10	1.51	23.60	28	13
96	4	53	39	14	7.1	1.43	25.10	35	18
94	6	50	39	11	5.7	1.41	27.00	42	24
92	8	55	42	13	5.0	1.43	29.00	34	19
90	10	55	43	12	3.6	1.45	30.20	30	17

Table 4.4: Evaluation of Effectiveness of Lime Stabilization on some geotechnical index properties of expansive soil from Lokpaukwu (Abakiliki Basin), Southeastern Nigeria.

% LIME ADDED	LL (%)	(%) REDUCTION	PI (%)	(%) REDUCTION	LS (%)	(%) REDUCTION
0	58.00	-	36.00	-	11.40	-
2	51.00	12.07	19.00	47.22	8.60	24.56
4	48.00	17.24	15.00	58.33	6.40	43.86
6	44.00	24.14	10.00	72.22	5.00	56.14
8	49.00	15.52	14.00	61.11	4.30	62.28
10	50.00	13.79	14.00	61.11	2.90	74.56

Table 4.5: Evaluation of Effectiveness of Lime Stabilization on some geotechnical index properties of expansive soil from Awgu (Abakiliki Basin), Southeastern Nigeria.

% LIME ADDED	LL (%)	(%) REDUCTION	PI (%)	(%) REDUCTION	LS (%)	(%) REDUCTION
0	72.00	-	43.00	-	14.30	-
2	55.00	23.61	18.00	58.14	10.00	30.07
4	53.00	26.39	14.00	67.44	7.10	50.35
6	50.00	30.56	11.00	74.42	5.70	60.12
8	55.00	23.61	13.00	69.78	5.00	65.03
10	55.00	23.61	12.00	72.09	3.60	74.83

Table 4.6: Evaluation of effectiveness of lime stabilization on California Bearing Ratio (CBR) of an expansive soil from Lokpaukwu (Abakiliki Basin), Southeastern Nigeria.

% LIME ADDED	UNSOAKED	(%) INCREASE	SOAKED CBR(%)	(%) INCREASE
0	15	-	3	-
2	32	113.30	16	433.30
4	38	153.30	20	566.67
6	44	193.30	26	766.67
8	37	146.67	23	666.67
10	30	100.00	19	533.30

Table 4.7: Evaluation of effectiveness of lime stabilization on California Bearing Ratio (CBR) of an expansive soil from Awgu (Abakiliki Basin), Southeastern Nigeria.

% LIME ADDED	UNSOAKED	(%) INCREASE	SOAKED CBR(%)	(%) INCREASE
0	12	-	3	-
2	28	133.30	13	333.30
4	35	191.67	18	500.00
6	42	250.00	24	700.00
8	34	183.30	19	533.30
10	30	150.00	17	466.67

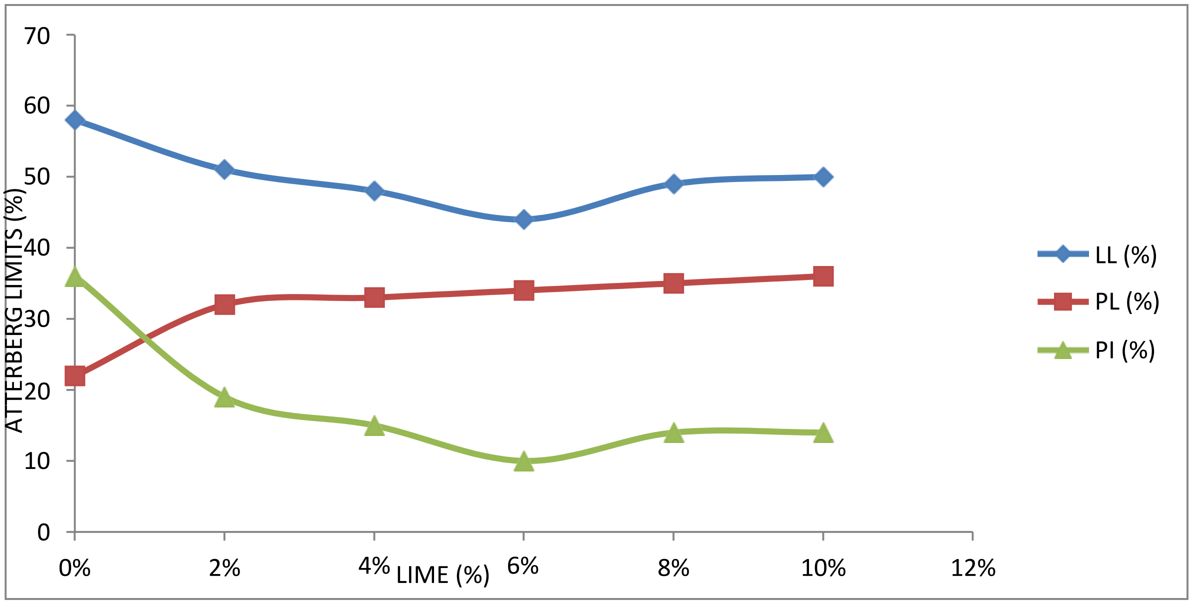

Fig. 4.1: Variation of Liquid Limit (LL), Plastic Limit (PL) and Plasticity Index (PI) of Lokpaukwu soil with different percentages oflime.

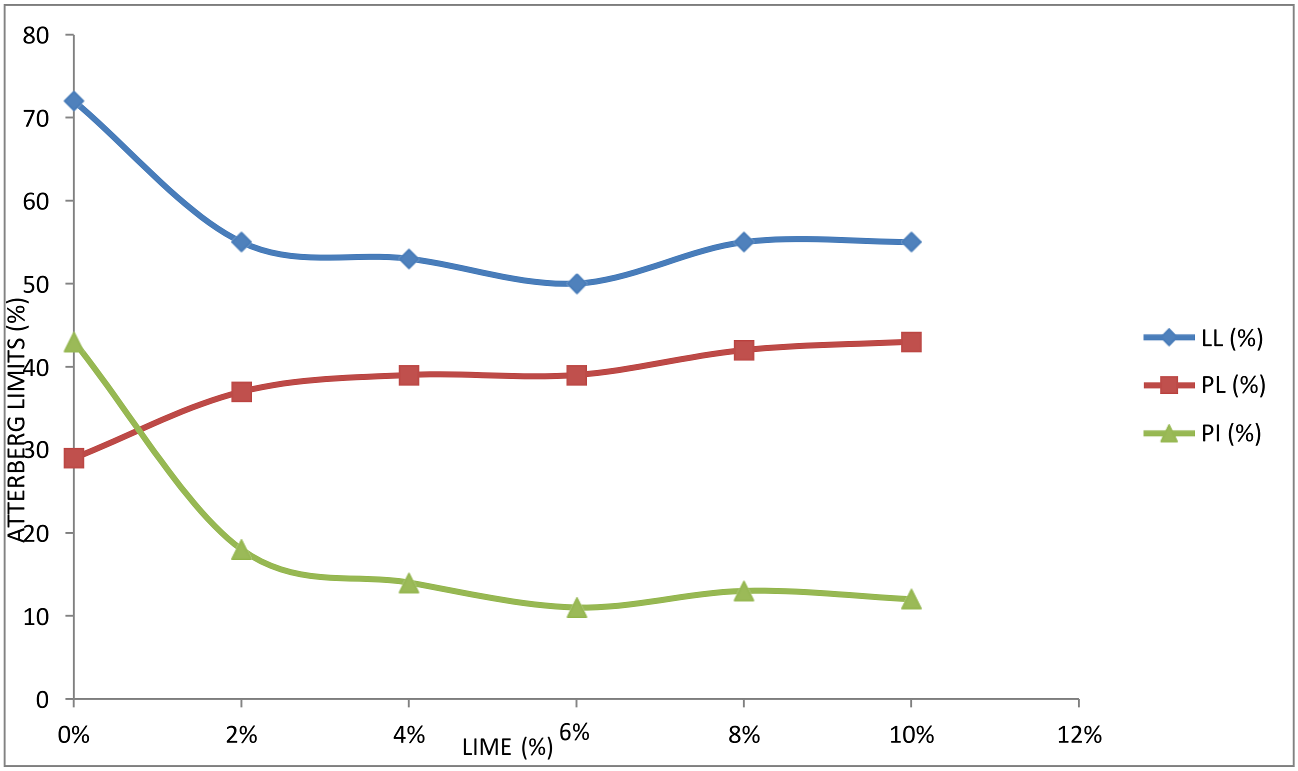

Fig. 4.2: ***Variation of Liquid Limit (LL), Plastic Limit (PL) and PlasticityIndex (PI) of Awgu soil with different percentages of lime.***

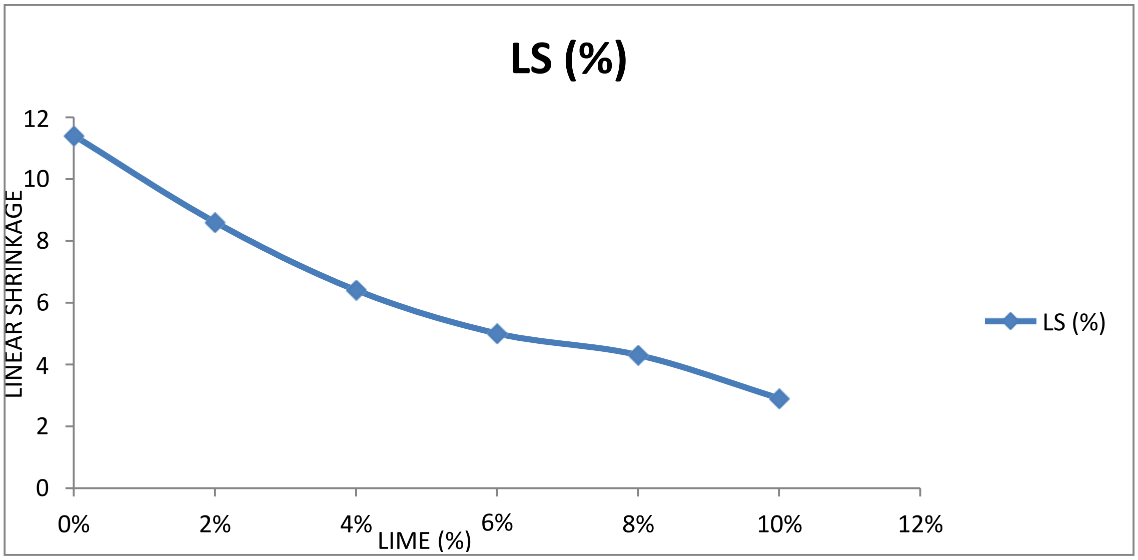

Fig. 4.3: ***Variation of Linear Shrinkage (LS) of Lokpaukwu soil withdifferent percentages of lime.***

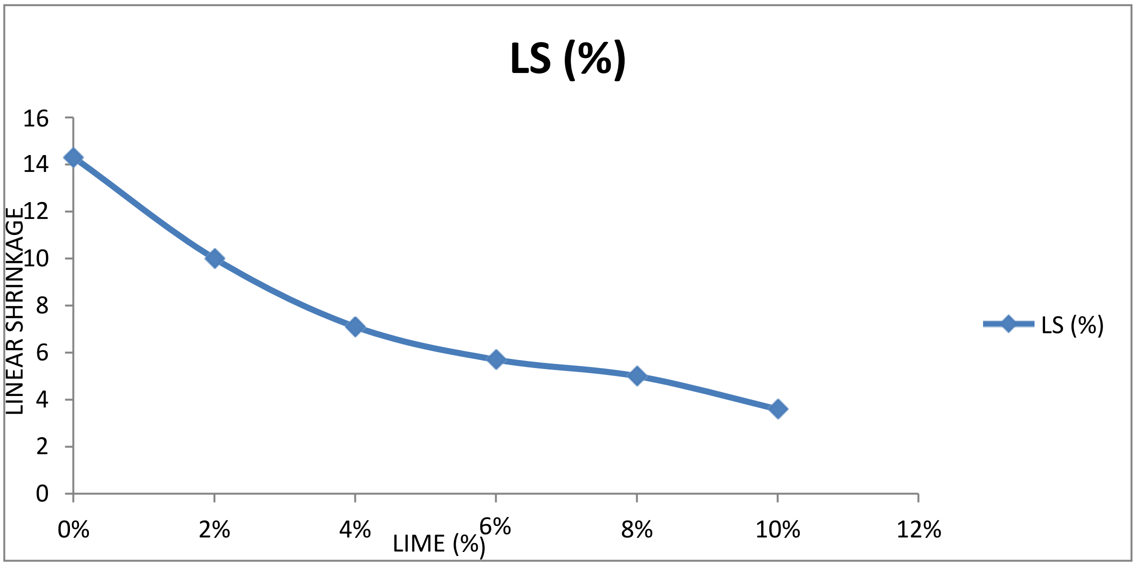

Fig. 4.4:* *Variation of Linear Shrinkage (LS) of Awgu soil with different percentages of lime.

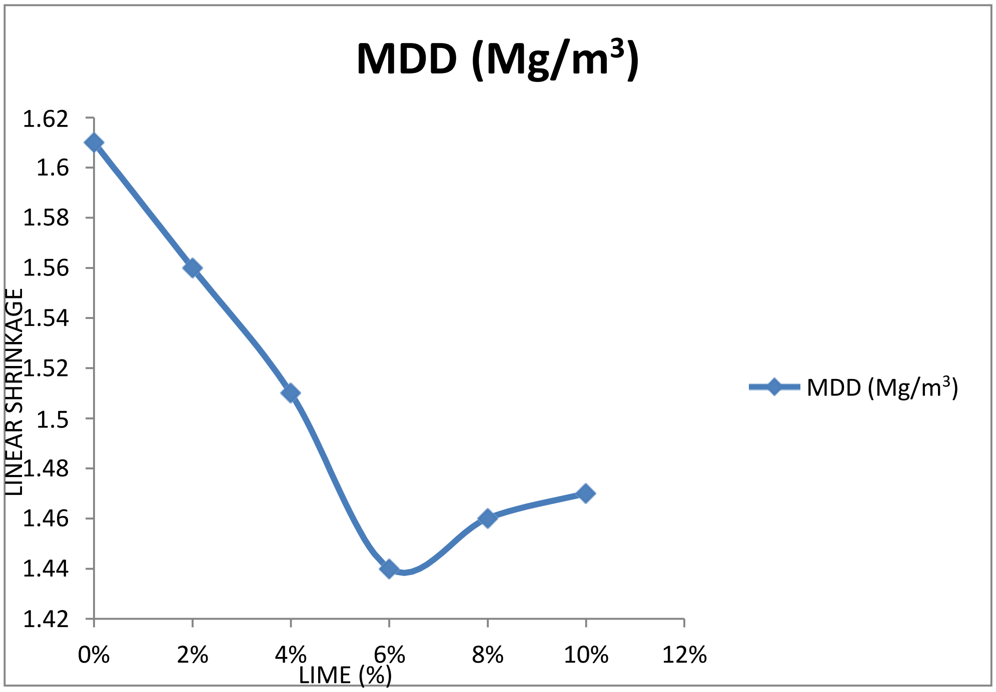

Fig. 4.5:* *Variation of Maximum Dry Density of expansive soil from Lokpaukwu with different percentages of lime.

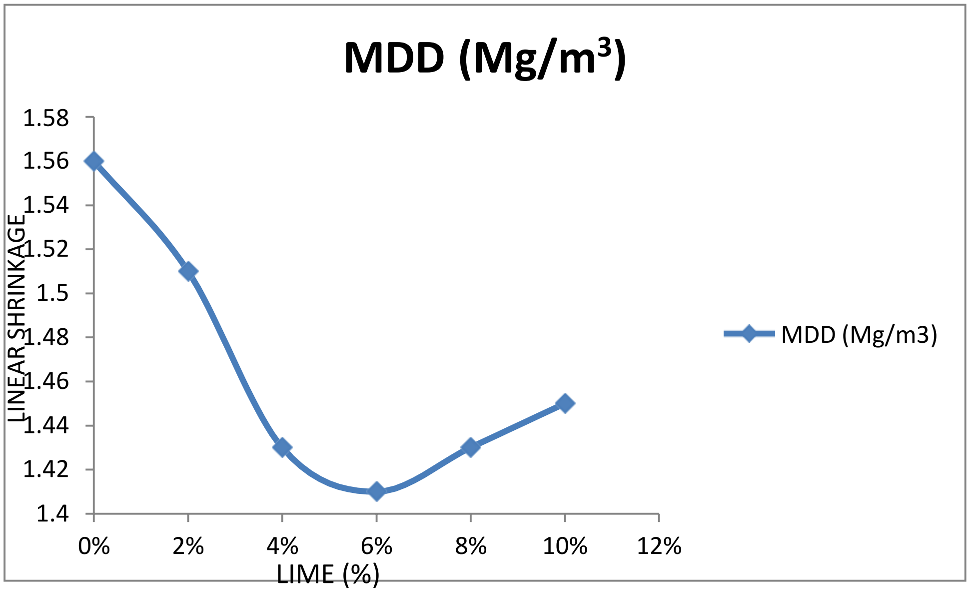

Fig. 4.6: *Variation of Maximum Dry Density of expansive soil from Awgu with different percentages of lime.*

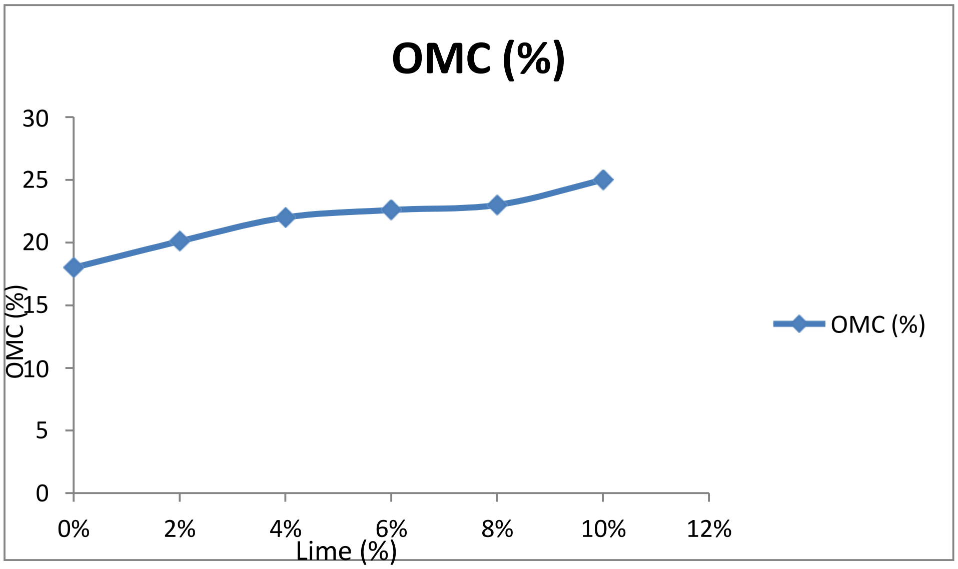

Fig. 4. 7: *Variation of Optimum moisture content of expansive soils from Lokpaukwu with different percentages of lime.*

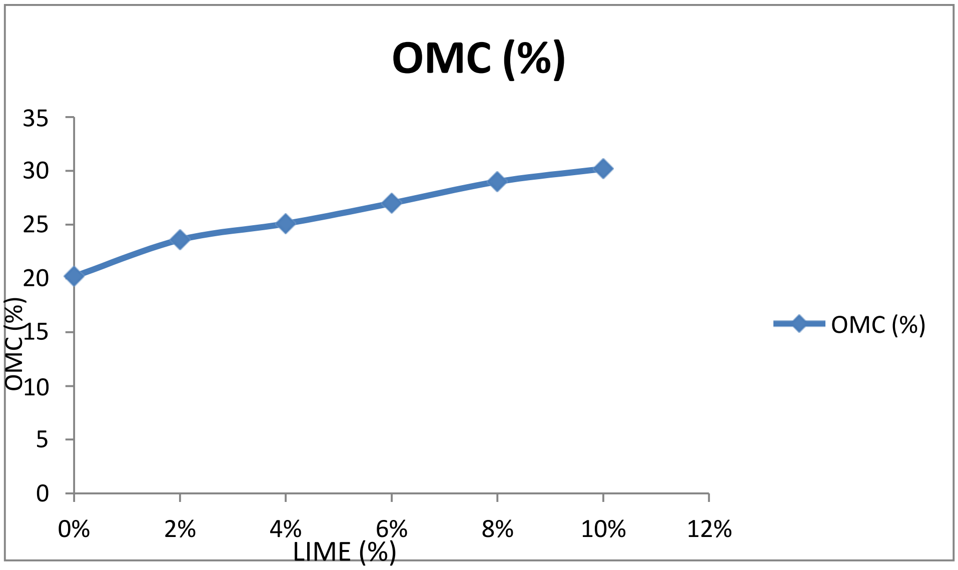

Fig. 4. 8: Variation of Optimum moisture content of expansive soils from Awgu with different percentages of lime.

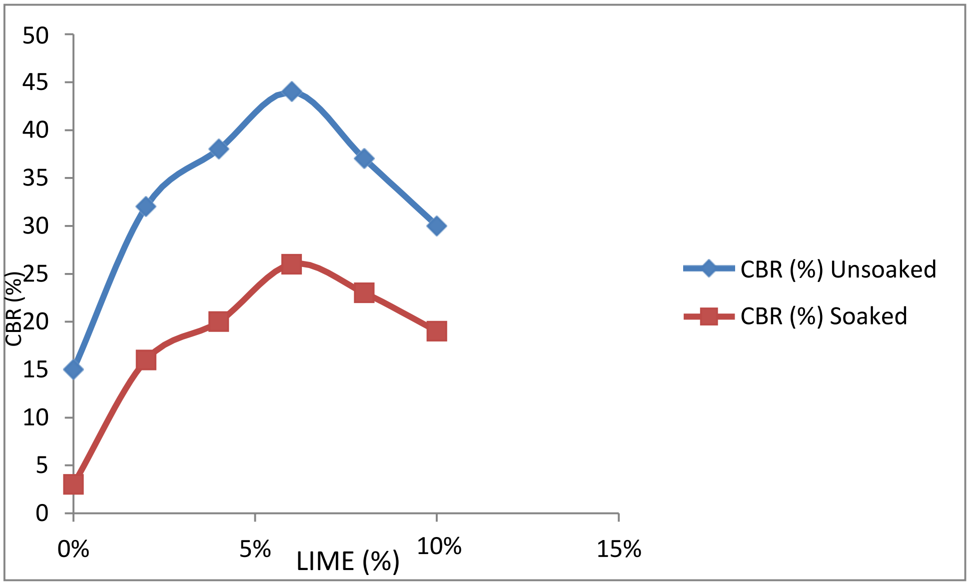

Fig. 4.9: Variation of CBR (soaked and unsoaked) of expansive soils from Lokpaukwu with different percentages of lime.

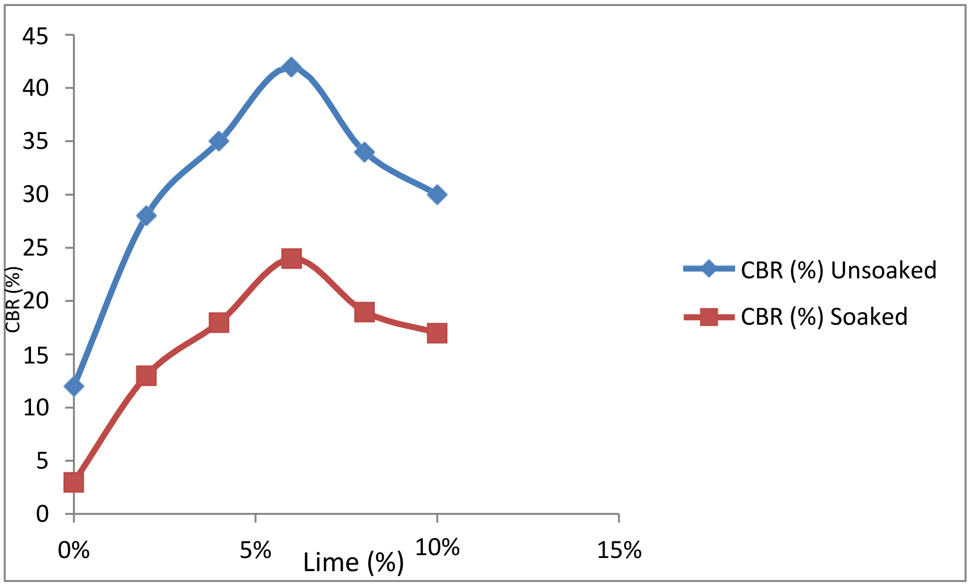

Fig. 4.10: Variation of CBR (soaked and unsoaked) of expansive soils from Awgu with different percentages of lime.

4.1.3.2 Effect of lime-fly ash stabilization

Table 4.8: Effects of Lime-Fly Ash admixtures on some geotechnical index properties of an expansive soil from Lokpaukwu (Abakiliki Basin), Southeastern Nigeria.

% SOIL	% LIME-FLY ASH ADMIXTURES	LL (%)	PL (%)	PI (%)	LS (%)
100	0%L - 0%FA	58	22	36	11.4
92	2%L - 6%FA	49	33	16	8.6
90	2%L - 8%FA	49	33	16	8.6
90	2.5%L - 7.5%FA	48	33	15	7.9
87.5	2.5%L - 10%FA	48	34	14	7.1
88	3%L - 9%FA	47	34	13	6.4
85	3%L - 12%FA	46	35	11	6.4
84	4%L - 12%FA	47	35	12	5.7
80	4%L – 16%FA	48	35	13	5.0
80	5%L - 15%FA	48	36	12	4.3
75	5%L - 20%FA	49	36	13	3.6

Table 4.9: Evaluation of Effectiveness of Fly ash on Lime Stabilization of expansive soil from Lokpaukwu (Abakiliki Basin), Southeastern Nigeria.

% ADDED MIXTURE	LL (%)	(%) REDUCTION	PI (%)	(%) REDUCTION	LS (%)	(%) REDUCTION
0%L - 0%FA	58.00	-	36.00	-	11.40	-
2%L - 6%FA	49.00	15.52	16.00	55.56	8.60	24.56
2%L - 8%FA	49.00	15.52	16.00	55.56	8.60	24.56
2.5%L - 7.5%	48.00	17.24	15.00	58.33	7.90	30.70
2.5%L - 10%FA	48.00	17.24	14.00	61.11	7.10	37.72
3%L - 9%FA	47.00	18.97	13.00	63.89	6.40	43.86
3%L - 12%FA	46.00	20.69	11.00	69.44	6.40	43.86
4%L - 12%FA	47.00	18.97	12.00	66.67	5.70	50.00
4%L – 16%FA	48.00	17.24	13.00	63.89	5.00	56.14
5%L - 15%FA	48.00	17.24	12.00	66.67	4.30	62.28
5%L - 20%FA	49.00	15.52	13.00	63.89	3.80	63.16

Table 4.10: Effects of Lime-Fly ash admixtures on some geotechnical index properties of an expansive soil from Awgu (Abakiliki Basin), Southeastern Nigeria.

% SOIL	% LIME-FLY ASH ADMIXTURES	LL (%)	PL (%)	PI (%)	LS (%)
100	0%L - 0%FA	72	29	43	14.3
92	2%L - 6%FA	54	36	18	10.7
90	2%L - 8%FA	53	37	16	10
90	2.5%L - 7.5%	53	37	16	8.6
87.5	2.5%L - 10%FA	53	38	15	8.6
88	3%L - 9%FA	52	38	14	7.9
85	3%L - 12%FA	51	39	12	7.1
84	4%L - 12%FA	52	39	13	6.4
80	4%L – 16%FA	52	39	13	5.7
80	5%L - 15%FA	53	40	13	5.0
75	5%L - 20%FA	54	40	14	4.3

Table 4.11: Evaluation of Effectiveness of Fly ash on Lime Stabilization of expansive soil from Awgu (Abakiliki Basin), Southeastern Nigeria.

% ADDED MIXTURE	LL (%)	(%) REDUCTION	PI (%)	(%) REDUCTION	LS (%)	(%) REDUCTION
0%L - 0%FA	72.00	-	43.00	-	14.30	-
2%L - 6%FA	54.00	25.00	18.00	58.14	10.70	25.17
2%L - 8%FA	53.00	26.39	16.00	62.79	10.00	30.07
2.5%L - 7.5%	53.00	26.39	16.00	62.79	8.60	39.86
2.5%L - 10%FA	53.00	26.39	15.00	65.12	8.60	39.86
3%L - 9%FA	52.00	27.78	14.00	67.44	7.90	44.76
3%L - 12%FA	51.00	29.17	12.00	72.09	7.10	50.35
4%L - 12%FA	52.00	27.78	13.00	69.77	6.40	55.24
4%L – 16%FA	52.00	27.78	13.00	69.77	5.70	60.14
5%L - 15%FA	53.00	26.39	13.00	69.77	5.00	65.03
5%L - 20%FA	54.00	25.00	14.00	67.44	4.30	69.93

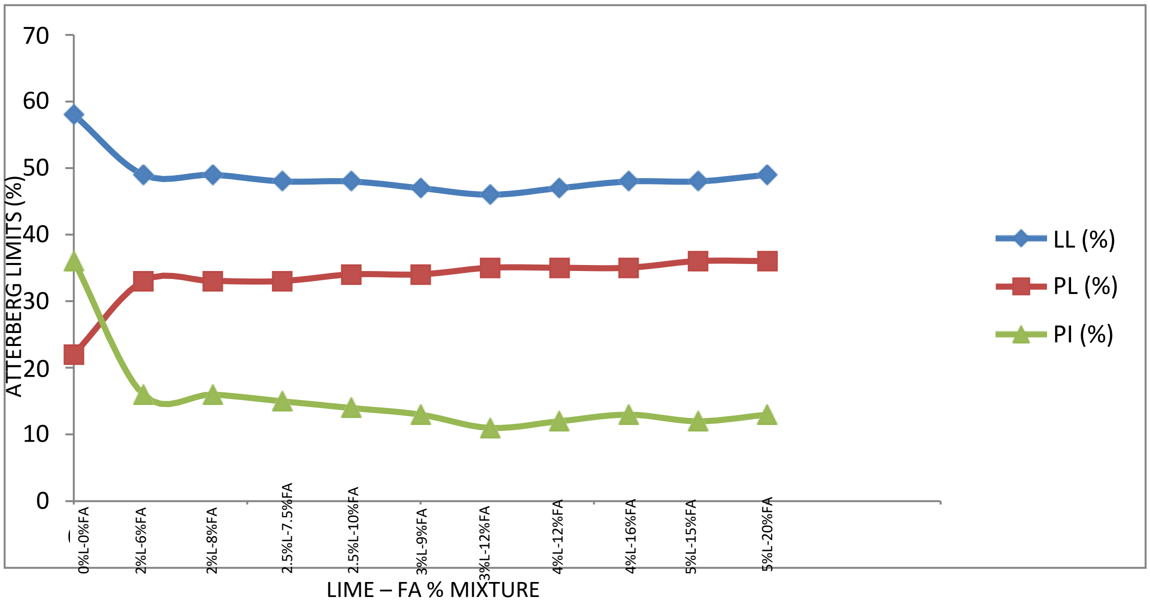

Fig. 4.11: Variation of Liquid Limit (LL), Plastic Limit (PI) and Plasticity Index (PI) of Lokpaukwu soil with different percentage mixture of lime and fly ash (FA).

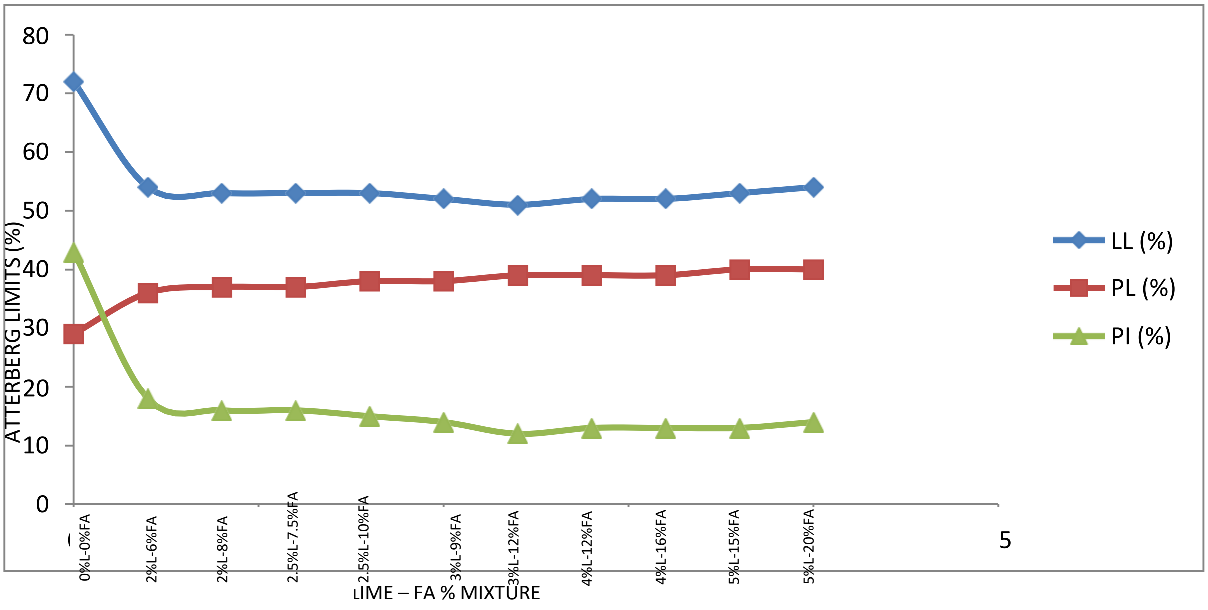

Fig. 4.12: Variation of Liquid Limit (LL), Plastic Limit (PI) and Plasticity Index (PI) of Awgu soil with different percentage mixture of Lime and Fly Ash (FA).

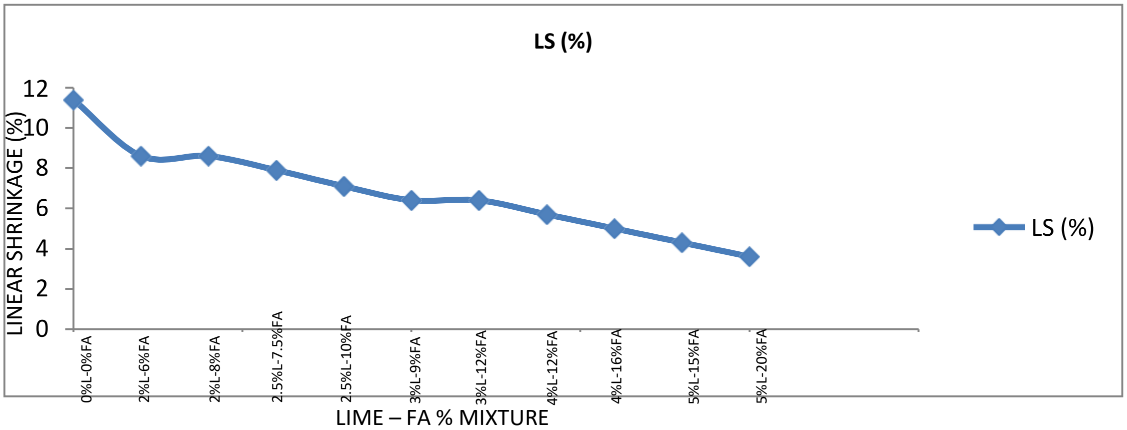

Fig. 4.13: *Variation of Linear Shrinkage (LS) of Lokpaukwu soil withdifferent percentage mixtures of Lime and FA*

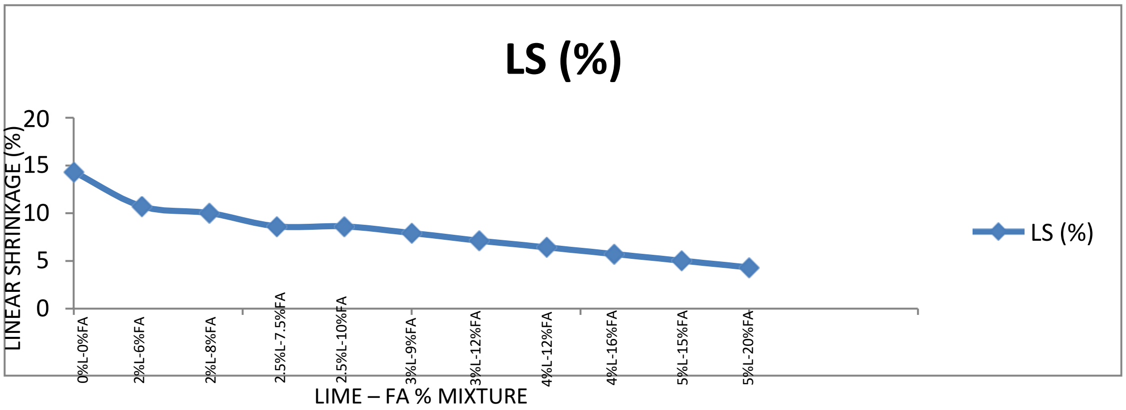

Fig. 4.14: *Variation of Linear Shrinkage (LS) of Awgu soil with differentpercentage mixtures of Lime and FA.*

4.1.3.3 Effects of Lime Rice Husk Ash Stabilization

Table 4.12: Effects of Lime-Rice-Husk Ash admixtures on some geotechnical index properties of an expansive soil from Lokpaukwu (Abakiliki Basin), Southeastern Nigeria.

% SOIL	% LIME-RICE HUSK ASH ADMIXTURES	LL (%)	PL (%)	PI (%)	LS (%)
100	0%L - 0%RHA	58	22	36	11.4
92	2%L - 6% RHA	49	33	16	8.6
90	2%L - 8% RHA	48	34	14	8.6
90	2.5%L - 7.5%RHA	48	35	13	7.9
87.5	2.5%L - 10% RHA	47	34	13	7.1
88	3%L - 9% RHA	45	35	10	6.4
85	3%L - 12% RHA	46	35	11	5.7
84	4%L - 12% RHA	47	35	12	5.0
80	4%L – 16% RHA	48	36	12	5.0
80	5%L - 15% RHA	47	36	11	3.6
75	5%L - 20% RHA	49	37	12	2.9

Table 4.13: Evaluation of Effectiveness of Rice-Husk Ash on Lime Stabilization of expansive soil from Lokpaukwu (Abakiliki Basin), Southeastern Nigeria.

% MIXTURE ADDED	LL (%)	(%) REDUCTION	PI (%)	(%) REDUCTION	LS (%)	(%) REDUCTION
0%L - 0%RHA	58.00	-	36.00	-	11.40	-
2%L - 6% RHA	49.00	15.52	16.00	55.56	8.60	24.56
2%L - 8% RHA	48.00	17.24	14.00	61.11	8.60	24.56
2.5%L- 7.5%RHA	48.00	17.24	13.00	63.89	7.90	30.70
2.5%L- 10% RHA	47.00	18.97	13.00	63.89	7.10	37.72
3%L - 9% RHA	45.00	22.41	10.00	72.22	6.40	43.86
3%L - 12% RHA	46.00	20.49	11.00	69.44	5.70	50.00
4%L - 12% RHA	47.00	18.97	12.00	66.67	5.00	56.14
4%L – 16% RHA	48.00	17.24	12.00	66.67	5.00	56.14
5%L - 15% RHA	47.00	18.97	11.00	69.44	3.60	68.42
5%L - 20% RHA	49.00	15.52	12.00	66.67	2.90	74.56

Table 4.14: Effects of Lime-Rice-Husk Ash admixtures on some geotechnical index properties of an expansive soil from Awgu (Abakiliki Basin), Southeastern Nigeria.

% SOIL	% LIME-RHA ADMIXTURES	LL (%)	PL (%)	PI (%)	LS (%)
100	0%L - 0%RHA	72	29	43	14.3
92	2%L - 6% RHA	53	37	16	10
90	2%L - 8% RHA	52	38	14	10
90	2.5%L - 7.5%RHA	51	38	13	8.6
87.5	2.5%L - 10% RHA	51	39	12	7.9
88	3%L - 9% RHA	51	40	11	7.1
85	3%L - 12% RHA	52	40	12	6.4
84	4%L - 12% RHA	52	40	12	5.7
80	4%L – 16% RHA	52	40	12	5.0
80	5%L - 15% RHA	53	40	13	4.3
75	5%L - 20% RHA	54	41	13	3.6

Table 4.15: Evaluation of Effectiveness of Rice-Husk Ash on Lime Stabilization of expansive soil from Awgu (Abakiliki Basin), Southeastern Nigeria.

% MIXTURE ADDED	LL (%)	(%) REDUCTION	PI (%)	(%) REDUCTION	LS (%)	(%) REDUCTION
0%L - 0%RHA	72.00	-	43.00	-	14.30	-
2%L - 6% RHA	53.00	26.39	16.00	62.78	10.00	30.07
2%L - 8% RHA	52.00	27.78	14.00	67.44	10.00	30.07
2.5%L-7.5%RHA	51.00	29.17	13.00	69.77	8.60	39.86
2.5%L- 10% RHA	51.00	29.17	12.00	72.09	7.90	44.76
3%L - 9% RHA	51.00	29.17	11.00	74.42	7.10	50.35
3%L - 12% RHA	52.00	27.78	12.00	72.09	6.40	55.24
4%L- 12% RHA	52.00	27.78	12.00	72.09	5.70	60.14
4%L–16% RHA	52.00	27.78	12.00	72.09	5.00	65.03
5%L - 15% RHA	53.00	26.39	13.00	69.77	4.30	69.93
5%L - 20% RHA	54.00	25.00	13.00	69.77	3.60	74.83

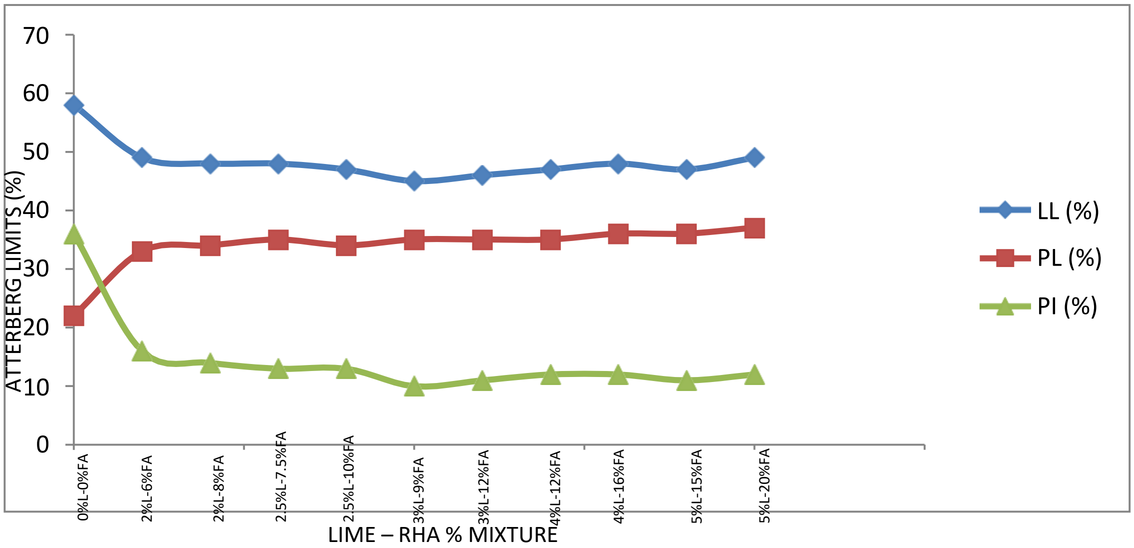

Fig. 4.15: Variation of Liquid Limit (LL), Plastic Limit (PL), Plasticity Index (PI) of Lokpaukwu soil with different percentage mixtures of Lime and RHA.

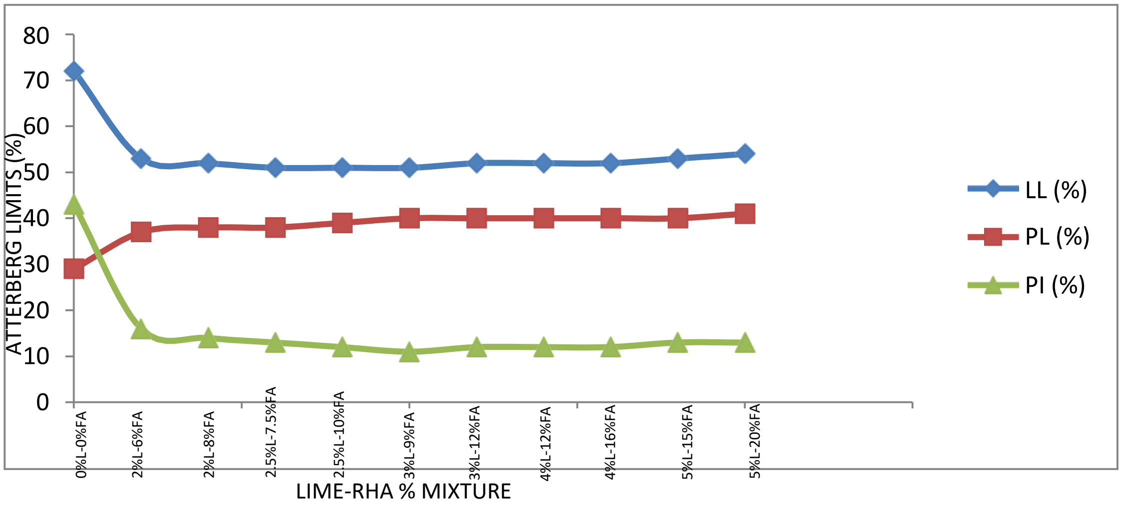

Fig. 4.16: Variation of Liquid Limit (LL), Plastic Limit (PL), Plasticity Index (PI) of Awgu soil with different percentage mixtures of Lime and RHA.

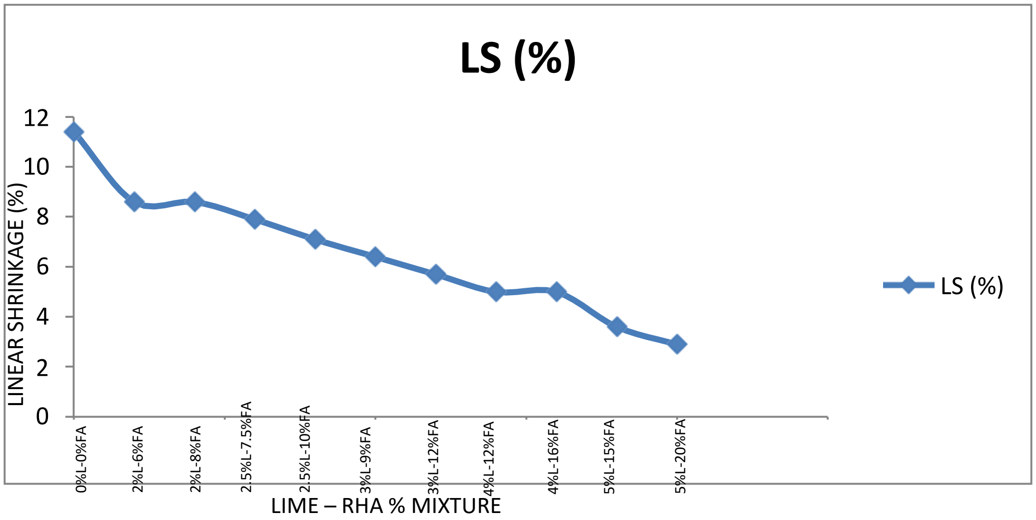

Fig. 4.17: *Variation of Linear Shrinkage (LS) of Lokpaukwu soil with different percentage mixtures of lime and RH*

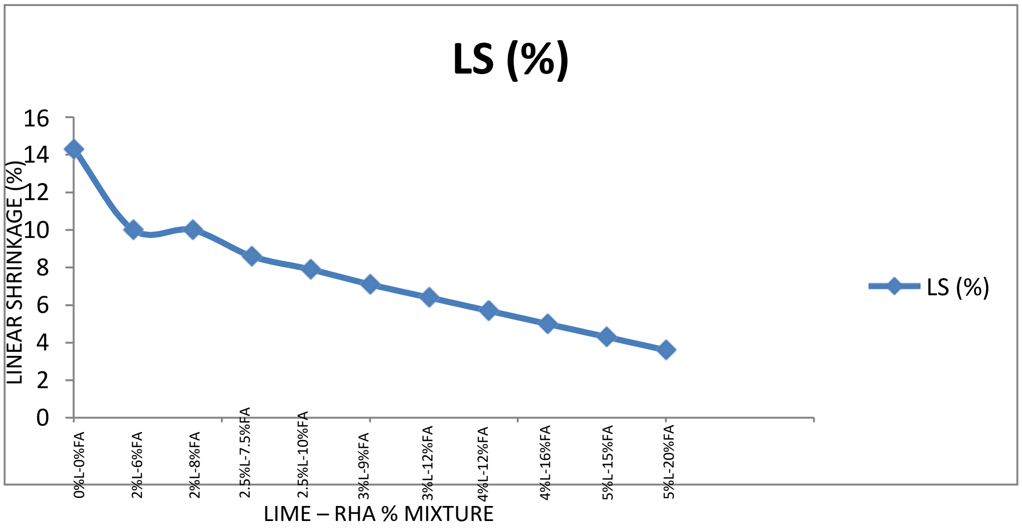

Fig. 4.18: *Variation of Linear Shrinkage (LS) of Awgu soil with different percentage mixtures of Lime and RHA*

4.2 Discussions

The results of the Atterberg's limits tests, linear shrinkage, compaction characteristics, and California bearing ratio are hereby discussed.

4.2.1 Effects on Atterberg Limits

The results of the geotechnical properties for the natural soils (Lokpaukwu and Awgu) are shown in Table4.1. Similarly, Tables 4.2, 4.3, 4.8, 4.10 4.12 and4.14 present the effects of lime, lime-fly ash and lime-rice husk ash stabilizations of the expansive clays. The graphical illustrations of these effects are presented in Figures 4.1 to 4.18 while the reduction percentages are shown in Tables 4.4, 4.5, 4.6, 4.7, 4.9, 4.11, 4.13 and 4.15.

The measured high values of liquid limits, 58% and 72%, plastic limits 22% and 29%, plasticity indices 36 and 43, and linear shrinkages of 11.4 and 14.3 for the untreated Lokpaukwu and Awgu soils respectively are indications of the high swelling potentials of the two soil samples (Ola, 1981; Okeke and Okogbue, 2010).

Figures 4.1 and 4.2 and Tables 4.2 and 4.8show that on the addition of lime, the high values of consistency limits and linear shrinkage recorded for the untreated soils of the two formations reduced remarkably.

This reduction continued significantly as the percentage of lime increased. For instance, the addition of 2% lime to Lokpaukwu and Awgu soils yielded (12.07%/23.61%), (47.22%/58.14%) and (24.56%/30.07%) reductions on the liquid limits, plasticity indices and linear shrinkages of the two formations respectively.

A maximum percentage reduction of (24.14%/30.56%) liquid limits, (72.22%/74.42%) plasticity indices, and (56.14%/60.12%) linear shrinkages were observed on the two formations respectively on the addition of 6% lime. This result supports that of Okeke and Okogbue (2010). Similar to lime stabilization, there was a significant reduction in the values of the geotechnical index properties of the natural soils from Lokpaukwu and Awgu Formations on stabilization with varying percentages of lime and fly ash (Tables 4.8and 4.10).

Tables 4.8 and 4.10 and Figures 4.11 and 4.12 show that on the addition of 2%L/6%FA, there was a reduction in the values of the liquid limits, plasticity indices and linear shrinkages of the natural Lopkaukwu and Awgu soils to 15.52%/25.00%, 55.56%/58.14% and 24.56%/25.17% respectively. From Figures 4.11 and 4.12, a maximum reduction can be observed on the addition of 3%L/12%FA which yielded 20.69%/29.17% liquid limits, 69.44%/72.09% plasticity indices, and 43.86/50.35% linear shrinkages on Lokpaukwu and Awgu samples respectively.

These reductions on index properties can be attributed to blended lime and fly ash which replaces the soil fines, having lesser affinity for water. This result confirms those obtained by Zumrawi and Hamza (2014).

On the same note, stabilization of the Lokpaukwu and Awgu soils with blended lime and rice husk ash yielded a remarkable reduction on the geotechnical index properties of the natural soils. Tables 4.12 and 4.14 and Figures 4.9 and 4.10 shows that on the addition of 2%L/6%RHA, there was 15.52%/26.39%, 55.56%/62.79%, and 24.56%/30.07% reductions on the liquid limits, plasticity indices and linear shrinkage of the two samples respectively. An optimal reduction can be observed as 3% and 9% RHA was added to the soil. 22.41%/29.17%, 72.22%/74.42% and 43.86%/50.35% reductions were observed on the liquid limits, plasticity indices and linear shrinkages of Lokpaukwu and Awgu soils respectively.

These reductions can be attributed also to the replacement of soil fines with blended lime and rice husk ash having lesser affinity for water. This result is in conformity with those of Muntohar and Hantoro (2000), and Jha and Tiwari (2016). Based on the reductions in the plasticity index values of the soil samples (Lokpaukwu and Awgu), the optimum percentage mixture for lime-fly ash and lime-rice husk ash lie at 3%L/12%FA and 3%L/9%RHA respectively.

Further observations on Figures 4.1, 4.2, 4.11, 4.12, 4.15 and 4.16and Tables 4.3, 4.5, 4.10, 4.11, 4.14 and 4.15show a similar trend for the optimum lime content, optimum lime – FA content and optimum lime – RHA content for Lopkaukwu and Awgu soils. For instance, optimum lime content (6% lime) yielded 24.14%/30.56%, 72.22%/74.42% and 56.14%/60.12% reductions on the liquid limit, plasticity indices and linear shrinkages of Lokpaukwu and Awgu samples respectively. The optimum lime-fly ash content (3%L – 12%FA) yielded 20.69%/29.17%, 69.44%/72.09% and 43.86%/50.35% reduction on the liquid limit, plasticity indices and linear shrinkages of Lopkaukwu and Awgu samples respectively, while the optimum lime-rice husk ash content (3%L – 9%RHA) yielded 22.41%/29.17%, 72.22%/74.42% and 43.86%/50.35% reductions on the liquid limit, plasticity indices and linear shrinkages of Lokpaukwu and Awgu samples. From this, it can be deduced that the use of less costly fly ash and rice husk ash is effective in improving the geotechnical properties of expansive soils and can go a long way in reducing the required amount of lime while still providing the needed result.

On a comparative scale, it can be observed that the values of the geotechnical index properties for Awgu samples are higher than those of Lokpaukwu (Table 4.1) and this may be attributed to a higher proportion of expansive minerals in Awgu soils as reported by Uduji *et al.,* (1994). A further observation reveals that rice husk ash (3%L/9%RHA optimum content) was more effective than fly ash (3%L/12%FA optimum content) in reducing the plasticity indices of the expansive soils, which can be related to reduction in swelling potential and strength increase. This observation is in conformity with the results reported by Muntohar (2002), and Yadu *et al.* (2011).

4.2.2 Effects on Compaction Characteristics

The results of the compaction test showing the maximum dry density (MDD) and the optimum moisture content (OMC) of the natural and lime treated expansive clays from Lokpaukwu and Awgu (Abakiliki Basin) are shown in Tables 4.2 and 4.3 and Figures 4.5 to 4.8. It can be observed that optimum moisture content (OMC) increased while maximum dry density (MDD) decreased on the addition of two percent (2%) lime.

With increasing percentage of lime, the two samples (Lokpaukwu and Awgu) experienced further increase and decrease on the optimum moisture content and maximum dry density respectively. Further observation shows that the maximum dry density decreased steadily up to 6% lime content and afterwards it increased with increasing lime content. That is, the lowest MDD was recorded at the addition of 6% lime. The decrease in the MDD can be attributed to the replacement of soil by lime, indicating that the compaction energy is less than that of the natural state while the increase in MDD after 6% lime content is an indication that the percentage of lime in the soil-lime mixture was in excess of the amount needed to improve the soil.

The OMC increased steadily with increasing percentage of lime (Figures 4.8 and 4.9). This increase in OMC may be attributed to hydration reactions between the cations of the clay particles and the lime. Similar results have been reported by Muntohar and Hantoro (2000), and Zumrawi and Hamza (2014).

Comparatively, it can be observed from Table 4.2 and Figures 4.5 to 4.8that Awgu soil (natural and treated) has lower maximum dry density and higher optimum moisture content than Lokpaukwu soil. This variation may be attributed to the fact that the former has higher water affinity and greater swelling potential as reported by Uduji *et al.* (1994).

4.2.3 Effects on California Bearing Ration (CBR)

Figures 4.9 and 4.10 present the variation of unsoaked and socked California bearing ratio with various percentages of lime in the Lokpaukwu and Awgu soils. It can be seen from the figures that CBR values of the natural soils increased with the addition of lime. For instance, the unsokaed CBR values increased from 15% and 12% (untreated) to 44% and 42% for Lokpaukwu and Awgu soils respectively when treated with 6% lime and then decreased to 30% and 30% (Lokpaukwu and Awgu) as the lime content increased further to 10%.

Further observation shows that the soaked CBR for Lokpaukwu and Awgu soils followed a similar trend with the unsoaked CBR. The cured strength of the two samples increased in soaked CBR from 3% (both samples) to 26% and 24% for Lokpaukwu and Awgu samples respectively as lime percentage increased from 0% to 6% and then decreased to 19% and 17% as lime content increased up to 10%. Hence, the maximum CBR values (unsoaked and soaked) for the two formations were obtained at lime content of six percent (6%).

The initial increase in CBR values up to 6% lime content may be due to cation exchange between clay particles and lime, while the reduction in CBR after 6% lime content may be attributed to the excess lime in the clay not required for the early strength gain as a result of flocculation. This result is in consistency with that reported by Okeke and Okogbue (2010).

CHAPTER FIVE

CONCLUSION, RECOMMENDATIONS AND CONTRIBUTION TO KNOWLEDGE

5.1 Conclusion

Recurrent volume changes due to the presence of expansive clay and the alternate wet and dry cycles is believed to be the major contributing factor to the failures of engineering structures in Lokpaukwu and Awgu areas. The soils in these areas have been confirmed to be poor construction materials as indicated by their poor geotechnical properties. This calls for adequate stabilization of these soils with stabilizing agents such as lime or lime blended with fly ash or rice husk ash to ensure the safety of civil structures while providing a pollution-free environment.

In line with the findings of the study, it is pertinent to say that soil stabilization can be achieved using a sole stabilizer or admixtures provided the blend is in the rightful proportion. Hence, it can be concluded that:

i. Lime stabilization significantly improved the engineering properties such as consistency and strength characteristics of the expansive soils from Lokpaukwu and Awgu areas.

ii. Geotechnical index properties of expansive soils such as Atterberg limits and linear shrinkage exhibit improvements when treated with the appropriate blend of lime-fly ash or lime-rice husk ash.

iii. The optimum lime, lime-fly ash and lime-rice husk ash contents needed to effectively treat a soil to reduce swelling and develop increased strength lie at 6%, 3%:12% and 3%:9% respectively.

iv. On the basis of environmental health and economic consideration, the utilization of lime-fly ash and lime-rice husk ash admixtures is a viable alternative for the sole conventional stabilizers.

v. Based on the reduction of plasticity index which can be related to strength increase and reduction in swelling potential, rice husk ash can be said to be more effective than fly ash.

vi. Based on the results of the geotechnical properties investigated in this study, Awgu sample (Awgu Shale) is probably more expansive than Lokpaukwu sample (Ezeaku Shale).

5.2 Recommendations

In line with the findings of this study, the following recommendations are crucial;

i. Stabilization with lime alone or in combination with residues (fly ash or rice husk ash) greatly improved the engineering properties of expansive soils from Lokpaukwu and Awgu, Southeastern Nigeria. Hence, expansive soils in these areas should be stabilized before embarking on any engineering construction so as to ensure the safety and durability of civil structures.

ii. The quantity of lime-fly ash and lime-rice husk ash needed to effectively treat an expansive soil were found to be 3% - 12% and 3% - 9% respectively. However, these percentage ratios solely based on consistency limits tests should be further checked by conducting strength based test such as CBR.

iii. Due to the availability and low cost of rice-husk ash and fly ash accruing from production of rice and coal respectively in Southeastern Nigeria , these residues (rice-husk ash and fly ash) in combination with lime should be used for soil stabilization in the area.

iv. Further investigations should be made on the bulk use of these residues (rice-husk ash and fly ash) in applications other than soil stabilization, as this will go a long way in eliminating the enormous amount of waste generated in this area and thereby promote environmental health.

v. Finally, a logical soil investigation of any proposed site should be carried out by experts before siting any engineering structure on that land so as to establish the geotechnical strength of the soil and the need for treatment.

5.3 Contribution to Knowledge

Based on the findings of this work, the following contributions are relevant to knowledge:

i. Though the quantity of lime in the optimum lime-residue blend is the same (3%) for the two different blends (L/FA and L/RHA), there is variation in the quantity of residues that produced the optimum blends (i.e. 9%RHA for 3%L – 9%RHA and 12%FA for 3%L – 12%FA). This indicates that RHA is more effective than FA, in combination with lime.

ii. Irrespective of the high swelling potential shown by Awgu Shale, the optimum lime-residue blends (3%L – 9%RHA and 3%L – 12%FA) remain the same for the two formations (Ezeaku and Awgu Shales). Probably, swelling potential has little or no effect on the quantity of admixtures needed to achieve an optimum blend.

iii. Stabilization results at 3%L – 9%RHA and 3%L – 12%FA optimum blends which are comparable to that shown by 6% optimum lime content are indications of the effectiveness of these industrial wastes. Hence, they can be extensively and economically utilized in soil stabilization in the study area while providing a pollution free environment.

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