CHAPTER ONE

1.0 INTRODUCTION

1.1 Background of the study:

Soil is a dynamic mixture (FAO/UNEP, 1999., Bot and Bennites, 2005) and an essential natural resource that provides several important ecosystem functions like a medium for plant growth, regulation and partitioning of water flow in the environment and an environment buffer in the formation, attenuation and degradation of natural and xenobiotic compounds (Larson and Pierce, 1991). In fact, soils are the basis for all terrestrial life. United States classify soils into 12 orders; Alfisols, Ultisols, Oxisols, Mollisols, Spodosols, Aridisols, Andisols, Entisols, Gelisols, Histosols, Vertisols, and Inceptisols (each with its own characteristic array of minerals). The first six are the common types found in each continent apart from Antarctica. The others are differentiated by their characteristics which are as a result of the soil forming factors: climate, parent material, topography, biota, and time, which all interact during soil formation (Conklin, 2005). Typically, three soil horizonation exists with different levels of chemical and biological activities at each horizon. The first horizon develops on the surface of the soil and is called the A horizon or top soil, higher in organic matter and lower in salts than the lower horizons. The subsoil or B horizons has high clay content with reducing conditions which result when the soil is saturated with water for a very long time and accumulation of oxides of alluvial iron and aluminium. The lowest horizon or C horizon is the bedrock or the parent material that has not been degraded into soil formation and has high level of soluble salts due to leaching from top soils (Akamigbo and Asadu, 1983).

Anambra State lies within, latitude 5° 40'N and longitude 7° 10' E on the South and latitude 6° 35'N and longitude 7° 20' E on the South; the tropical rainforests. Rainforests are very fragile habitats. In many tropical regions, the bedrock is very old and weathered, and consequently, depleted in minerals and nutrients. The acidic nature of many tropical soils inhibit mineral release into the soil horizons. The soil types derived from the bedrock underlying tropical forests are mainly soils called oxisols and ultisols (Richter and Babbar, 1991). Oxisols are acidic soils and contain considerable quantities of iron and aluminium. Ultisols are highly-weathered, acidic soils and are less frequently found than oxisols. These two types of soils, generally of low fertility, comprise about 43% of the soils under tropical rainforests; many of which have low pH, poor physical structure, low phosphorus and other

nutrient deficiencies, or high salt or aluminium levels (Hoffman and Carroll, 1995). The minerals found in these soils form insoluble compounds with phosphorus, and under dry conditions and, particularly in soils with high iron contents and low silicate content, the oxides in oxisols form impermeable layers, known as laterite, below the surface (Igwe, *et al*., 1999; Onwuka, *et al.,* 2012). Interestingly, tropical soils can vary a great deal within a relatively small area, which leads to a variety of vegetation types because of differences in nutrient concentrations and availability, variations in the ability of the soil types to retain water, and the like (many other factors are also involved in determining the vegetation which grows in any particular area) (Rainforest Conservation Fund, 2013). Thus, when the forests overlying such oxisols are cut down, the logged area becomes much drier and eroded, and this often leads to laterization. This will not happen if the surface is covered with trees and vegetation. Because laterite is impermeable, rain will run off quickly, leading to erosion and flooding (Igwe, *et al.*, 1999)

Erosion is the washing or blowing away of surface soil, sometimes down to bedrock. While some erosion takes place without the influence of man, the soil is lost so slowly that it is usually replaced through natural processes of decay and regeneration. Erosion is an intrinsic natural process, but in many places it is increased by human land use (FAO/UNEP, 1999). Soils are eroded because of the following reasons; Firstly, billions of tons of soil are physically lost each year through accelerated erosion from the action of water and wind (erosivity factors) and by undesirable changes in soil structure. Secondly, many soils are degraded by increases in their salt content, by waterlogging, or by pollution through the indiscriminate application of chemical and industrial wastes. Thirdly, many soils are losing the minerals and organic matter that make them fertile, and in most cases, these materials are not replaced nearly as fast as they are depleted (FAO/UNEP, 1999).

Soil erosion is considered a main process of land degradation (Kirby *et al.,* 2000). South-eastern zone of Nigeria in the Sub-Saharan Africa is besieged by this serious environmental degradation; soil erosion due to very high intensive rainfall resulting in heavy runoff and soil loss. The problem has adversely affected agricultural productivity and thus casting doubt of food security in the zone. When soil erosion cannot be checked by the recommended soil conservation practices, it results in gullies of different dimensions (Igwe, 1999; Oguike and Mbagwu, 2009). Ofomata (1981) pointed out that more than 1.6% of the entire land area of eastern Nigeria is occupied by gullies. The situation has worsened ever since then. This is very significant for an area that has the highest population density of more than 500 persons

per km^2 in Nigeria. Before the 1980's, the classical gully sites in the region were the Agulu, Nanka, Ozuitem, Oko in Aguata area, Isuikwuato and Orlu but these have escalated to more regions of the southeast making it a major concern to the government and different stakeholders (Oguike and Mbagwu, 2009).

Anambra state is one of the greatly affected states of soil erosion menace which has jeopardized many lives and properties of the people as their means of livelihood is destroyed periodically. This is seen in the loss of farmlands, residential buildings, industrial lands and sometimes infrastructural facilities. Before now, studies on erosion has been limited to erosive factors (ie climatic factors) like action of water and wind. There is no concerted effort to appraise the possible influence of soil chemistry and edaphic factors on soil erodibility.

Lovelock (2009) in his Gaia hypothesis see the earth as alive and claims that the earth's biosphere acts to maintain a prefered homeostasis. He hypothesized "that the biosphere and the physical components of the earth are closely integrated to form a complex interacting system that maintains the climatic and biogeochemical conditions on earth in a prefered homeostasis". He submits that because of this complex system, the Earth reacts to changes in a manner similar to a living organism. Could soil erosion be an example of such changes? Though Gaia hypothesis is largely disputed by scientists, it no doubt appears real and applicable in certain circumstances as this.

1.2   Statement of the problem

Erosion menace in Anambra State has upstaged ecological imbalance, imposed economic loss, physical damage and psychological trauma on the people eliciting catastrophic consequences beyond what we know. Understanding the soil chemistry and edaphic factors underlying soil erodibility in the area based on empirical scientific data could be a sure way to abate it thereby safeguarding the lives and properties of our people rather than fight the menace when it has developed.

1.3 Research Questions

i. What biochemical characteristics are associated with soil erosion in Anambra state?

ii. How do these biochemical factors affect the rate of erosion?

iii. Do these erodibility factors affect soil strength and health?

iv. What is the relationship between the degree of erosion and the mechanical, physicochemical and biotic factors of erodible soils?

1.4 Aim of study

To determine the chemistry and edaphic factors of erodible soils in Anambra State.

1.5 Objectives of the study

The specific objectives of the study are;

i. To determine the degree of soil horizon differentiation in delineated soil erosion classes in Anambra State.

ii. To study the biochemical characteristics of the soil horizons within the gully profiles in Anambra State.

iii. To determine the consistency and rheological properties of soils among the four erosion classes in Anambra State

iv. To determine the relationship between soil edaphic factors and selected biochemical properties.

1.6 Research Hypothesis:

Null:

i. There is a significant difference in soil biochemical properties among the soil blocks in Anambra state.

ii. Soil erosion has effect on soil biochemical and edaphic characteristics.

iii. There is a relationship between soil edaphic factors and biochemical properties.

Alternative:

i. There is no significant difference in soil biochemical properties among the soil blocks in Anambra state.

ii. Soil erosion has no effect on soil biochemical and edaphic characteristics.

iii. There is no relationship between soil edaphic factors and biochemical properties.

1.7 Justification of the study

This study is relevant for the following reasons;

i. Most of the available literature on soil erosion deals more on soil erosivity (climatic) factors rather than erodibility (soil) factors. There is therefore deliberate need to build information on these erodibility factors.

ii. Literature available suggest that most studies conducted so far have not considered elemental characteristics and edaphic factors of the soil as potential indicators of soil erodibility in Anambra State.

iii. Publications from studies conducted overseas outside Nigeria and Anambra State cannot adequately be used as models for Anambra State as their biogeographical as well as physiographic factors are not the same.

1.8 Scope of the Research

This research was limited to the following;

i. Taking GPRS locations of erosion sites within Anambra state and checking the length, temperature, percolation rates, colours, texture and natural moisture *in situ*.

ii. Collecting samples from these sites, pretreated them for further laboratory analysis

iii. Determination of the pH, electrical conductivity, organic matter and loss on ignition

iv. Determination of trace elements, macro elements and heavy metals using AAS

v. Determination of the particle sizes, sedimentation rates, pore density, bulk density and calculation of the porosity of the samples.

vi. Determination of the Atterberg limits, Rheology, Compactions, and California Bearing Ratio of the soil samples

2.0 LITERATURE REVIEW

2.1 SOIL EROSION

Soil erosion may be defined as the physical wearing away of earth's surface by water, wind or ice; by down-slope movement of soil and other material under the force of gravity or by living organisms. It works by hydraulic or eloigns actions and transport of solids (sediment, soil, rock and other particles) in the natural environment, and leads to the deposition of these materials elsewhere. In our part of the world, the primary or perhaps, sole agent of erosion is water. Soil erosion is a subset of a larger natural process known as sedimentation. Sedimentation embodies five different physical processes: Erosion, Entrainment, Transportation, Deposition and Compaction (Chiew, 2006).

These processes are part of the natural cycle in which landform on earth are built up, warn down and built up again. It can be said to be a means by which earth's surface is shaped. Although erosion is a natural process which occurs in all areas regardless of human activities, human (anthropogenic) land use policies affect the rate of erosion rather than erosion itself. Land that is used for industrial (especially if tillage employed) agriculture, deforestation, overgrazing or urbanization generally experiences a significantly greater rate of erosion than that of land under natural vegetation, or land used for sustainable agricultural practices (Montogomery, 2008). At such extreme events and their increased rates of erosion, nature and special segments of the ecosystems definitely slowly adjusts to the landscape changes. In nature, increased rates of sediment transport are associated with extreme events like storms, earthquakes, avalanches, tidal waves, typhoons, etc (Chiew, 2006). Excessive erosion, however, causes serious problems, such as receiving water sedimentation, ecosystem damage and outright loss of soil. Egboka (1993) had claimed that over 70% of the land of Anambra State were ravaged or threatened by erosion at various levels of development and stages of maturity and over 20% of the land has been lost to Hadesian gullies.

2.2 TYPES AND STAGES OF SOIL EROSION

There are many ways in which soil erosion can be classified; either based on causative factors such as wind, water and anthropogenic erosion or subdivisions as soil erosion, geologic erosion, stream/river bank erosion, coastal erosion and agricultural erosion (Egboka, 1993). Since there is no single causative agent that causes erosion, the pedologic, geologic, geotechnical and geometric characteristics are acceptable; therefore water erosion can be described thus:

2.2.1 Splash/Pluvial erosion: may not be considered a type of soil erosion but it is the airborne movement or detachment of small soil particles caused by the impact of raindrops on soil. It is the first and least severe stage in the type of erosion processes (Agronomy guide, 2013-2014).

2.2.2 Sheet erosion: which primarily affects the shallow soil zone or solum, predominantly occurring to depths of less than 3mm, is the detachment of soil particles by raindrop impact which breaks apart the soil aggregate (Egboka, 1993). Particles of clay, silt and sand as a result of this fill the soil pores and reduce infiltration rates of water into the soil thereby causing flowing of water overland as a sheet instead of in definite channels or rills. Once the rate of falling rain is faster than infiltration, runoff takes place (Zuazo and Pleguezuelo, 2009). This stage of sheet erosion commonly travel short distances and last only for a short time.

2.2.3 Rill/Channels erosion: refers to the development of small, ephemeral concentrated flow paths, which function as both sediment source and sediment delivery systems for erosion on hillslopes. Eroding rills evolve morphologically in time and space with flow velocity, depth, width, hydraulic roughness, local bed slope, friction slope, and detachment rate as time and space variable functions of the rill evolutionary process (Chiew, 2006). Flow depths in rills are typically on the order of a few centimeters or less and slopes may be quite steep. These conditions constitute a very different hydraulic environment than typically found in channels of streams and rivers (Agronomy guide, 2013-2014).

2.2.4 Gully erosion: also called ephemeral gully erosion is the last or mature stage of erosion before the eroded area attains some degree of stability or becomes quasi-stable (Egboka, 1993). It occurs when water flows in narrow channels during or immediately after a heavy rain. A gully is noticeably deep that it cannot be routinely destroyed by tillage operations but a rill can. The depth is about 1 to 2 feet and more depending on the extent of the damage to soil surface. Gully erosion is not accounted for in the revised universal soil loss equation (Agronomy guide, 2013-2014)

2.3 CAUSES OF SOIL AND GULLY EROSION

Erosion is an intrinsic natural process, but in many places it is increased by human land use (FAO/UNEP, 1999). Soil erosion loss is caused by wind, water, ice and movement in response to gravity. Firstly, billions of tons of soil are being physically lost each year through accelerated erosion from the action of water and wind and by undesirable changes in soil

structure. Secondly, many soils are being degraded by increases in their salt content, by waterlogging, or by pollution through the indiscriminate application of chemical and industrial wastes. Thirdly, many soils are losing the minerals and organic matter that make them fertile, and in most cases, these materials are not being replaced nearly as fast as they are being depleted. Some of the factors that cause or facilitate gully erosion are here discussed;

2.3.1 Landscape: The nature of the landscape determines the velocity at which surface runoff will flow, which in turn determines the erosivity of the runoff; hilly, slopey and sandy areas are easily eroded and new landscapes are continuously formed and destroyed through a quasi-stable isostatic readjustment (Humberto and Rattan, 2010; Egboka, 1993). Areas with steep slopes erode more easily as against plain lands.

2.3.2 Soil texture: Sediments with high sand or silt contents erode more easily than clayed soils because the clay helps bind soil particles together (Mirsal, 2008). High level of organic material in the soil is equally a factor in determining the rate of soil erodibility because the soil organic material coagulate soil colloids and create a stronger and more stable soil structure. Soil compaction also affects the permeability of the soil to water as more compacted soils will have a larger amount of surface runoff than less compacted soils (Humberto and Rattan, 2010).

2.3.3 Weathered rocks: Predominantly sandy geologic formations, highly fractured or weathered rocks erode more easily than consolidated materials of same geologic make. Weathering refers to the breakdown and changes in rocks and sediments at or near the Earth's surface brought about by biological, chemical, and physical agents or combinations thereof. Weathering also involves the synthesis of new (secondary) minerals that are of great importance in soil (e.g. clay minerals) (USDA, 1999). Sedimentary rocks of diverse types are formed through the complex events or happenings of the geologic cycle that may span in age and consequently are more erodible as opposed to igneous and metamorphic rocks which form stable platforms (Egboka, 1993). The interplay of factors implicated in the weathering process are shown in figure 1 below.

2.3.4 Nature of surface water and ground water: Both surface and ground waters have a serious deleterious effect on pore water pressures and seepage forces. Attention is often paid on surface water in form of flood, streams, rivers and raindrops/runoff water with less concern on ground waters which have brought about serious gullies, bank erosion and landslides by
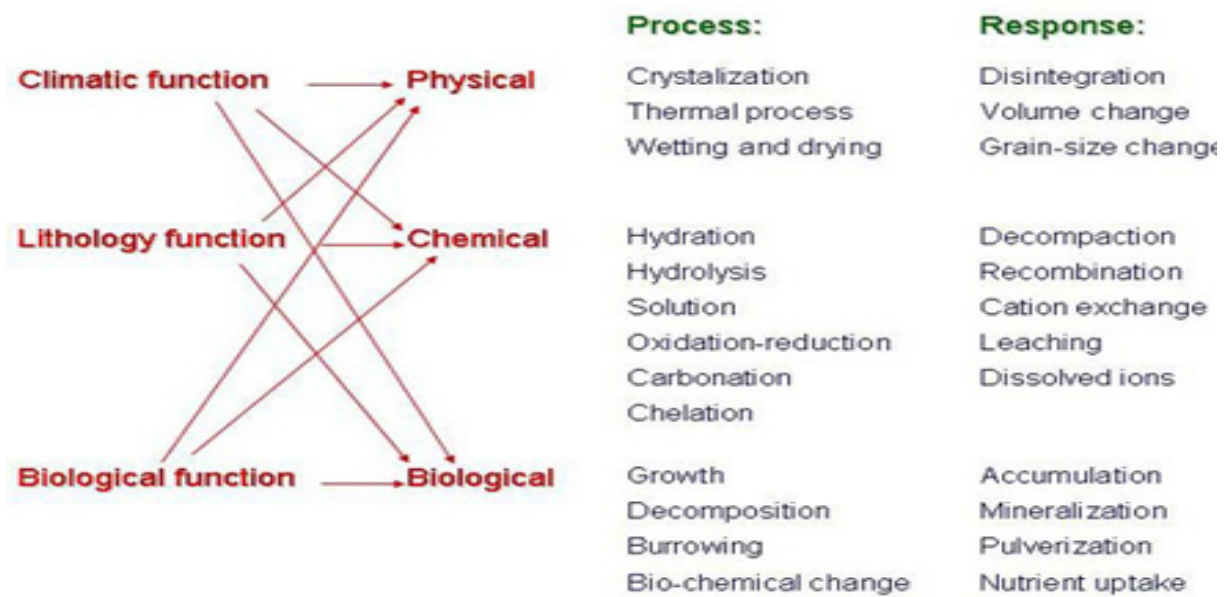
Process:	Response:
Crystalization	Disintegration
Thermal process	Volume change
Wetting and drying	Grain-size change
Hydration	Decompaction
Hydrolysis	Recombination
Solution	Cation exchange
Oxidation-reduction	Leaching
Carbonation	Dissolved ions
Chelation	
Growth	Accumulation
Decomposition	Mineralization
Burrowing	Pulverization
Bio-chemical change	Nutrient uptake

Figure 1: Weathering processes
Source: USDA (1999)

subsurface flows and undermining. Wet, saturated soils will not be able to absorb as much rain water, leading to higher levels of surface runoff and thus higher erosivity for a given volume of rainfall (Torri, 1996). The indirect effect of climate on soil erosion is through the medium of vegetation. Areas under effective cover of vegetation are more prone to sliding and slumping (provided that the gradient is steep enough) as they are characterised more by infiltration (ground water) than by surface runoff (Ofomata, 1981).

2.3.5 Amount and type of ground cover/Vegetation: This explains the types of vegetation found in a forest that covers the soil layers. In an undisturbed forest, the mineral soil is protected by a litter layer and an organic layer. These two layers protect the soil by absorbing the impact of the rain drops. They are porous and permeable to rain water but on high intensity of rainfall, the overland flow of flood will still be attenuated. Change in the amount and type of vegetation by any unnatural means within the forest increases the susceptibility of the land to erosion as it may compromise the litter layer/organic layer cycle (Balasubramanian and Nnadi, 1977). The roots of the plants also bind the soil together, and interweave with other roots, forming a more solid mass that is less susceptible to water erosion (Styczen and Morgan, 1995). The amount of this plant therefore confers increased protection to the soil compared to fewer plants and the type of the plants too determines the extent of its litter layer and organic layers.

2.3.6 Anthropogenic (Man-made) factors: Poor land use practices including deforestation, overgrazing and improper construction activities are several contributory factors to increased soil erosivity and these are basically man-made.

Unsustainable agricultural practices like *mechanization* that plows deep into the soil thereby exposing more soils to be transported during erosion, *tillage* which breaks more soils into finer particles increasing soils to be transported, *chemical fertilizer and pesticides* which kills microorganisms that binds soils together and lots of poor land practices that endangers the soil health and stability (Majewski and Capel, 1996; Bot and Benites, 2005) are all man-made factors that increase soil erosion thereby leading to gully of all types.

Removal of trees by fire (bush burning) or logging removes the protection conferred by litter layers and organic layers in mineral soils and greatly increases soil erosion as infiltration rate becomes high. Logging equipment brings about heavy soil compaction increasing surface runoff (Megahan, 1992).

Heavy grazing can reduce vegetation and increase compaction, and certainly changes in the vegetation type in an area changes the infiltration rates of rain in that area which affects the surface runoff and consequently erosion rate. This is possible as terminal velocity of rain drop is reached in about 8meters (Satterlund and Adams, 1992) so change in vegetation type which may increase the throughfall of raindrop from mature canopies can affect the soil layers which may not absorb the impact of the rainfall (Stuart and Edwards, 2006).

Construction due to urbanization can greatly compromise the forest floor; significantly change drainage patterns and compaction of the soil. This in effect increases the susceptibility of the soil to erosion.

2.4 OTHER PROCESSES THAT CAUSE EROSION OTHER THAN WATER

2.4.1 Gravity: Though all erosion processes is believed to go downslope under the influence of gravity, there are different processes under gravitational force by which soil erosion may be considered (El-Swaify, *et al*., 1982). *Mass wasting* is the down-slope movement of rock and sediments, mainly due to the force of gravity from region of higher elevations to lower elevations where other eroding agents such as streams and glaciers can pick up the material and move it even further to a lower level. *Slumping,* another type of gravity influenced erosional process happens on a steep hillsides, occurring alongside fracture zones, which is a

detachment possibly as a result of water beneath or poor engineering work and may move rapidly downhill. *Surface creep* is a slow movement of soils which often is not detected except by prolonged observation (Torri, 1996).

2.4.2 Ice: This process which is not common to our environment is caused by the movement of ice typically as glaciers eroding the soil surface which results in all forms of detachment possible or by freeze-thaw process in which case, trapped water inside pores or fracture in rocks may expand causing further cracking (Bot and Bennites, 2005).

2.4.3 Wind: Wind is a major cause of erosion in arid climates; areas with little or no vegetation (Glennie, 1970; Moore, 2001). Its either that the wind causes small particles of soil to be moved to another region *(deflation)* or these suspended particles may impact on solid soil areas causing abrasion *(ecological succession)* (Glennie, 1970).

2.4.4 Heat/Thermal: This process occurs both along the river banks and at the coast due to moving water resulting in the melting and weakening of permafrost. Much of this erosion occurs as the weakened banks fell in large slumps (Costard, *et al*., 2003).

2.4.5 Exfoliation: When a rock is suddenly heated up by the sun, its expansion and contraction as cooling takes effect results in break off of parts of the rock. This normally occurs in deserts where heating up happens by day and cooling occurs by night (Glennie, 1970).

2.4.6 Lightning strike: When water in cracked rock is rapidly heated by a lightning strike, the resulting steam explosion can erode rock and shift boulders. It may be a significant factor in erosion of tropical and subtropical mountains that have never been glaciated. Evidence of lightning strikes includes craters, partially melted rock and erratic magnetic fields (Boroughs, 2014).

2.4.7 Rainfall Intensity: Rainfall intensity is the primary determinant of erosivity, with higher intensity rainfall generally resulting in more erosion. The size and velocity of rain drops is also an important factor. Larger and higher-velocity rain drops have greater kinetic energy, and thus their impact will displace soil particles by larger distances than smaller, slower-moving rain drops.

2.5 GLOBAL EFFECTS OF SOIL EROSION

Two categories of human-induced soil degradation processes were recognized. The first category deals with soil degradation by displacement of soil material. The two major types of soil degradation in this category are water erosion and wind erosion. Displacement of soil material will also lead to off-site effects: reservoir, harbour or lake sedimentation; flooding, river bed filling and riverbank erosion; excessive situation of the basin land; coral, shellfish beds and seaweed destruction are all examples of water erosion off-site effects. The second category of soil degradation deals with internal soil physical and chemical deterioration. In this category only on-site effects are recognized of soil that has been abandoned or is forced into less intensive usages. It does neither refer to cyclic fluctuations of soil chemical and physical conditions of relatively stable agricultural systems, in which the soil is actively managed to maintain its productivity, nor to gradual changes in the chemical composition as a result of soil forming processes (Oldeman, 2000).

Due to the severity of its ecological effects, and the scale on which it is occurring, erosion constitutes one of the most significant global environmental problems we face today (Toy, *et al.,* 2002).

Approximately 40% of the world's agricultural land is seriously degraded (Sample, 2007). According to the UN (2008), an area of fertile soil the size of Ukraine is lost every year because of drought, deforestation and climate change. In Africa, if current trends of soil degradation continue, the continent might be able to feed just 25% of its population by 2025, according to United Nations University's (UNU) Ghana-based Institute for Natural Resources in Africa (Sample, 2007., UN, 2008)).

2.5.1 Land degradation: Water and wind erosion are now the two primary causes of land degradation; combined, they are responsible for 84% of degraded acreage (Humberto & Rattan, 2010). Each year, about 75 billion tons of soil are eroded from the land—a rate that is about 13-40 times as fast as the natural rate of erosion (Zuazo and Pleguezuelo, 2009).

The loss of soil fertility due to erosion is further problematic because the response is often to apply chemical fertilizers, which lead to further water and soil pollution, rather than to allow the land to regenerate. Soil erosion and subsequent sediment transport and deposition not only have caused serious environmental and ecological problems, but also economic and engineering problems (Chiew, 2006). The extent of gully erosion in one of the study areas is depicted in Anambra State is shown in plate 1;

Plate 1: Ekwulobia Erosion site showing extent of land degradation (Photoshot by Ubaoji, 2012)

2.5.2 Sedimentation of aquatic ecosystems: There is a very important relationship between fine sediment, contaminant transport and the ecology of water bodies (Chiew, 2006) Soil erosion (especially from agricultural activity) is considered to be the leading global cause of diffuse water pollution, due to the effects of the excess sediments flowing into the world's waterways. The sediments themselves act as pollutants, as well as being carriers for other pollutants, such as attached pesticide molecules or heavy metals.

The effect of increased sediments loads on aquatic ecosystems can be catastrophic. Silt can smother the spawning beds of fish, by filling in the space between gravel on the stream bed. It also reduces their food supply, and causes major respiratory issues for them as sediment enters their gills (Merrington, 2002). The biodiversity of aquatic plant and algal life is reduced, and invertebrates are also unable to survive and reproduce. While the sedimentation event itself might be relatively short-lived, the ecological disruption caused by the mass die off often persists long into the future (Merrington, 2002).

2.5.3 Airborne dust pollution: Soil particles picked up during wind erosion are a major source of air pollution, in the form of airborne particulates (dust). These airborne soil particles

are often contaminated with toxic chemicals such as pesticides or petroleum fuel, posing ecological and public health hazards when they later land, or are inhaled/ingested (Majewski and Capel, 1996)

Dusts have been linked to a whole lot of health conditions ranging from catarrh to nasal blockage. Even, some oesophageal challenges can be attributed to dust particles being carried by the wind erosion especially in desert regions (Heyder, *et al.*, 1986).

2.6 THE EXTENT OF SOIL EROSION

Despite the universal nature of the problem of erosion by water, we do not yet have sufficient information regarding the overall extent of erosion by water even today. Data on the severity of erosion is also often limited.

The Global Assessment of Human-Induced Soil Degradation (GLASOD, 1991) study estimated that around 15 per cent of the Earth's ice-free land surface was afflicted by all forms of land degradation. Of this, accelerated soil erosion by water was responsible for about 56 per cent and wind erosion was responsible for about 28 per cent.

This means that the area affected by water erosion was, very roughly, around 11 million square kilometer and the area affected by wind erosion around 5.5 million square kilometer.

The area affected by tillage erosion was unknown but according to Chiew (2006), statistics suggests that approximately 75% of man-induced erosion was from agriculture and mining activities in China.

The gully types are the more obvious forms of erosion in Nigeria compared to sheet and rill types, mainly because of the remarkable impression they leave on the surface of the earth. They are also a visible manifestation of the physical loss of the land due to erosion. Good examples of gullies are widespread in Nigeria, especially in the Agulu-Nanka (Plate 2 & 3), Obioma, Nsukka, Alor, Nnobi, Nnewi, Orlu, Ozuitem, Abiriba, Ohafia, Uruala, Amucha and Uyo areas of Southeastern Nigeria. Other examples, but on a much smaller scale, exist on the Jos Plateau, especially in Heipang, around Zaria, in Ankpa and at Auchi. Yet, gully erosion is only one aspect of the soil erosion phenomenon, and one which has affected the smallest area of land in the country. In the particular case of Southeastern Nigeria, active gully erosion affected only about 0.60% of the total land area, while all types of gully erosion occupied a little less than 2%. The situation was worse in Omambala and Imo States, where comparable

figures were 1.90% (active) and 5.40% (all types) (Ofomata, 1981). The extent of gully presently has escalated beyond measure that it can estimated as more than double what it was then.

Because soil is formed slowly, it is essentially a finite resource. The severity of the universal erosion problem is only now becoming widely appreciated. The degree to which the soil is presently degraded is estimated in relation to changes in agricultural suitability, in relation to declined productivity and in some cases in relation to its biotic functions.

Four levels are recognized:

2.6.1 Light: The land area or terrain has somewhat reduced agricultural suitability, but is suitable for use in local farming systems. Restoration to full productivity is possible by the modifications of management system. Original biotic functions are still largely intact.

2.6.2 Moderate: The terrain has greatly reduced agricultural productivity but is still suitable for use in local farming systems. Major improvements are required to restore productivity. Original biotic functions are partially destroyed.

2.6.3 Strong: The terrain is non reclaimable at farm level. Major engineering works are required for terrain restoration. Original biotic functions are largely destroyed.

2.6.4 Extreme: The terrain is irreclaimable and beyond restoration. Original biotic functions are fully destroyed. (GLASOD, 1991)

2.7 SOIL CHEMISTRY AND EDAPHIC FACTORS

Soil chemistry is the study of the chemical characteristics of soil. An understanding of its physical characteristics and the chemistry occurring in it are important in the analysis of the various chemical, biological and physical processes that determine the behaviour of chemicals in the soil; be they liquid or gas, nutrient or pollutant. CO_2 and water vapour play a key role in favouring the earth's climate and can be used in modelling and measuring transfer of these between soil, vegetations and the atmosphere. Soil chemistry is affected by mineral composition, organic matter and environmental factors (Conklin, 2005).

2.7.1 Soil Minerals: Mineral particles are inorganic materials derived from rocks and minerals. They are extremely variable in size and composition (Brady and Weil, 1999). They are categorized into primary and secondary minerals.

➤ **Primary minerals** are formed at high temperature and pressure, under reducing conditions without free oxygen**.** These minerals are mainly present in soils as sand and silt particles. They are crystallized and deposed from molten lava. Examples include Quartz (SiO^2), Feldspars (containing Na, K and Ca), Primary mica like muscovite and biotite, Pyroxene, Olivine and Amphiboles.

➤ **Secondary minerals** are formed at low temperature and pressure through oxidation. They are the weathering product of primary minerals, either through alteration of their structure or through re-precipitation. Secondary minerals are often present in soils as clay particles. Examples are Silicate clay minerals (Phyllosilicates), Soluble minerals (carbonates and sulfates), Sesquioxides ie oxides or hydroxides of iron and aluminium and Amorphous aluminosilicates (Brady and Weil, 1999).

➤ **Soil salinity:** Salt is found naturally in soils and water and the ions responsible are: Na^+, K^+, Ca^{2+}, Mg^{2+} and Cl^-. Sodium often predominates in soils making them sodic. Sodic soils present particular challenges because they often have very poor structure which reduces or inhibits water infiltration and drainage (Schmitter and Giresse, 1999; Conklin, 2005). Disrupting drainage patterns that provide leaching can also result in salt accumulations. Soil tillage influences water erosion, and consequently, losses of calcium, magnesium and organic carbon in surface runoff. Nutrients and organic carbon are transported by surface runoff in particulate form, adsorbed to soil colloids or soluble in water (Hartanto *et al*., 2003; Bot and Bennites, 2005).

➤ **Heavy metals:** Accumulation of heavy metals in soils is toxic to both humans and other animals. Exposure to heavy metals over a long period of time is normally chronic due to food chain transfer. Acute poisoning from heavy metals through ingestion or dermal contact is not common but it is possible. Chronic problems associated with long-term heavy metal exposures; Cadmium leads to kidney, liver and GI tract problems while Lead results to mental lapses (USDA, 2000). Implication of heavy metals in erosion menace has not been documented.

2.7.2 Edaphic factors: This can be seen as ecological properties of the soil which are caused by its physical and chemical characteristics. It may also characterize organisms such as plants communities in their relationship with soils.

- **Soil pH**: is the measure of the acidity or alkalinity of soils and its dependent on many factors. In strongly acid soils, the availability of the macronutrients (Ca, Mg, K, P, N and S) as well as Mo and B is curtailed. In contrast, availability of micronutrient cations (Fe, Mn, Zn, Cu, and Co) is increased by low soil pH even to the extent of toxicity to higher plants and microorganisms (Conklin, 2005). In slightly to moderate alkaline soils, Mo and all macronutrients (except P) are amply available but levels of available Fe, Mn, Zn, Cu, and Co are so low that plant growth is constrained. P and B are likewise reduced in alkaline soils even to a deficiency level (Hoffman and Carroll, 1995; Conklin, 2005). Alkaline soils make Fe, Mn and Zn unavailable or sparingly available.

  Though it cannot be generalized but the pH ranges of 5.5 to 6.5 or perhaps 7 may provide the overall most satisfactory plant nutrient levels (Conklin, 2005). Worthy of note is the fact that high Na ion concentration coming from NaCl drives the reaction towards acidity. In low rainfall region, soil pH is typically basic.

- **Cation Exchange Capacity:** CEC of alkaline soils are commonly higher than those of acidic soils with comparative soil texture. This is because of two primary factors 1. The high CEC associated with the constant charges on 2 : 1 type clays are most common in alkaline soils. 2. The even higher CEC resulting from the pH-dependent charges present on the humus colloids at these high pH levels (Jastrow and Miller, 1997; Conklin, 2005).

- **Soil Colour:** colour is a very distinctive feature and can portray other characteristic features of the soil. The presence of iron oxides, organic matter and most times manganese oxides results to different colours of a soil. Few soils colours are from the parent materials (Moore, 2001). High chroma (bright colours) throughout the profile are indices of well drained soils with good percolation and good pore spaces for oxygen presence. Since iron is a component of most rocks, prolonged anaerobic condition can reduce iron oxides (high chroma) red colour to brown then gray, bluish or gray-green colours (low chroma). This is often used to identify soils in wet land (Brady & Weil, 1999)

- **Percolation:** Soils with low infiltration or poor percolation will generally have lower oxygen content as there is an inverse relationship between water and air in soils (Conklin, 2005). High infiltration and percolation leach Ca and Mg out of the soils and

increases the acidity of the soils. Ca and Mg containing soils tend to be neutral or basic while Si and Al which are relatively immobile dissolve slowly also and are eluted into the lower areas of the soil that is developing (Conklin, 2005).

➢ **Soil rheology:** The rheology of a soils increases with Ca and clay. Soil organic matter except disturbed also increases soil rheology. Binding factors for soil aggregation; Ca, Mg, Fe, Al are inorganic ions while clay, organic matter especially microbial gums are organic (Conklin, 2005). High Ca increases stability of microaggregates while high Na decreases stability or leads to dispersion of soils aggregate stability which hinders soil rheology (Saidi, 2012).

➢ **Soil Organic Matter:** Soil organic matter is a complex and varied mixture of organic substances which provides most of the water holding capacity and cation exchange capacity of surface soils. It therefore is responsible for soil stability (Brady and Weil, 1999). Although organic matter is only a small fraction of most soils (Agronomy guide, 2013-2014), it exerts a strong influence on many soil edaphic features or characteristics (MacCarthy *et al*., 1990). Hydrphobic organic matter can cause water repellence which affects wetting pattern of soils due to dry coating. This can result in significant runoff and erosion on sloping sites. Rills and gullies have been observed on soils which would ordinaryly have a negligible runoff if they were not repellent (Moore, 2001). Soil organic matter content of most cultivated lands ranges from a trace to 30% and the levels of many nutrients (N, P, and S) are intrisically tied to the level of organic matter (Hoffman and Carroll, 1995; Bot and Bennites, 2005).

In sandy soils, however organic matter content generally are low, the solid particles are less likely to be aggravated together and the bulk densities are commonly higher in the finer textured soils (Brady and Weil, 1999).

➢ **Soil Mechanic:** Soil compaction increases bulk density thereby increasing soil strength which hinders penetration. Low moisture content causes hardening of soils and this brings about high bulk density (Brady and Weil, 1999).

2.7.3 Soil formation: Soil is formed by the process of disintegration and decomposition of rocks and minerals at or near the earth's surface through the actions of mechanical/natural and chemical agents into smaller particles. Many factors may contribute to this weathering; atmospheric in which case temperature and pressure are involved, wind, glacier or water

erosion, chemical actions like crystal growth, oxidation, carbonation, leaching by water especially by rainfall and hydration (Brady and Weil, 1999).

2.7.4 Soil profile: These soil materials described above are subject to further physical and chemical changes which are brought about by the climate and other prevalent factors. Erosion sets in with its effects of leaching and eluviations and vegetation develops as well; all these with time lead to the development of soil strata otherwise known as *soil profile*. Below are pictures (Plate 2 and 3) depicting different soil horizons of study sites in Anambra State.

Plate 2; Soil horizon (profile) of Nanka erosion site (Photoshot by Ubaoji, 2012)

These natural processes which eventually alter the original parent material may extend to different depths at different areas with varying thickness and composition. This varying thickness and composition of different layers termed 'strata' or horizon defines our natural soil profile into three, though some areas with unusual weathering intensity or very old soil may have more strata or horizon to the tune of five or more.

From top to bottom, these horizons are designated as the A-horizon (top soil), the B-horizon (subsoil) and the C-horizon (underlying rocks and stones). The A-horizon is rich in organic plant residue and humus particles. This is usually leached and eluviated. It is dark in colour and its thickness may range from a few centimetres to half a metre. This horizon often

exhibits many undesirable engineering characteristics and is of value only to agricultural soil scientists. The B-horizon is sometimes referred to as the zone of accumulation. The material which has migrated from the A-horizon by leaching and eluviation gets deposited in B zone. There is a distinct colour difference between this zone and the dark top soil of the A-horizon.

Plate 3: Erosion site at Nanka showing soil profile (another view); Photoshot by Emeka Anyaegbule, 2012)

This soil is very much chemically active at the surface and contains unstable fine-grained material. The thickness of B-horizon may range from 0.50 to 0.75m (Brady and Weil, 1999). The material in the C-horizon is in the same physical and chemical state as it was first deposited by water, wind or ice in the geological cycle. The thickness of this horizon may

range from a few centimetres to more than 30 m. The upper region of this horizon is often oxidised to a considerable extent. It is from this horizon that the bulk of the material is often borrowed for the construction of large soil structures such as earth dams. Each of these horizons may consist of sub-horizons with distinctive physical and chemical characteristics and may be designated as *A*1, *A*2, *B*1, *B*2, etc. The transition between horizons and sub-horizons may not be sharp but gradual. At a certain place, one or more horizons may be missing in the soil profile for special reasons that cannot always be known. The morphology or form of a soil is expressed by a complete description of the texture, structure, colour and other characteristics of the various horizons, and by their thicknesses and depths in the soil profile (Egboka, 1993; Rainforest Conservation Fund, 2013).

2.7.5 Soil particle size distribution: The solid portion of soil is composed of inorganic sand, silt, clay, and organic matter, which interact to produce the large soil features (i.e., peds, profiles, pedons, and landscapes). However, topography and time will also determine the vegetation, as well as its age and whether it can survive in a certain locality. The soil parent material will be acted on by the other factors but will in turn provide the support and minerals needed for plant growth and other activity (Conklin, 2005; Soil Research Centre, 2013).

The relative proportions of the soil particles are extremely variable in sizes. There are four components mixed in complex pattern that greatly influence the behaviour and productivity of soil. These four components are air (20-30%), water (20 -30%), organic matter (5%) and minerals (45%) although a handful of soil may at first seem to be a solid material (mineral and organic); the other half are pore spaces (air or/and water). The spaces between the particles of solid material are just as important to the nature and property of a soil as are the solid themselves (Brady and Weil, 1999).

The mineral (soil) particles range in sizes of magnitude of four; **Sand** particles are somewhat more familiar to us because of its dominance in nature, ranging from 2.0 to 0.05mm, to be seen by the naked eyes and feel gritty when rubbed between fingers. **Silts** are smaller, 0.05 to 0.002mm in size, seen mostly with a microscope and feel smooth but not sticky. **Clays** are the smallest, less than 0.002mm and can be seen only with electron microscope. Clays adhere together to form a sticky mass when wet and hard clods when dry. The proportion of particles in these different size ranges is called soil texture (Brady and Weil, 1999; Moore, 2001; Agronomy Guide, 2013-2014).

The settling of soil particles after dispersion in water is described by the relationship referred to as 'STOKE'S LAW'

$$V = kd^2$$

The velocity of the settling V is proportional to the square of a particle diameter (d); k = constant related to acceleration due to gravity and the density and viscosity of water (Hydrometer used or pipette) (Salako *et al.,*1995) . Stoke's Law: the velocity of a particle falling through a fluid is directly proportional to the gravitational force g, the difference between the density of the particle and the square of the effective particle diameter (d^2).

2.8 MATHEMATICAL MODEL FOR SOIL EROSION PREDICTION

The mathematical model that best describes soil erosion processes is the Universal Soil Loss Equation (USLE) developed in the US based on soil erosion data collected from 1930's. Other models developed were Water Erosion Prediction Projects (WEPP), a physically based erosion simulation model, the Revised Universal Soil Loss Equation (RUSLE) and the Modified Universal Soil Loss Equation (MUSLE). All these models were equally being used for the purpose of soil loss prediction but none has been employed in gully erosion processes. There are two primary types of erosion models employed in predicting soil losses in erosive sites. They are process-based models and empirically-based models. While process-based model mathematically describes the erosion process of detachment, transport and deposition, the empirically-based model relate management and environmental factors directly to soil loss and/or sedimentary yields through statistical relationships (Renard, *et al.*, 1997; Samar, *et al.,* 2002).

The USLE was developed from erosion plot and rainfall simulator experiment and is composed of six factors that predict the long-term average annual soil loss (A)

$$A = RKLSCP \qquad \text{.. (i)}$$

Where R = Rainfall erosivity factor

K = Soil erodibilty factor

S & L = Topographic factors; slope and length

C & P = Cropping management factors; cropping and conservation practices

From the above equation, soil erodibility factor K if made the subject of the formular becomes

$$K = A/RLSCP \qquad \text{...................................... (ii)}$$

The equation concept has experimental importance in unit plot defined as standard plot condition to determine soil erodibility. In this condition, the topographic factors are assumed 1 (a unit) and no conservation practices is applied (CP = 1).

If the topographic factors (S & L) = a unit, 1 and the cropping management factors (C & P) =1
Then substituting the real values of equation (ii)

$$K = A/\ R.1.1 = A/R$$ .... *(iii)*

2.9 SOIL ERODIBILITY IN RELATION TO BIOCHEMICAL PROPERTIES:

Soil erosion can be attributed to a number of environmental factors as well as anthropogenic activities resulting from land use and tillage methods (Igwe, 1994). Among the factors initializing and determining soil erosion rates, soil erosivity is one natural factor that is not directly influenced by human action and potentially the most devastating (Anderson, 2012). Soil erosion rates induced by rainfall are high in tropical environments (Salako, *et al.*, 1995). In classical modelling, works on soil erosion prediction and estimation, works by Renard, *et al.* (1997), Igwe, *et al.* (1999) among others recognised topography/relief, rainfall, vegetation and soil factors as being the main agents that determine the extent of soil erosion hazard. The soil factor represents the soil erodibility which is also a product of geology and soil characteristics (Bryan, 1968). The erodibility of the soil is defined as the vulnerability or susceptibility of the soil to erosion. Igwe *et al* (1995) found that the soil clay content, level of soil organic matter (SOM) and sesquioxides such as Al and Fe oxides, clay dispersion ratio (CDR), mean-weight diameter (MWD) and geometric-mean weight diameter (GMD) of soil aggregates all influence soil erosion hazards in southeastern Nigeria. SOM, Al and Fe oxides control dispersion and flocculation of the soils. In the event of very aggressive rainfall, the soil inherent properties often combine with the physical forces of rainfall to produce soil erosion in the soils.

Erodibility varies with soil texture, aggregate stability, SOM contents and hydraulic properties of the soil. The textures of the soils are related to their parent materials (Akamigbo and Asadu, 1983) which accounted for the similarity in particle size distribution obtained. Igwe *et al* (1999) made similar observation as they reported that soils derived from different geologic formations varied in particle size distribution. Igwe (2005) claimed that the soil dispersion ratio (DR) and the clay dispersion ratio were good indices of erodibility. The soils with high

water-dispersible clay (WDC) in southeastern Nigeria often create problem in that in tilled land use, mud flow and soil loss from runoff cause major alteration in the stream flow within watersheds causing severe environmental challenges. Soil crusting, sealing resulting from aggregate breakdown are secondary problems arising from deposited sediments. The large particle sizes are resistant to transport because of the greater forces required to entrain these large particles while the fine particles are resistant to detachment because of their cohesiveness. Aggregate stability and associated indices have been shown to be most efficient soil properties that predict the extent of soil erosion (Oguike and Mbagwu, 2009).

Anthropogenic factors arising from misuse of land often combine to weaken soils to produce severe gullies. Poor farming systems have contributed to collapse of soil structure and thus encouraging accelerated runoff and soil loss due to erosion. However, continuous cultivation, physical properties and productivity of many soils commonly decline due to decrease in organic matter content (Lal, 1986) and soil pH. Intensive cropping has led to disaggregation in surface soils due to a combination of machinery movement and decrease in organic matter, OM (Kutilek, 2005). The event of uncontrollable grazing caused by the nomads has resulted in deforestation and compaction of the landscape while indiscriminate foot paths created on the landscape has helped the incipient channels on the landscape to form. These channels eventually metamorphose to gullies especially when they are not checked at inception. Road constructions including uncontrolled infrastructural developments have contributed significantly in gully developments (Oguike and Mbagwu, 2009).

In other parts of the world, the use of aggregate stability indices in predicting soil erodibility have shown reliable information on the extent and degree of soil erosion (Bajracharya *et al.,* 1992). In Western Europe, Le Bissonnais (1990) indicated that the mean-weight diameter (MWD) of soil aggregates was a very reliable soil property that could show the erosion potential of the soil in the sense that MWD predicts soil erodibility. Tillage and clean weeding together reduces organic matter content which may explain the low value of MWD in soil erosion sites by lowering the aggregate stability. Therefore aggregate stability and MWD are very reliable properties in explaining, quantifying or predicting soil erosion and other soil problems such as crusting and sealing (Igwe, 2012).

Land use significantly influence soil physical properties, especially structure parameter. Changes in land use such as conversion of natural forest to crop land contributed to land degradation that manifested in losses of soil organic matter and reduced stability of soil

aggregates. Since the physical properties and organic matter content of the soils under the land use types varied, it implied therefore that land degradations could be land use type-specific (Oguike and Mbagwu, 2009). Soil Organic Matter (SOM) is a major determinant of soil fertility, water retention and biological activity (Soil Research Centre, 2013). Organic matter (OM) is one of the most important constituents of soils due to its capacity in affecting plant growth indirectly and directly. Indirectly, OM improves the physical conditions of soils by enhancing aggregation, aeration and water retention, thereby creating a suitable environment for root growth (Senesi and Loffredo, 1999). It also helps to prevent soil erosion and locks up carbon that could otherwise be released as CO_2, contributing to global warming. One way of maintaining and increasing SOM in soils is through the addition of compost (Soil Research Centre, 2013).

The relationship between OM and soil aggregation or structure formation was described by Tisdall and Oades (1982) in a conceptual model, affected by three types of aggregation agents. In soils, where the OM is the main binding agent, aggregates of different sizes can be formed. Primary particles and clay microstructure are bound together into extremely stable microaggregates which may be bound with fungal and plant debris giving a larger microaggregates. The humic matter, considered as a persistent cementing agent, is involved in stabilizing microaggregates. These microaggregates are bound into macroaggregates, due to the effect of transient binding agents (polysaccharides derived from plants and microorganisms) and temporary binding agents (fungal hyphae, fine roots, bacterial cells) (Tisdall and Oades, 1982; Oades, 1993). Particulate Organic Matter (POM) improves the soil aggregation since it can form an organic core surrounded by clay, silt particles, and aggregates (Jastrow and Miller, 1997).

The macroaggregates are less stable than microaggregates to wetting or mechanical actions such as plowing, and their destruction by tillage may result in exposure of the inner core of organic substances (Golchin, *et al.*, 1997; Six, *et al.*, 2000), facilitating rapid oxidation and attack by microorganisms of these important binding agents (Angers and Chenu, 1997). Because of synthesis and mineralization occurring at the same time, the concentrations of humic substances is generally at equilibrium and remain constant at the prevailing ecoclimatic condition. However, when the precursors of humic matter disappear, the changes occurring in its composition and chemistry can modify its resistance to decomposition (Stevenson, 1982). Due to lower condensation, new complex polymeric humic substances fail to develop, resulting in formation of fewer and considerably less resistant humic compounds, serving as

binding agents, with the consequent collapse or destruction of the aggregates. According to the works of Bongiovanni and Lobartini (2006), the decomposition of transient dilute acid soluble carbohydrates (CHda), and hot water soluble carbohydrates (CHhw), brought about by cultivation resulted in the breakdown of macroaggregates (2800–250μm) rich in organic matter with a subsequent increase of microaggregates (250–53μm) depleted in organic matter.

Characterization of soil loss is very important for environment and natural resources. In modelling for soil loss, Hartanto, *et al.,* (2003) highlighted four groups of variable to be considered which include the soil characteristics, physiographic properties (altitude, exposition, aspect, slope and exposure length), climatic properties and stand characteristics (mean height, mean diameter, crown closure and stand density). Different prediction model have been used to estimate soil loss or soil erosivity from cropland, rangeland and forestland. They include the Universal Soil Loss Equation (USLE), the Water Erosion Prediction Project (WEPP). WEPP has been implemented to develop an improved model based on modern technology for estimating soil erosion by water. WEPP technology is based on fundamental hydrologic and soil erosion processes and is designed to replace the widely used USLE (De Bano and Wood, 1990; Megahan, 1992; Misir and Misir, 2012). In other parts of the world the use of some soil parameters such as the water-dispersible clay (WDC) has been adopted as a major parameter in soil erosion models as in the Water Erosion Prediction Project, WEPP. Soils with high WDC have high soil erosion potential and therefore WDC constitutes a great problem to the soil and the entire environment. The negative influence of high clay dispersion on soil erosion results in detachment, transportation and deposition of sediments with essential plant nutrient elements downstream. This clay associated sediments constitute high environmental menace to man, livestock and agricultural fields. The streams and rivers are silted, while the aquatic life suffers serious problems due to high concentration of nitrates, organic matter and phosphorus in clay suspension downstream. The Universal Soil Loss Equation (USLE) is a widely used method for calculating annual soil losses, based on rainfall, runoff, slope, runoff length, soil type and land use parameters (Igwe, 2012).

Samar *et al.,* (2002) developed three soil loss prediction models (WEPP, EPIC, ANSWERS) and used them for simulating soil loss and testing their capability in predicting soil losses for three tillage systems (rigde-till, chise-plow, and no-till). In other study by Sun and Mc Nulty (1998), USLE and GIS (Geographical Information System) combination were used to predict long-term soil erosion and sediment transportation from hillslopes to stream networks under different climate conditions and forest management scenarios. Soil erosion was predicted by

the USLE watershed level. The GIS utilities are employed to calculate total mass of sediment moving from each cell to nearest stream network. Mısır, *et al.,* (2007) developed a soil loss model applicable for forest management scenarios for forested areas in northern Turkey.

3.0   MATERIALS AND METHODS

3.1 MATERIALS

3.1.1 Instruments for *in situ* field studies:

- Auger
- Shovel
- Rope
- Thermometer
- 1 litre container
- Timer

3.1.2 Equipment/Apparatus:

- Global Positioning System (GPS) instrument

3.1.3 Chemicals and Reagents

All reagents are of analytical grade and are manufactured by BDH Chemicals Ltd, UK.

- Conc HNO_3;
- Perchloric acid;
- Conc H_2SO_4

3.2 SAMPLE COLLECTION:

Disturbed sub-grade soil samples were collected from six (6) different natural erosion sites in Anambra state; Agu-Awka (Awka South L.G.A.), Ogidi (Idemili North L.G.A.), Nkpor (Idemili North L.G.A.), Agulu (Anaocha L.G.A.), Nanka (Orumba North L.G.A.), Ekwulobia (Aguata L.G.A.), an artificial erosion site Agu-Awka burrow pit (Awka South L.G.A) and control from a none eroded sites in Anambra state; Alor (Idemili North L.G.A.), Odekpe (Ogbaru L.G.A.) and Igbariam (Anambra East L.G.A.).

Figure 4a: Auger for sample collection

Plate 4b: Collection of sample at Agulu erosion site (Photoshot by Emeka Anyegbule, 2012)

The soil profiles were grouped into zones to find out the possible variations in their soil compositions with regard to their biochemical and edaphic factors as possible deterministic properties to soil erodibilty.

To that effect, the soil samples were grouped into four zones; AGULU-NANKA ZONE (Agulu, Nanka and Ekwulobia), AWKA SOUTH ZONE (Agu-Awka and Agu-Awka burrow pit), IDEMILI ZONE (Alor, Nkpor and Ogidi) and CONTROL (Igbariam and Odekpe).

The following *in-situ* tests were conducted at the erosion sites and were recorded appropriately;

3.2.1 Site location mapping: The erosion sites were mapped using google earth and GPS instrument.

Plate 5a: The Global Positioning System Instrument

Plate 5b: GPS mapping of Agulu erosion site (Photoshot by Emeka Anyaegbule 2012)

3.2.2 Soil depth: The depths of the eroded sites were measured using a rope and an industrial tape. The rope was used to span the horizons and the tape used to check the actual length of the horizons which is equivalent to the length of the rope that spans the erosion depths.

3.2.3 Soil Colour: The soil colour was analysed using MUNSELL soil colour chart.

3.2.4 Soil temperature: The temperatures of the shoulder levels (SL), ground surface (GS), 2" depth, 4" depth and 6" depth into the soil surface were taken from both area under the shade and under the sun using thermometer and all were recorded appropriately.

Plate 6; Measurement of temperatures of eroded sites (Photoshot by Emeka Anyegbule, 2012)

3.2.5 Percolation test:

Caution:

Test results are sensitive to external factors such as ashes so no smoking or touching with bare hands. Crumble sample very well and remove particulates present in the sample

Procedure:

To test the soil's drainage:

➢ We dug a hole about six inches wide and one foot deep.

➢ The hole was filled with1 litre of water and was let to drain completely.

➢ The time for the complete drainage was recorded

➢ The hole was filled with water and allowed to drain completely again.

➢ The step was repeated for the third time and the time recorded in each case.

➢ The average of the drainages were taken as the percolation rates of the soil area.

Plate 7; Percolation test being carried out at B-Horizon in Agulu Erosion site (Photoshot, Emeka, 2012)

If the water takes more than four hours to drain, the soil have very poor drainage.

Laboratory tests: were further conducted to ascertain the physical, elemental characteristics and geotechnical properties of these samples. All geotechnical tests conducted were in

conformity with AASHTO sampling and testing protocols described by (Holtz and Kovacs, 1981) and also as recommended by the Federal Ministry of Works (F.M.W) specifications for Roads and Bridges (Ekeocha and Akpokodje, 2014).

The soil samples collected were subjected to the following laboratory tests for elemental characteristics and classification purpose:

3.3 LABORATORY DETERMINATION OF NATURAL MOISTURE CONTENT OF SAMPLES AASHTO T 265

3.3.1 Summary of Test Procedure:

The test method used to determine the percentage of moisture in a soil is a simple procedure. First, the wet mass of the soil specimen was determined (weighed) and dried using an oven. Then the dried soil was weighed again and the drying process was repeated until the mass of the dried soil stops changing (constant mass). Finally, to determine the percentage of moisture removed from the soil (the moisture content), the value was calculated from the data obtained.

3.3.2 Apparatus:

  I.   Balance - conforming to AASHTO M 23
 II.   Oven capable of maintaining temperature of $110 \pm 5^{o}C$ ($230 \pm 9^{o}F$)
III.   Drying Containers

A representative quantity of soil sample was tied in a cellophane (kept from drying out before analysis was carried out) bag and taken straight away to the oven in the laboratory.

3.3.3 Procedure:

➢ The oven was turned on and its temperature allowed to stabilize at $110^{o}C$ ($230^{o}F$).

➢ The mass of the empty container with cover was determined and recorded.

➢ The wet test specimen was placed in the drying container, covered immediately. Then the mass of the covered container and test specimen were determined and the mass of the wet specimen, container and cover were recorded.

➢ The lid was removed and immediately placed the drying container holding the test specimen in the oven.

➢ The test specimen was allowed to remain in the oven until it reached constant mass.

Constant mass is that point at which the test specimen has the same mass on two successive weighing. If the test specimen can be allowed to remain in the oven for an extended period (e.g., 15-16 hours or overnight), it is safe to assume that constant

mass has been reached. If test results must be obtained quickly, to determine if constant mass has been reached, remove the container and test specimen from the oven. Place the lid back on the container. The drying container must be cool enough to be placed on the balance without causing inaccuracy in the balance reading. Determine the mass of the container, lid, and test specimen. Repeat this step until two successive weighings show no change in mass. Be sure to record the mass at each weighing

Calculations:

➢ The mass of the dried test specimen, container and cover was subtracted (from fifth step) from the mass of the wet test specimen, container and cover (from third step). This gave the mass of moisture in the specimen.

➢ The mass of moisture was divided by the mass of the dried specimen minus the mass of the container and cover.

➢ The dividend obtained in the second step above was multiplied by 100. This gave the percent moisture in the sample.

The calculation steps are represented by the following equation:

Moisture content w(%) = $\dfrac{\textit{Weight of water in soil}}{\textit{Weight of dry soil}} \textit{ X 100}$

3.4 PH MEASUREMENT:

3.4.1 Apparatus:

- Warring micro-blender
- pH meter

3.4.2 Procedure:

i. 10% w/v suspension of the sample in distilled water was prepared.

ii. Was thoroughly mixed in a warring micro-blender, then the pH was measured with a good pH meter

iii. The pH reading was recorded

3.5 DETERMINATION OF ELECTRICAL CONDUCTIVITY (RESISTIVITY):

3.5.1 Apparatus:

- Conductivity meter

3.5.2 Method: Analysis was carried out according to APHA 2510 B guideline Model DDS-307 (Laker and Dupreez, 1982)

3.5.3 Principles: It employs the magnitude of the total concentration of ionic solutes in solution and also the degree of dissociation.

3.5.4 Procedure:

➢ 10g of sample was dissolved in 10ml of distilled water

➢ The conductivity cell was rinsed with at least three portions of the sample

➢ The temperature of the sample was then adjusted to 20 ± 0.1^0C

➢ The conductivity cell containing the electrodes was immersed in sufficient volume of the sample

➢ The conductivity meter was turned on and the conductivity of the sample recorded.

➢ Resistivity is the inverse of electrical conductivity

3.6 METHODS FOR THE METAL ANALYSIS:

Heavy metal analysis was conducted using Varian AA240FS Atomic Absorption Spectrophotometer according to the method of APHA (American Public Health Association) described by (Laker and Dupreez, 1982).

3.6.1 Sample Digestion:

i. 2g of the dried sample were weighed into a digestion flask and 20ml of the acid mixture (650ml conc HNO_3; 80ml Perchloric acid; 20ml conc H_2SO_4; ie Calgon) were added.

ii. The flask was heated until a clear digest was obtained.

iii. The digest was diluted with distilled water to the 250ml mark

iv. Appropriate dilutions were then made for each element

3.6.2 Apparatus:

• Varian AA240FS Atomic Absorption Spectrophotometer

3.6.3 Working principle: Atomic absorption spectrometer's working principle is based on the sample being aspirated into the flame and atomized when the AAS's light beam is directed through the flame into the monochromator, and onto the detector that measures the amount of light absorbed by the atomized element in the flame. Since metals have their own characteristic absorption wavelength, a source lamp composed of that element is used, making the method relatively free from spectral or radiational interferences. The amount of energy of the characteristic wavelength absorbed in the flame is proportional to the concentration of the element in the sample.

3.6.4 Procedure: The sample was thoroughly mixed by shaking, and 100ml of it was transferred into a glass beaker of 250ml volume, to which 5ml of conc. nitric acid was added and heated to boil till the volume was reduced to about 20ml, by adding conc. nitric acid in increments of 5ml till all the residue was completely dissolved. The mixture was cooled, transferred and made up to 100ml using metal free distilled water. The sample was aspirated into the oxidising air-acetylene flame. When the aqueous sample was aspirated, the sensitivity for 1% absorption was observed.

Table 1; Preparation of reference solutions

Standard Flame Emission Conditions for Ca

Wavelength (nm)	Slit (nm)	Flame
422.7	0.2	Nitrous oxide-acetylene

Stock Standard Solution	Calcium, 500mg/l. to 1,249g of calcium carbonate, $CaCO_3$, add 50ml of deionized water. Dissolve by adding dropwise 10ml of HCL. Dilute to 1 liter with deionized water.

Standard Flame Emission Conditions for Al

Wavelength (nm)	Slit (nm)	Flame
396.2	0.2	Nitrous oxide-acetylene

Stock Standard Solution	Aluminium, 1000mg/l. Dissolve 1,000g of aluminium wire in a minimum amount of (1+1) HCL, adding a small drop of mercury as a catalyst. Dilute to 1 liter with 1% (v/v) HCL. Filter the solution to remove the mercury.

Standard Flame Emission Conditions for Ag

Wavelength (nm)	Slit (nm)	Flame
328.1	0.2	Air-acetylene

Stock Standard Solution	Silver, 500mg/l. Dissolve 787g of silver nitrate, $AgNO_3$ in 50ml of deonized water. Dilute to 1 liter with 1% (v/v) HNO_3. *Silver is sensitive to light. Store in an amber glass bottle. Prepare standards in 5% (v/v) HNO_3 to keep the silver in solution.*

Standard Flame Emission Conditions for Cd

Wavelength (nm)	Slit (nm)	Flame
326.1	0.2	Air-acetylene

Stock Standard Solution	Cadmium, 100mg/l. Dissolve 1,000g of cadmium metal in a minimum volume of (1+1) HCL, Dilute to 1 liter with 1 % (v/v) HCL.

Standard Flame Emission Conditions for Co

Wavelength (nm)	Slit (nm)	Flame
315.4	0.2	Air-acetylene
Stock Standard Solution	Cobalt**,** 1000 mg/l. Dissolve 1,000g of cobalt metal in a minimum volume of (1+1) HCL. Dilute to 1 liter with 1% (v/v) HCL.	

Standard Flame Emission Conditions for Cr

Wavelength (nm)	Slit (nm)	Flame
425.4	0.2	Air-acetylene
Stock Standard Solution	Chromium**,** 1000mg/L. Dissolve 3,735g of potassium chromate, $K_2C_rO_4$, in deionized water and dilute to 1 liter with deionized water.	

Standard Flame Emission Conditions for Fe

Wavelength (nm)	Slit (nm)	Flame
372.0	0.2	Air-acetylene
Stock Standard Solution	Iron, 1000mg/l. Dissolve 1,000g of iron wire in 50ml of (1+1) HNO_3. Dilute to 1 liter with deionized water.	

Standard Flame Emission Conditions for Mn

Wavelength (nm)	Slit (nm)	Flame
403.1	0.2	Air-acetylene
Stock Standard Solution	Manganese, 1000 mg/l, Dissolve 1,000g of manganese metal in a minimum volume of (1+1) HNO_3. Dilute to 1 liter with 1% (v/v) HCL,	

Standard Flame Emission Conditions for K

Wavelength (nm)	Slit (nm)	Flame
766.5	0.2/0.4	Air – acetylene
Stock Standard Solution	Potassium, 1000mg/l. Dissolve 1,907g of potassium chloride, KCL, in deionized water and dilute to 1 liter with deionized water.	

Standard Flame Emission Conditions for Ni

Wavelength (nm)	Slit (nm)	Flame
341.5	0.2	Air-acetylene
Stock Standard Solution	Nickel,1000 mg/l. Dissolve 1,000g of nickel in a minimum volume of (1+1) HNO_3. Dilute to 1 liter with 1% (v/v) HCL.	

Standard Flame Emission Conditions for Zn

Wavelength (nm)	Slit (nm)	Flame
213.9	0.2	Air-acetylene
Stock Standard Solution	Zinc,1000 mg/l. Dissolve 1,000g of zinc metal in a minimum volume of (1+1) HNO_3. Dilute to 1 litre with 1% (v/v) HCL.	

Standard Flame Emission Conditions for Pb

Wavelength (nm)	Slit (nm)	Flame
403.1	0.2	Air-acetylene

Stock Standard Solution   Lead, 1000mg/L. Dissolve 1,000g of lead metal in a minimum volume of (1+1) HNO_3. Dilute to 1 liter with 1% (v/v) HCL.

Standard Flame Emission Conditions for Cu

Wavelength (nm)	Slit (nm)	Flame
324.8	0.2	Air-acetylene

Stock Standard Solution   Copper,1000 mg/l. Dissolve 1,000g of copper metal in a minimum volume of (1+1) HNO_3. Dilute to 1 liter with 1% (v/v) HCL.

Standard Flame Emission Conditions for Si

Wavelength (nm)	Slit (nm)	Flame
251.6	0.2	Air-acetylene

Stock Standard Solution   Silicon,1000 mg/l, Dissolve 1,000g of standard silicon ion in a minimum volume of (1+1) HNO_3. Dilute to 1liter with 1% (v/v) HCL.

Standard Flame Emission Conditions for Mg

Wavelength (nm)	Slit (nm)	Flame
285.21	0.2	Air-acetylene

Stock Standard Solution   Magnesium,1000 mg/l. Dissolve 1,000g of magnesium in a minimum volume of (1+1) HNO_3. Dilute to 1 liter with 1% (v/v) HCL.

Standard Flame Emission Conditions for Na

Wavelength (nm)	Slit (nm)	Flame
589.6	0.2	Air-acetylene

Stock Standard Solution   Sodium,1000 mg/l. Dissolve 1,000g of sodium in a minimum volume of (1+1) HNO_3. Dilute to 1 liter with 1% (v/v) HCL.

3.7 REDUCING SAMPLES OF SOIL TO TESTING SIZE AASHTO T 248

3.7.1 Apparatus:

The following are the apparatus needed to perform AASHTO T 248.

- Straight-edged scoop.

- Flat-edged shovel or trowel.

- Broom or brush.

- Raffle box (sample splitter).

3.7.2 Sample Preparation:

The sample splitter was used to reduce the aggregate sample; the aggregate was in an air dry condition prior to splitting.

3.7.3 Reduction Procedure:

The original sample or a portion thereof was placed in the hopper (pan) and was uniformly distributed from edge to edge making sure the sample appears homogenous. The sample was carefully introduced into the chutes in a manner to allow the aggregate to flow freely through the openings and into the catch pans. This procedure was continued until the entire large sample has been halved, being careful that catch pans do not overflow. The catch pans were then removed and set aside while the other half was further split into quarters. This procedure was followed being sure to split entire increments, until the desired test sample size was obtained.

Plate 8; shows quartering of sample using Raffle Box

3.8 PARTICLE SIZE ANALYSIS OF SAMPLES USING INDIAN SIEVES:

3.8.1 Summary of Procedure:

This test method was performed on a soil sample prepared by dry preparation of disturbed soil and Soil Aggregate Samples for Test. A portion of the soil sample passing the 2.00 mm (No. 10) sieve is subjected to a dry sieve analysis (SAA, AS 1289, 1976).

3.8.2 Steps for dry sieving of particle retained in the 75 micro meter sieve:
- ➢ Sieves were arranged according to their sizes (2.0mm – 0.075mm)
- ➢ Pass dry sample to sieves
- ➢ Shake sample in sieves using a mechanical sieve shaker
- ➢ After 2mins of shaking, remove first sieve and weigh the retained weight, then place the lid on the remaining sieves and shake.

➢ Do the same for other sieves after 2mins of shaking

Plate 9 showing the arrangement of sieves according to diameter of aperture

Plate 10 showing the mechanical sieve shaker (machine shaker)

➢ Calculate the percentage retained and the total percentage passing

Percentage Retained (g) = $\dfrac{\text{weight of soil retained}}{\text{Total weight of soil sample}}$ *X 100*

Percentage passing (g) = 100 – cumulative percentage retained

Plot a graph of percentage passing against sieve sizes.

Plate 11: showing wire brushing of sieve to remove all particles

3.9 DETERMINING THE LIQUID LIMIT OF SAMPLES AASHTO T 89:

The Liquid Limit test was performed on material passing the 0.425 mm (No. 40) sieve. First, mix the test specimen with water, alternately stirring and chopping the soil and adding water until the soil is at a uniform stiff consistency. When the correct consistency for each soil type has been reached, place some of the test specimen in the cup of the Liquid Limit device. Then use the spatula to press and spread the material to the correct thickness. Be careful not to trap air bubbles in the test specimen when spreading it in the cup. Use the grooving tool to divide the test specimen in the cup through its centre moving the tool from back to front only one time for each stroke. Be sure to form a clean, sharp groove. Use not more than six strokes of the grooving tool to divide the specimen; only the last stroke of the grooving tool is to scrape the bottom of the cup. Turn the crank at approximately 2 revolutions per second and count the number of blows of the machine or use the automatic counter if the device is equipped with one. When the groove closes to 13 mm (0.5 inch), stop the device. Record the number of blows the device needed to close the groove.

3.9.1 Procedure:

➢ Take a sample of approximately 50g from the thoroughly mixed portion of the 100g obtained in accordance with T 87. The portion of the material used passes the No. 40 (0.425 mm) sieve.

➢ Place the sample in the mixing dish and thoroughly mix with 8 to 10 mL of distilled water by alternately and repeatedly stirring, kneading, and chopping with a spatula.

➢ Add additional water in increments of 1 to 3 mL and thoroughly mix until a stiff uniform mass of soil and water is achieved. Once testing begins, do not add additional

41

dry soil to the moistened soil.

➢ Use the spatula to scoop a representative specimen of the mixed material about the size of a golf ball. Immediately cover mixing dish to eliminate moisture loss.

➢ Place this specimen in the cup of the liquid limit device directly above the point where the cup rests on the base.

➢ Use the spatula to press, spread, and level the specimen so that the material is not more than 10 mm thick at its maximum thickness and is centred as close as possible over the contact point of the cup and the base. Use as few spatula strokes as possible.

➢ Trim excess soil from the specimen during Step 6, return the excess to the mixing dish and immediately cover to prevent moisture loss.

➢ Apply blows. (If the device is automatic, turn on the device). For the manual device, turn the crank at approximately two revolutions per second. Continue applying blows until the two sides of the material come in contact at the bottom of the groove along a distance of about 13 mm (0.5 inch).

➢ Use the spatula to take a slice of soil from the specimen in the cup. Remove the slice from edge to edge of the soil cake at right angles to the groove. Include that portion of the groove where the soil has flowed together. Place the slice in a drying container.

➢ Determine the moisture content of the slice in accordance with AASHTO T 265.

➢ Determine the percentage of moisture to the nearest 0.1% for each test specimen in accordance with AASHTO T 265.

➢ Prepare a semi-logarithmic graph paper by labelling the x and y axes for moisture content and number of shocks.

➢ For each test specimen, plot the point corresponding to the blow count and moisture content.

➢ Draw a flow curve (as straight a line as possible passing through all plotted points).

➢ Identify the moisture content at which the flow curve intersects the 25-blow line.

3.10 DETERMINING THE PLASTIC LIMIT AND PLASTICITY INDEX OF SAMPLES AASHTO T 90

To determine the Plastic Limit of a soil, water was first added to a dried soil sample and mixed thoroughly. When the moisture content is uniform, the test specimen was placed on a flat, smooth, impermeable surface and, with the heel of the hand, rolled into a thin thread. The test specimen was remoulded without adding additional water and the procedure was repeated until the specimen crumbled. Then the moisture content of the test specimen was determined in accordance with AASHTO T 265. The moisture content is the Plastic Limit. The Plasticity

Index was determined by subtracting the Plastic Limit from the Liquid Limit in accordance with AASHTO T 89.

3.10.1 Procedure:

➢ Squeeze the 8 g test specimen into an ellipsoidal mass.

➢ Then place the test specimen on the rolling surface. Applying just enough pressure to cause the specimen to move, roll it back and forth with hand until it forms a thread of uniform diameter throughout its length. Then roll it back and forth at a speed of approximately 80 – 90 strokes per minute being sure to apply pressure uniformly during the procedure. A stroke equals one complete motion back and forward to the starting point.

➢ Squeeze the pieces between the thumbs and fingers to create a uniform ellipsoidal mass.

➢ Repeat 2nd and 4th steps until the thread crumbles under the pressure required for rolling and the specimen can no longer be rolled into a thread.

➢ Gather the pieces of the crumbled thread together. Place them in a tare container that is suitable for drying to determine the moisture content.

➢ Determine the moisture content in accordance with AASHTO T 265 and record the results.

Calculations:

The Plastic Limit is determined using the following formula and reported to the nearest whole number.

$$Plastic\ Limit\ (PL) = \frac{Mass\ of\ water}{Mass\ of\ Oven – dry\ Soil} \times 100$$

➢ Plastic limit: The moisture content at which a soil moves from a semisolid to a plastic state.

➢ Liquid Limit: The moisture content at which a soil moves from a plastic to a liquid state.
Plastic index = liquid limit – plastic limit
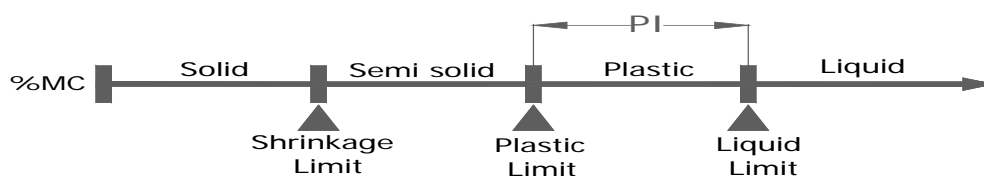
Figure 2: showing Atterberg limits of soil samples   PI= Plasticity Index

3.11 SPECIFIC GRAVITY OF SAMPLES ACCORDING TO AASHTO T 100:

This method requires the material to be passed through the 2.0mm sieve size, then through the calibration of the pycnometer. The soil sample was weighed in the pycnometer, partially filled the bottle with water, and then the sample was distilled by evacuating air from the soil-water mixture, refilling the pycnometer with de-aired water, weighed and completed calculations.

3.11.1 Procedure:

An oven-dried sample was used;

➢ The sample was dried in accordance with AASHTO T 265. Cooled to room temperature, using desiccators to prevent absorption of hygroscopic moisture. The sample was weighed and transfered to the pycnometer.

Plate 12 shows specimens for specific gravity in the desiccators.

➢ Distilled water was added into the pycnometer in an amount that will provide complete sample coverage. Then the sample was soaked for 12 hours.

➢ After sample preparation, entrapped air was removed by using the vaccum pump gently for at least 10 minutes, while occasionally rolling the pycnometer to assist in the removal of air, as shown below.

Plate 13 shows pycnometer + sample + water, thus observe that the sample is covered by water

Plate 14 shows removal of air bobbles gently using the vacuum pump assisted by Nonso Okeke, Lab. Technologist.

➢ The pycnometer was filled with distilled water to its calibrated capacity.

➢ The outside was cleaned and dried with clean, dry cloth.

➢ The mass of the pycnometer and contents were determined and recorded.

Calculation of Specific Gravity

Calculate the specific gravity of the soil in accordance with the following equation:

Where:

Specific gravity = weight of a given volume of material
Weight of equal volume of water

3.11.2 Method for pore density:

A clean dry density bottle was weighed and recorded as M1. The density bottle was filled with water and the volume of water measured using a measuring cylinder and recorded as V. The density bottle was emptied and dried in an oven. The density bottle was refilled with the particles without shaking the bottle and weight recorded as M2.

Calculate:

Mass (M) = M2 – M1

Density (D) =   Mass (M)
Volume (V)

3.11.3 Method for bulk density:

A clean dry density bottle was weighed and recorded as M1. The density bottle was filled with water and the volume of water measured using a measuring cylinder and recorded as V. The density bottle was emptied and dried in an oven. The density bottle was refilled with the particles shaking the bottle and weight recorded as M2.

Calculate:

Mass (M) = M2 – M1

Density (D) =   Mass (M)
                    Volume (V)

3.11.4 Method for calculating soil porosity:

Soil porosity is calculated from the relationship below:

Soil Porosity = { 1 – bulk density   } x 100
                {   Particle density   }

3.12 SOIL SEDIMENTATION DETERMINATION:

3.12.1 Reagents:

➢ 25% sodium hexametaphosphate (calgon)
➢ 250g of sodium hexametaphophate was dissolved in 900mml warm deionised water. It was allowed to cool, sufficient sodium carbonate was added to bring to pH 8 or 9 and diluted to 1 litre with deionised water.

3.12.2 Sample preparation:

Carry out sample preparation according to sample receipt, preparation and storage (S1A/5). The sample was weighed and recorded. The sample was passed through the 4.75mm and 2mm sieves making sure that no aggregates were retained on the sieve. The amount of particles >4.75mm and 2.0 to 4.75mm were weighed and recorded.

3.12.3 Sample pretreatment:

Removal of soluble salts:

The soluble salts were removed as follows:

1. 50g of air dry soil (<2mm) were weighed into a shaking bottle. 500ml of a hot tap water was added and shook for 10 minutes. The soil was allowed to settle until the supernatant was clear.
2. The clear liquid was siphoned off, refilled with deionised water and repeated more than

four times.

3.12.4 Dispersion and shaking:

1. 200ml of deionised water and 20ml of 25% sodium hexametaphosphate was added.

2. The bottle was placed on an end-over-shaker and shook for 16hours (overnight) at 15rpm

3.12.5 Procedure:

1.   On completion of shaking, the prepared sample and dispersed samples were transfered to 1 L measuring cylinders and filled to the 1 L mark with deionised water and the hydrometer used was noted.

2.   The sample was stirred with a plunger for 20-30 seconds ensuring that all materials at the bottom are brought into suspension. At the end of stirring, the plunger was removed and the interval timer was started immediately.

3.   After 4 minutes of sedimentation, the hydrometer was immersed to a depth slightly below its floating position and allowed to float freely. A reading was taken at 5 minutes at the top of the meniscus and recorded to the nearest 0.5g/L.

4.   The hydrometer was removed slowly, rinsed clean and placed in a sedimentation cylinder filled with deionised water and 20ml of 25% sodium hexametaphosphate (blank solution). The water temperature in the blank cylinder was the same as that of the soil suspension.

5.   The hydrometer was re-inserted in the soil suspension for reading at different periods taken in the same manner as above. At about the same time as each soil suspension hydrometer reading, a hydrometer and temperature reading was taken (to the nearest $0.5^{\circ}C$) of the blank solution. The hydrometer was read at the top of the meniscus. The hydrometer was left in the blank solution between readings.

Calculation:

Calculate for each hydrometer reading the summation percentage (P)

$$P(\%) = \frac{(H) \times 100}{W}$$

Where :

$$H = \text{Hydrometer reading in soil suspension(g/L)}$$

3.12.5 Sand measurement:

1. The contents of the cylinder was passed through the 0.70mm sieve and thorough washed free of all fine particles. Those particles retained on the sieve are the coarse sand fraction.

2. The coarse sand was transfered from the sieve into a pre-weighed, numbered weighing tin. It was allowed to dry by placing in a drying oven between 105°C and 110°C and cooled in a dessicator afterwards and then weighed.

After the sedimentation period, the suspend clay fraction was decanted from the settled silt particles and discarded . The settled silt fraction was then dried in the beaker at 105⁰C to a constant weight. The soil sand % and silt % were calculated based on their fraction of the original sample mass:

% Sand = $\frac{(\text{oven dry sand mass})}{\text{Original sample mass}}$ *X 100%*

% Silt = $\frac{(\text{oven dry silt mass})}{\text{Original sample mass}}$ *X 100%*

The % clay was determined by calculating the difference of 100 % minus the sum of the % sand and % silt,

% Clay = 100 – (% sand + % silt)

3.13 PROCEDURE FOR DETERMINING PERCENTAGE LOSS ON IGNITION OF INORGANIC SOILS:

3.13.1 Scope

This procedure is intended as an indicator of the amount of coarse (+ 75µm sieve) mica present in inorganic soil such as the residual soils of the SC piedmont (South Carolina census designated place in US). The water of crystallization contained within the mica is driven off by ignition at approximately 1000⁰C. The loss in mass of the sample is an index to the amount of mica present.

3.13.2 Apparatus:

- High temperature porcelain crucibles
- Muffle furnance capable of maintaining a temperature of 1000⁰C ± 50⁰C
- Desicator

- AASHTO Class B Analytical Balance

3.13.3 Test specimens:

This test is normally performed in conjuction with particle size analysis (SC T 34 or AASHTO T 88). The sample is prepared by recombining and mixing thoroughly the material above the 75-µm sieve from the sieve analysis performed on the portion of the sample passing the 2-mm sieve.

3.13.4 Procedure

➢ The soil sample was reduced in size to approximately 20 grams by quartering using a riffle splitter. Visual inspection confirmed no large mica was present after quartering.

➢ The crucible was cleaned, weighed and recorded to the nearest 0.01 gram.

➢ The sample was placed in the crucible and the weight of the sample and crucible determined to the nearest 0.01 gram.

➢ The temperature of the oven reached 1000^0C ($\pm 50^0C$) before placing the crucible in it.

➢ The sample was allowed to remain in the oven at 1000^0C ($\pm 50^0C$) for 45 minutes.

➢ The crucible was removed from the oven and placed in the dessicator to cool until it reaches room temperature before it was weighed again.

➢ The crucible and sample was weighed and recorded to the nearest 0.01 gram.

Calculate the loss on ignition as:

Loss (L) = mass (grams) of crucible and sample prior to ignition − mass of crucible and sample after ignition

Calculate the % ignition loss for the material passing the 2-mm sieve as:

% Ig = (P x L)/ M X 100

Where:

P = percentage of material above the 75-µm sieve. This corresponds to the percentage of total sand in the material passing the 2-mm sieve on the soil test report.

L = loss on ignition (grams).

M = mass of sample prior to ignition. This procedure calculates the % ignition loss as a percentage of the material passing the 2-mm sieve. If the % ignition loss of the sample as a whole is desired, multiply the value for % ignition loss calculated in the

last step (before calculation of loss on ignition) by the percentage of material passing the 2-mm sieve in the sample as a whole.

Calculations

The loss on ignition is calculated as follows:

Wt. of sample = w1

Wt. of crucible = w2

Wt. of crucible and sample after ignition = w3

Wt . of crucible and sample prior to ignition = 195.33 grams

Weight of dish after ignition – Weight of sample before ignition X   100
Weight of sample

3.14 SOIL ORGANIC MATTER:

➤ The mass of an empty and dry porcelain dish was determined and recorded as Mp

➤ 10g of the soil sample was weighed and dried at 100^oC for 2hours.

➤ The content with the crucible was weighed again after 2hours as Mp_{DS}

➤ The dish was placed in a muffle furnace and the temperature gradually increased to 440^oC for 8hours

➤ The porcelain dish was carefully removed using tongs, allowed to cool to room temperature and the mass of the dish containing the ash was weighed and recorded as Mpa

Calculation

Mass of dry soil (M_D) = Mp_{DS} – Mp

Mass of ashed soil (M_A) = Mpa – Mp

Mass of organic matter Mo = M_D - M_A

% Organic matter content   =   Mo X   100
                              M_D 1

3.15 CATION EXCHANGE CAPACITY (CEC):

CEC expressed as ($cmol_c$/kg) centimoles of charge per kilogramme of dry soil can be estimated from simple routine agronomic (Mehlich 3 or modified Morgan) soil test and therefore can easily be done for large numbers of soils without additional analytical costs.

Calculate

CEC_{sum} from values of Ca, Mg, and K obtained with routine soil test:

For agronomic soil test results in ppm or mg/dm3

$CEC_{sum}(meq/100g$ or $cmol_c/kg) = (ppm\ Ca/200) + (ppm\ Mg/120) + (ppm\ K/390)$

3.15.1 Determination of Base saturation:

The values of the summation of Calcium, Potassium, Magnesium and Sodium all in $cMol_c/Kg$ multiplied by 100 and divided by Cation Exchange Capacity in % gives Base Saturation

$Base\ Saturation = \dfrac{\sum(Ca + K + Mg + Na)\ cMol/Kg\ X\ 100}{(CEC)\ \%}$

3.16 COMPACTION TEST: STANDARD METHOD; AASHTO T 99

3.16.1 Apparatus:

- Rubber hammer
- Rattle box
- 19mm Sieve

3.16.2 Summary of Procedure:

This procedure determines the moisture-density relationship of soils and soil-aggregate mixtures. It is sometimes referred to as the standard proctor or the modified proctor test. A quantity of soil or soil and aggregate mixture is prepared at determinable moisture content and compacted in a standard mould using a manual or mechanical rammer. The wet mass of this compacted sample is divided by the volume of the mould to determine the wet density. Moisture content testing on the material from the compacted mass is used to determine the dry density of this material. This procedure is repeated at varied moisture contents and the results are plotted on a graph. A smooth line is drawn through the points to obtain a curve. The maximum density and optimum moisture content are determined by selecting a point at the peak of the curve.

3.16.3 Detailed Steps:

I.   Sample was air dried; hence in this case air dried sample is preferred. However sample collected from the site is spread on the tray and allowed to dry for 24 hours.

Plate 15 showing dislodging of sample using rubber hammer

II. The sample was passed through 19mm sieve: the air dried sample was then sieved through the 19mm and the portion that passes the sieve was used for the next step.

Plate 16 showing 19mm sieve used to sieve sample.

III. The sample was quartered using the raffle box and then divided into four using the raffle box.

Plate 17 showing raffle box used to quarter sample.

IV.   3000g of sample was taken and water was added from 4% upwards till it got to 240g of water and since the density of water is 1g/cm^3, 240cm^3 of water was measured and added to the 3000g of soil sample weighed, thoroughly mixed and the sample was divided into three parts. The first part of the soil sample was put into the mould, given 27 blows per layer using the 2.5kg rammer. Hence the soil sample was compacted into the mould in three layers giving 27 blows per layer, then smooth mould surface using straight edge iron.

Plate 18 and 19: Showing tray and 4.5 & 2.5kg rammer used to mix sample thoroughly.

V.   The weight of mould + sample was weighed and recorded, then sample removed and 2% of water added making it 6%. Note prior to step IV and V above, the volume and weight of mould was known.

VI.   The test was repeated five (5) times and the subsequent weights recorded.

VII.   The wet density, moisture content and dry density was calculated. The mixed sample was put in two tins as to determine the moisture content. In total, the tins were 10.

VIII. Graph of dry density against moisture content was plotted to determine the M.D.D and O.M.C.

Bulk density Ᵽ (kgm⁻³) = *weight of compacted soil*
                                           Volume of soil

Moisture content w (%) = *weight of water in soil* *X 100*
                                              Weight of dry soil

Dry density (kgm⁻³) = _____Ᵽ_____ .
                                           1 + ᵂ/100

Where:

Ᵽ = Bulk density

w = moisture content

3.17 CALIFORNIA BEARING RATIO; CBR (48 HOURS SOAKED)

This covers the determination of the California bearing ratio of a soil which is obtained by measuring the relation between load and penetration when a cylindrical plunger of cross-sectional area 1935-mm^2 is made to penetrate the soil at a given rate. At any value of penetration, the California bearing ration (C.B.R) values are normally quoted for 2.50mm and 5.00mm penetration or average of both. The CBR occur in the range of penetration 1.27 – 5.08mm, the highest value is quoted.

3.17.1 Apparatus:

- CBR machine

3.17.2 Detailed Steps:

After the Optimum Moisture has been determined from compaction test, the result is used to mix the sample for C.B.R test.

I. The sample was air dried.

II. Sample was passed through sieve 19mm.

III. Sample quartered using raffle box

IV. 6000g of soil sample weighed

V. 6000g of sample mixed with O.M.C. as determined by compaction test

VI. Sample mixed thoroughly and then divided into three (3) parts

VII. The mould was filled in 3 layers given each layer 62 blows using then 2.5kg rammer

VIII. Mould was smothered using straight edge iron and soaked for 48 hours

IX. After soaking for 48 hours, mould + sample was placed on the C.B.R machine

X. The dial gauges was set on the machine and then the sample was loaded.

XI. The dial reading was taken after every 30s till the last 6mm penetration of the top

XII. The mould was turned and the bottom loaded. The dial reading was also taken to the last 6mm penetration of the bottom.

Plate 20: Showing the loading of sample by C.B.R machine for top and bottom respectively

XIII. The C.B.R was calculated at 2.5mm and 5.0mm penetration and the average taken. The same was done for the top and bottom, the higher C.B.R value was the C.B.R value for the material.

XIV. A graph of force (load) against penetration was plotted.

$$CBR = \frac{Test\ load\ (force)\ X\ 100}{Standard\ load}$$

Hence for the machine used in this study the CBR is given as follows:

$$CBR_{2.5mm} = \frac{Dial\ Gauge\ Reading\ x\ proof\ ring\ factor\ x\ 100}{1359}$$

$$CBR_{5.0mm} = \frac{Dial\ Gauge\ Reading\ x\ proof\ ring\ factor\ x\ 100}{1359}$$

Proof ring factor = 2.949

3.18 Statistical Analyses:

The results obtained were subjected to Independent student's t-test, Correlation Analysis, Analysis of Variance (ANOVA) and Mulitiple comparism (MANOVA) using SPSS (Version 15.0) statistical software package. Values are taken to be significant at $P < 0.05$.

3.19 Google maps/gps location of study areas in Anambra State:
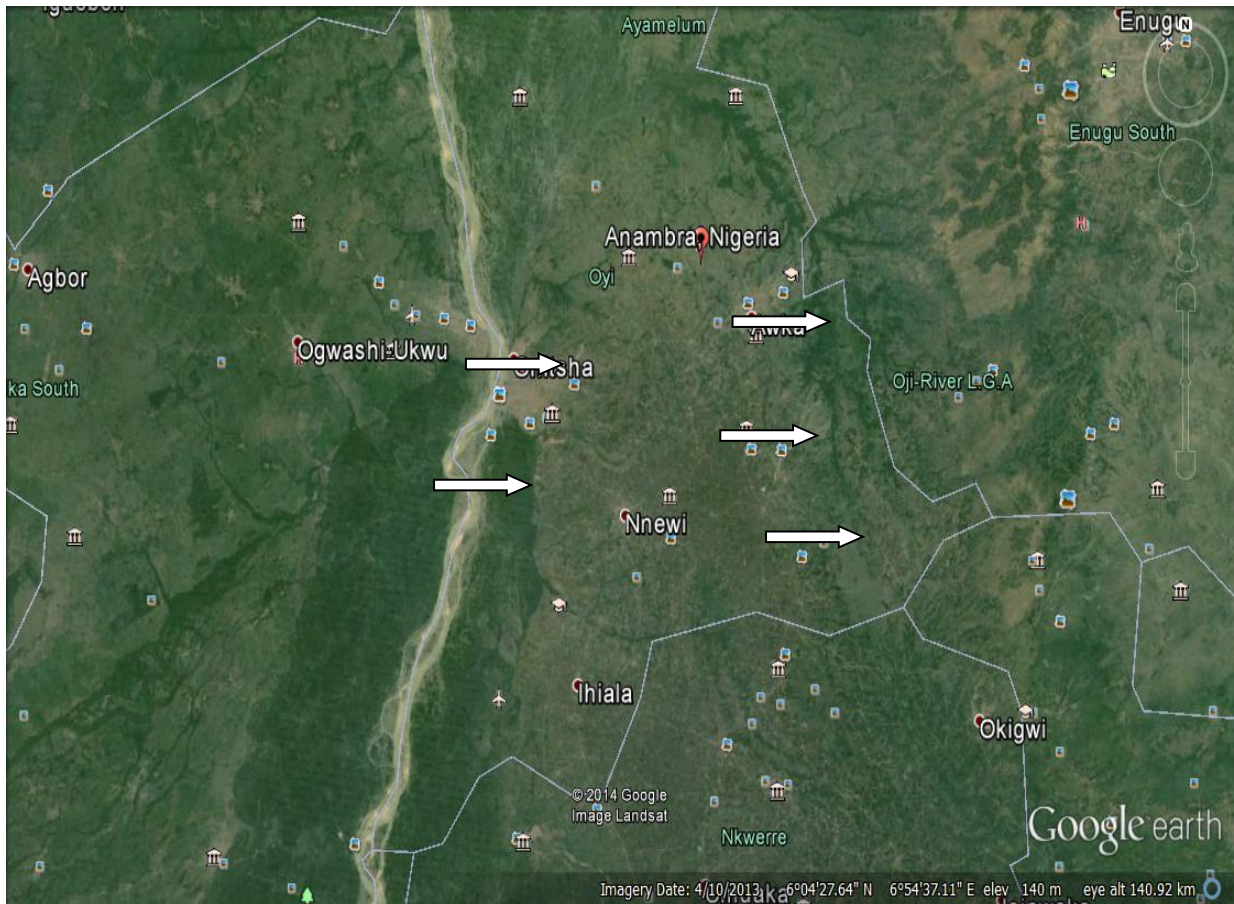
Plate 21: Google map of Anambra state, the study area using google earth. The map shows the locations of the major towns and Local Government Areas in Anambra State. (Google earth search, 2014). Arrows showing study sites.

Plate 22: Google earth map location of Agulu Erosion site (2014)
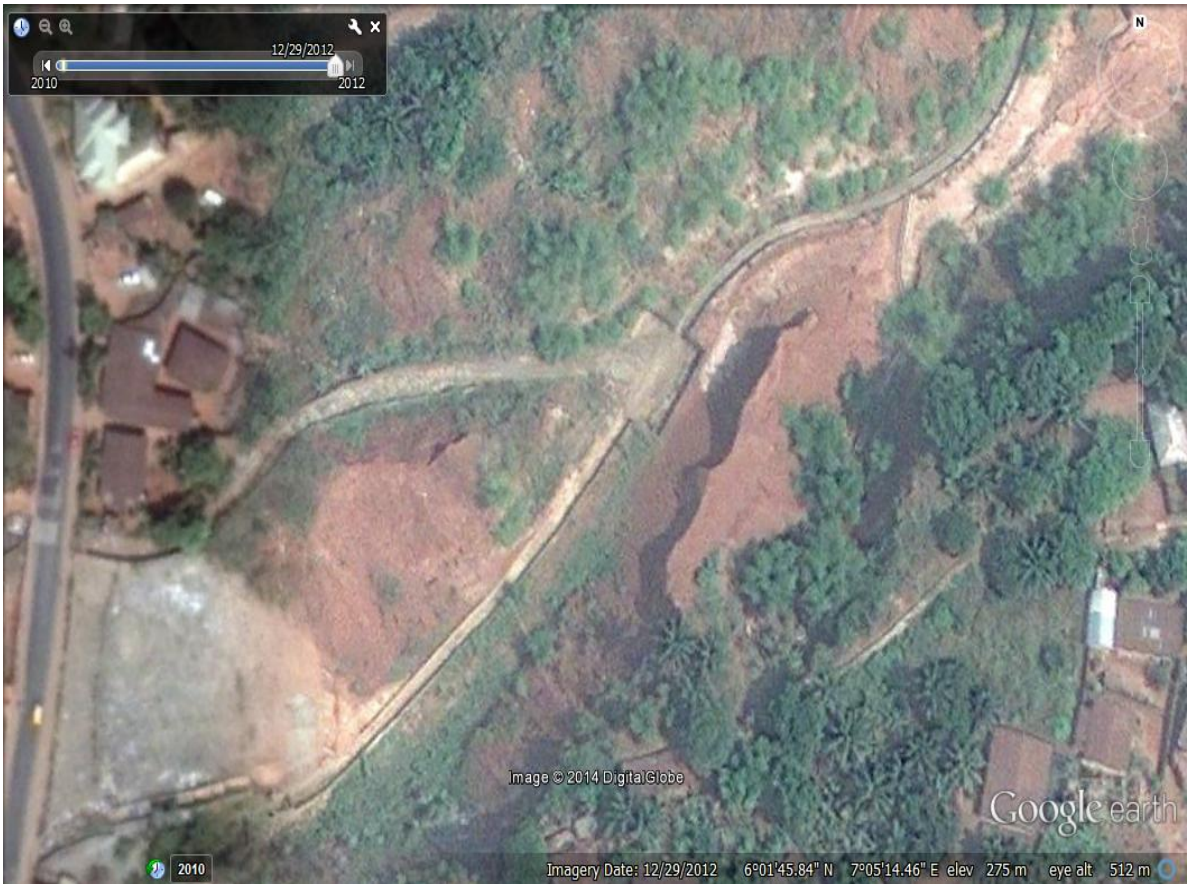
Plate 23a: Google earth map location of Ekwulobia Erosion sites (2014)

Plate 23b: Google earth map location of different views of Ekwulobia Erosion sites (2014)

Plate 24: Google earth map location of Nanka Erosion site (2014)
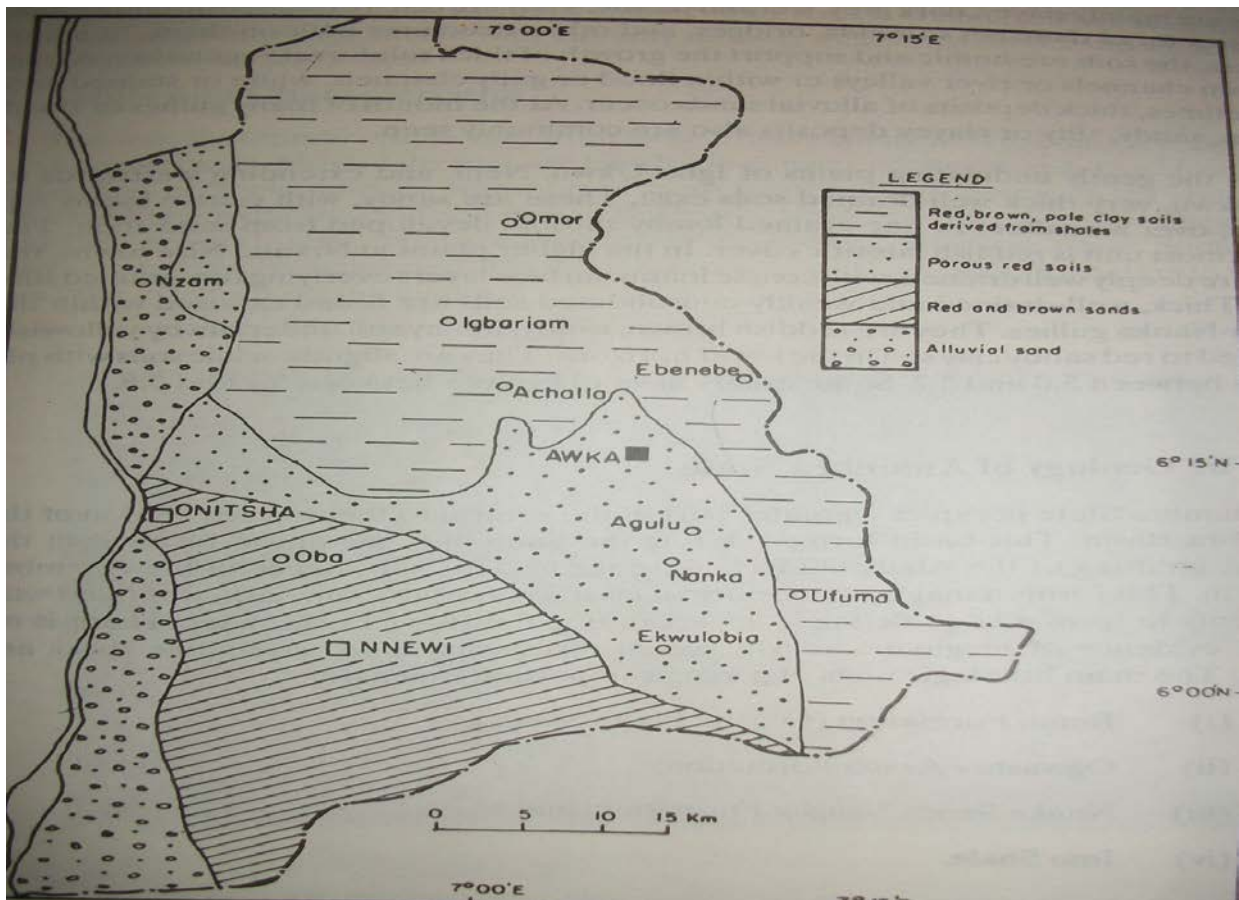
Plate 25: Distribution of soil types in Anambra state
Source: Egboka, (1993)
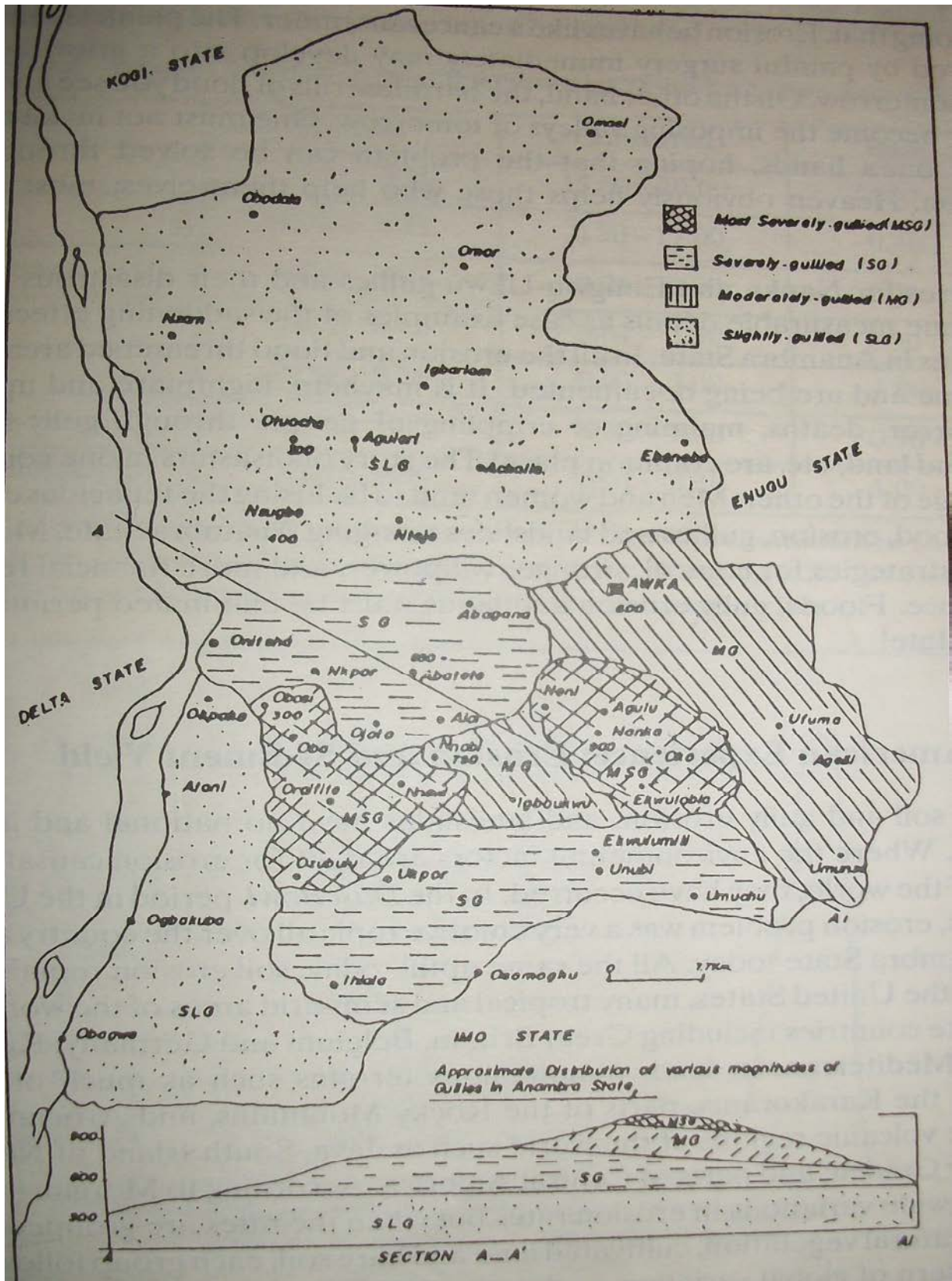
Plate 26: Distribution of various magnitude of gullies in Anambra state
Source: Egboka, (1993)

CHAPTER FOUR

4.0 RESULTS

4.1 CHARACTERIZATION OF SOILS IN ANAMBRA STATE INTO ZONES

Sequel to the geological classification of Anambra State soils according to soil types and various magnitude of gullies, the results of these soil zone profiles were presented thus;

4.1.1 Soil Zone Profile and GPS location:
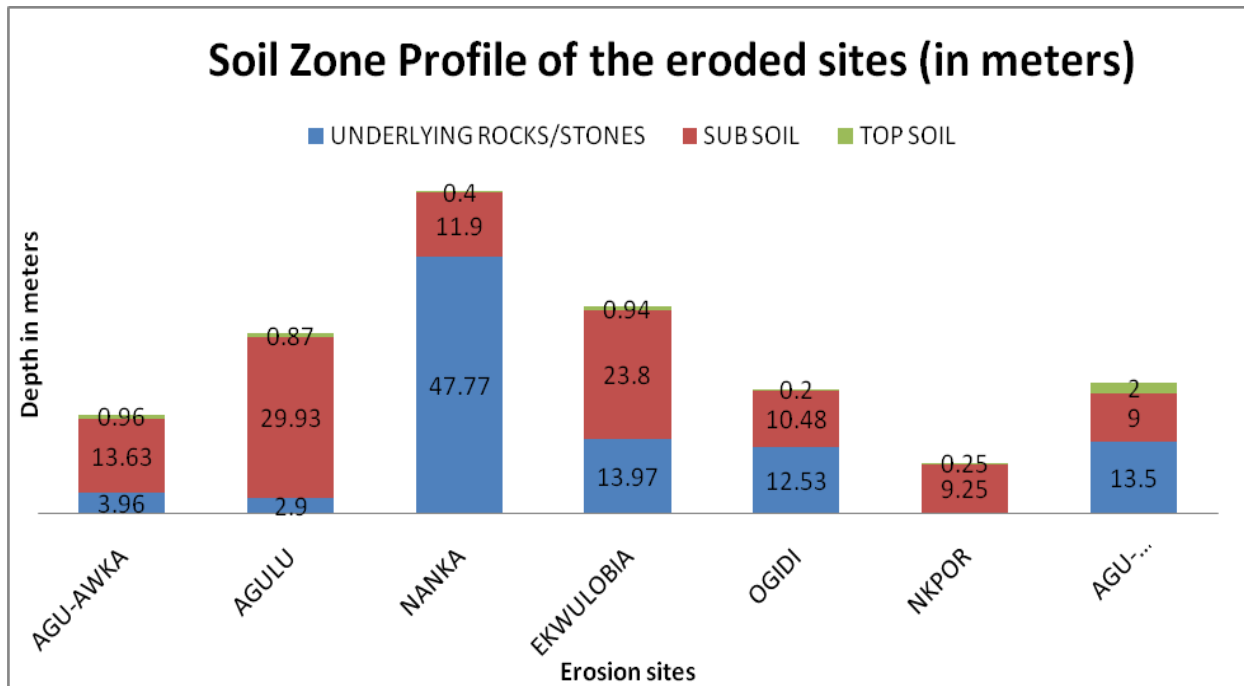
Figure 3: The soil profile of the eroded sites in Anambra state measured in meters. Agu Awka burrow pit is the last bar in the plot represented as AGU-.... Nkpor erosion site has not reached the underlying stones. See (Appendix 1) for the detailed table of values and erosion status for these eroded sites.

Table 2: GPS location of some study sites in Anambra state using GPS instrument.

S/No	GULLY PROFILES	GPS LOCATION	G.E.
1	Agu-Awka	N06^O 13.159/E007^O 05.258'	140M
2	Agulu	N006^O 06.895/E07^O 02.434'	193M
3	Nanka	N06^O 02.654'/E007^O 04.922'	259M
4	Ekwulobia	N06^O 01.761'/E007^O 05.198'	283M
5	Ogidi	N06^O 09.448'/E006^O 51.062'	138M
6	Nkpor	N06^O 08.961'/E006^O 49.166'	102M
7	Agu-Awka(Burrow pit)	N06^O 13.198'/E007^O 05.703'	126M
8	Odekpe (Control)	N06^O 03.445'/E006^O 44.644'	26M
9	Igbariam (Control)	N06^O 15.148'/E006^O 57.00'	106M
10	Alor (Control)	N06^O 05.471'/E006^O 57.351'	151M

Legend: GPS; Global Positioning System   G.E.; Ground Elevation above sea level.
The table above shows the readings obtained from GPS intrument indicative of the erosions sites that were studied as well as the control sites.

4.2 SOIL MORPHOLOGY AND PHYSICAL PROPERTIES:

4.2.1 Relative size of soil particles:

The results of the relative size of soil particles; sand, silt and clay for the top soils, sub soils and underlying stones and rocks were as shown in figure 4 (See Appendix II for details).

The Mean ± SEM value for percentage sand is highest in Idemili zone (91.56 ± 4.85%) decreasing to Control (77.57 ± 0.59%), Awka South zone (76.71 ± 3.81%) to the least Agulu-Nanka zone (74.58 ± 4.97%). When the percentage sand of the zones were compared using oneway ANOVA, an f value of 3.248 and a p value of 0.102 were obtained. At 95% level of significance, there exist no significance difference between the percentage sand of the zones.

The Mean ± SEM value for percentage silt is highest in Awka South zone (10.9 ± 2.4%) decreasing to Agulu-Nanka zone (10.36 ± 4.38%), Control (7.47 ± 4.67%) to the least Idemili zone (5.11 ± 5.01%). When the percentage silt of the zones were compared using oneway ANOVA, an f value of 0.363 and a p value of 0.782 were obtained. At 95% level of significance, there exist no significance difference between the percentage silt of the zones.

The Mean ± SEM value for percentage clay is highest in Agulu-Nanka zone (15.23 ± 4.52%) decreasing to Control (14.96 ± 4.08%), Awka South zone (12.4 ± 6.21%) to the least Idemili zone (3.27 ± 0.83%). When the percentage clay of the zones were compared using oneway ANOVA, an f value of 2.260 and a p value of 0.182 were obtained. At 95% level of significance, there exist no significance difference between the percentage clay of the zones.
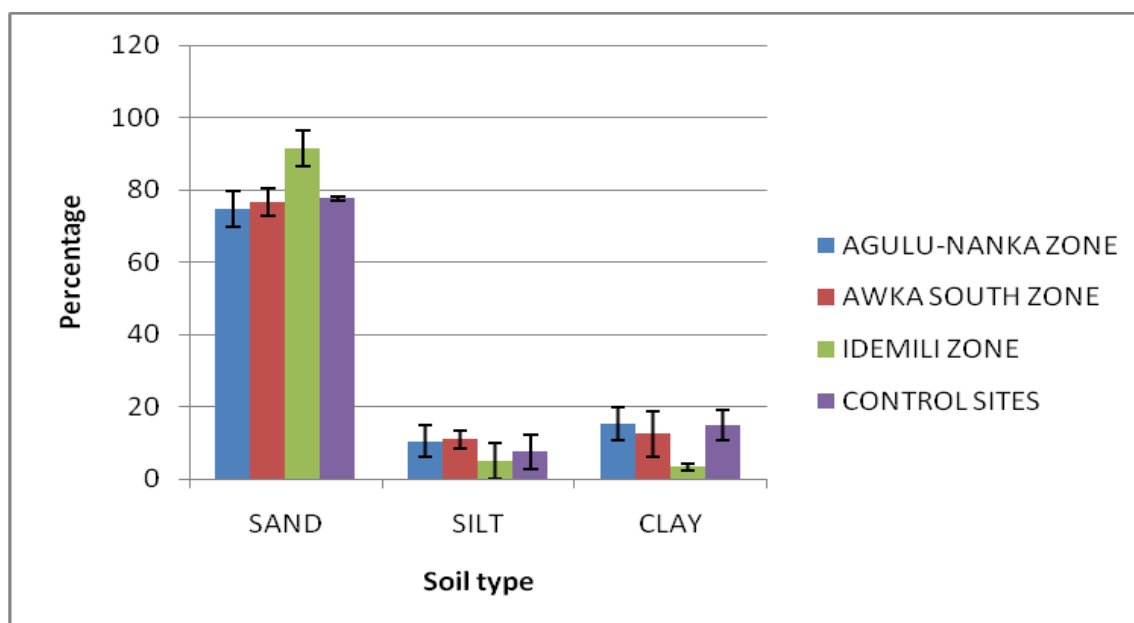
Figure 4: Plot of the Mean ± SEM of the relative size of soil particles of zones measured in percentage.

4.2.2 Soil sedimentation:

Figure 5 shows the plot of the mean ± SEM value of soil sedimentation of the zones for Agulu-Nanka zone (0.12 ± 0.05sec, 0.15 ± 0.08sec, 0.2 ± 0.11sec), Awka South zone (0.14 ± 0.04sec, 0.06 ± 0.05sec, 0.14 ± 0.06sec), Idemili zone (1.27 ± 0.79sec, 1.34 ± 0.77sec, 1.12 ± 0.89sec) and Control (1.22 ± 0.94sec, 0.53 ± 0.39sec, 1.56 ± 1.26sec) for 5seconds, 10seconds and 20seconds respectively (See Appnedix III for detailed soil sedimentation values). When the sedimentation values of the zones were compared using oneway ANOVA, f values of 1.153, 1.467 and 0.846 and p values of 0.402, 0.315 and 0.517 were obtained respectively. At 95% level of significance, there exist no significance difference between the cumulative soil sedimentation values of the zones.
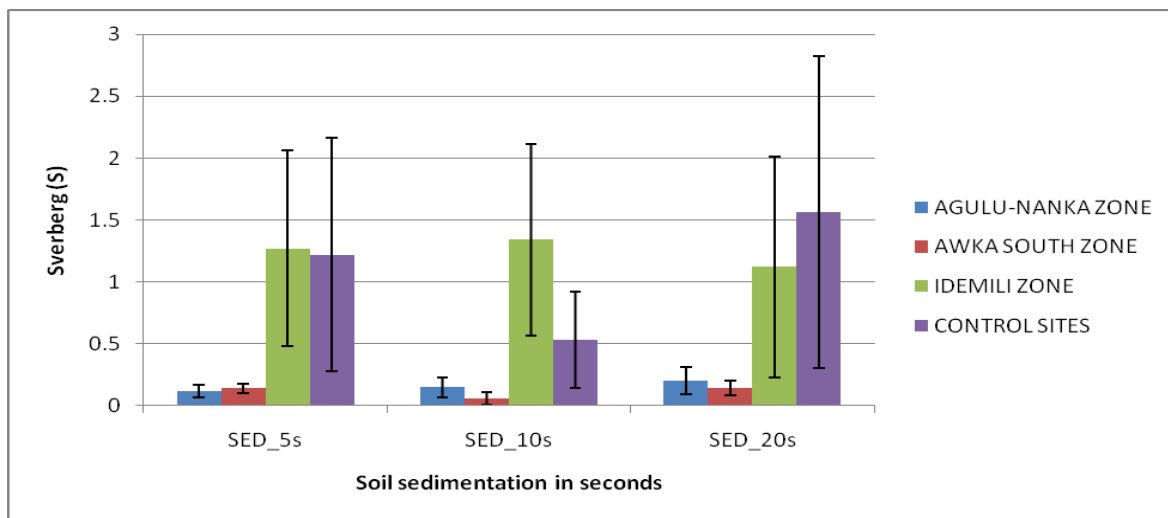
Figure 5: Plot of the Mean ± SEM of soil sedimentation of the zones measured in seconds cumulatively.

4.2.3 Natural moisture and CBR:

Figure 6 shows the plot of the Mean ± SEM value of natural moiture and California Bearing Ratio (CBR) for Agulu-Nanka zone (8.19 ± 0.65%, 40.67 ± 5.36%), Awka South zone (7.08 ± 0.76%, 59.5 ± 13.5%), Idemili zone (7.72 ± 2.86%, 30.67 ± 10.41%) and Control (7.27 ± 0.77%, 47.5 ± 3.5%) respectively. (See Appendix IV for detailed information on natural moiture and CBR tables and Appendix V for CBR detailed plot). From the mean values of the zones above, we observed that the natural moisture content is higher in Agulu-Nanka zone while the CBR value is higher in Awka South zone. When the natural moiture content and the CBR of the zones were compared using oneway ANOVA, f values of 0.068 and 1.744 and p values of 0.975 and 0.257 were obtained respectively. At 95% level of significance, there exist no significant difference between the natural moisture content as well as the CBR values of the zones.
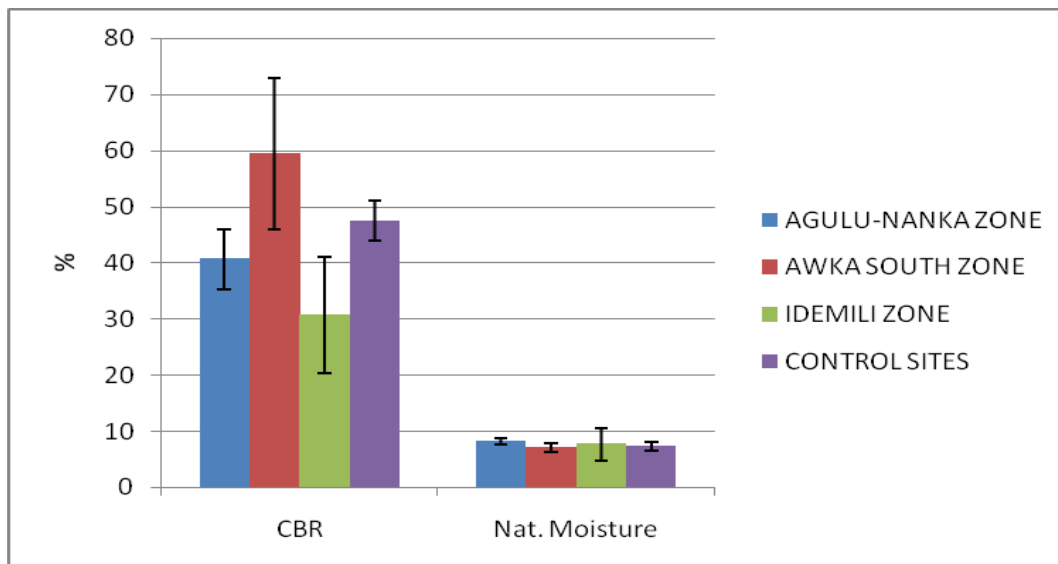
Figure 6: Plot of the Mean ± SEM of the natural moisture content and California Bearing Ratio of the zones measured in percentages.

4.2.4 Soil densities:

The Mean ± SEM values of soil pore densities and bulk densities of the Agulu-Nanka zone $(1.18 \pm 0.1 \text{g/cm}^3, 1.08 \pm 0.02 \text{g/cm}^3)$, Awka South zone $(1.29 \pm 0.01 \text{g/cm}^3, 1.23 \pm 0.02 \text{g/cm}^3)$, Idemili zone $(1.13 \pm 0.02 \text{g/cm}^3, 1.24 \pm 0.04 \text{ g/cm}^3)$ and Control $(0.98 \pm 0.13 \text{g/cm}^3, 1 \pm 0.04 \text{g/cm}^3)$ respectively were as shown in figure 7 (See Appendix VI for details). The values of the pore density from the Awka South zones were slightly higher while in bulk density, the value of Idemili zone is higher. When the pore density and bulk density of the zones were compared using oneway ANOVA, f values of 1.915 and 13.492 and p values of 0.228 and 0.004 were obtained respectively. At 95% level of significance, there exist no significant difference between the pore density of the zones but there exist a high significant difference between the bulk density values of the zones.
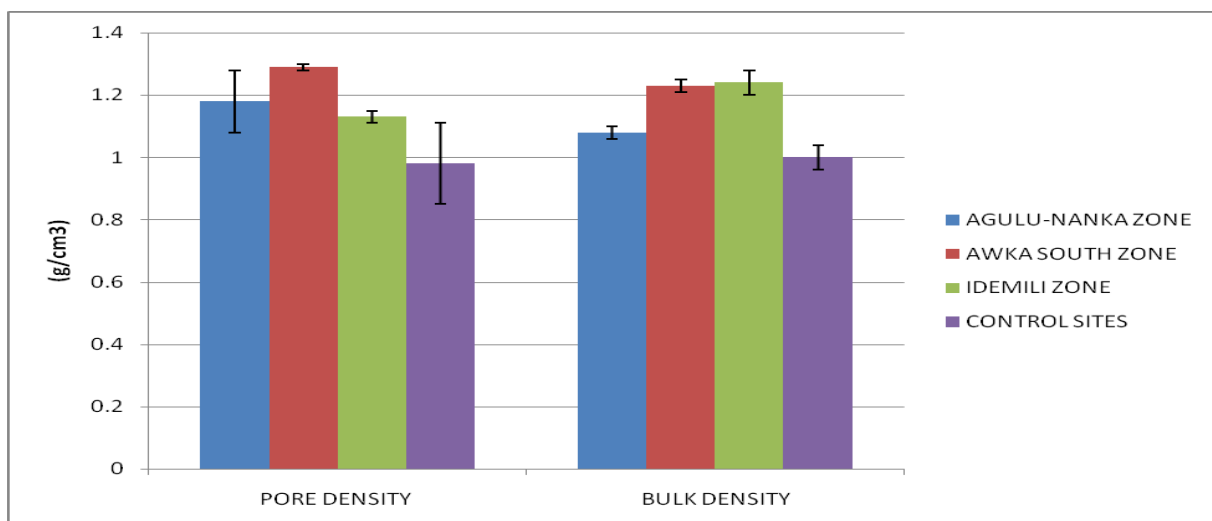

Figure 7: Plot of the Mean ± SEM of the pore density and bulk density of the zones.

4.2.5 Porosity:

Figure 8 shows the Mean ± SEM of the soil porosity of the Agulu-Nanka zone (0.16 ± 0.01), Awka South zone (0.15 ± 0.02), Idemili zone (0.18 ± 0.03) and Control (0.17 ± 0.03). From the plot, we will observe that the values of the porosity of the Idemili zone is slightly higher than the rest of the zones (See Appendix VII for details). When the porosity of the zones were compared using oneway ANOVA, an f value of 0.310 and p value of 0.818 were obtained. At 95% level of significance, there exist no significant difference between the porosity of the zones.
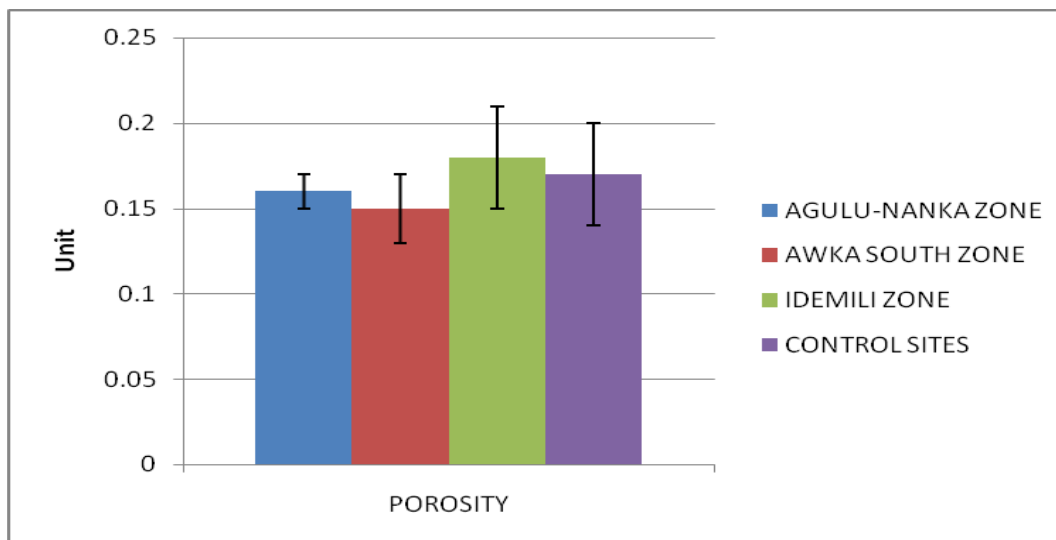

Figure 8: Plot of the Mean ± SEM of the Porosity of the zones.

4.2.6 Compaction:

The Mean ± SEM plot of the compaction values; MDD (Maximum Dry Density in kg/m^3) and OMC (Optimum Moisture Content in %) of the zones; Agulu-Nanka (1.92 ± 0.05g/cm^3, 11.54 ± 1.16%), Awka South (1.90 ± 0.04g/cm^3, 11.76 ± 0.06%), Idemili (1.97 ± 0.05g/cm^3) and Control (1.76 ± 0.11g/cm^3, 15.76 ± 3.6%) were plotted from the results as shown in Figure 9 below (See Appendix VIII for details of both MDD and OMC). When the Compaction_MDD and Compaction_OMC of the zones were compared using oneway ANOVA, f values of 1.880 and 0.779 and p values of 0.234 and 0.547 were obtained respectively. At 95% level of significance, there exist no significant difference between the Compaction_MDD as well as the Compaction_OMC values of the zones.
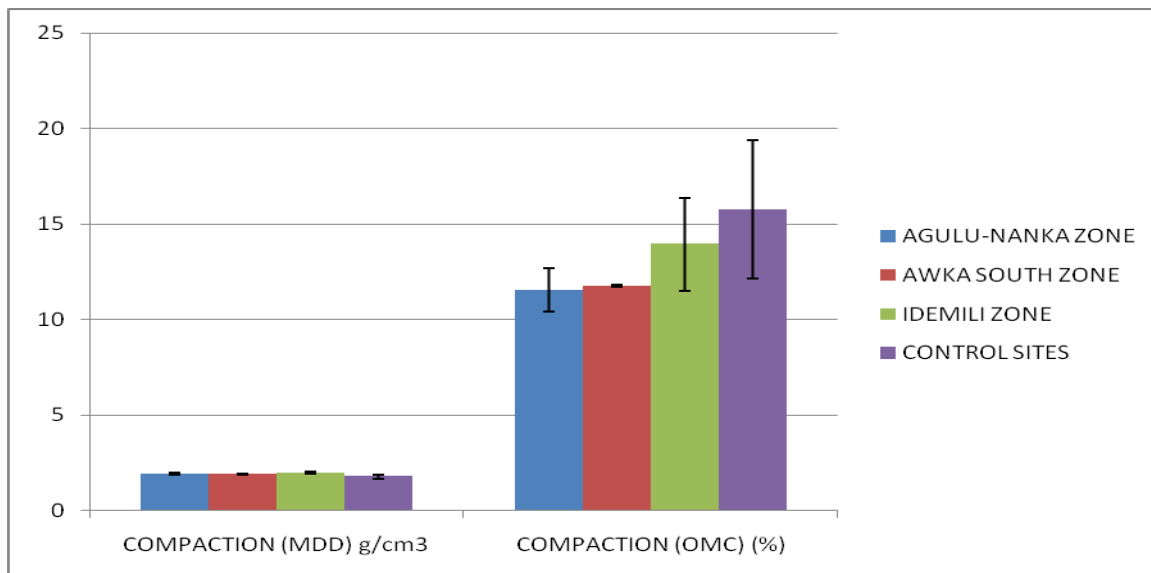
Figure 9: Plot of Mean ± SEM values for COMPACTION_MDD and COMPACTION_OMC for soil zones.

4.3 SOIL PHYSICOCHEMICAL PROPERTIES

4.3.1 Soil percolation:

Figure 10 shows the plot of the Mean ± SEM value of soil percolation of zones; Agulu-Nanka (462.11 ± 304.22sec), Awka South (214.5 ± 178.17sec), Idemili (551.67 ± 174.33sec) and Control (1043 ± 837sec). The results suggest that the values of the control are higher than the rest of the zones (See Appendix IX for details). When the percolation of the zones were compared using oneway ANOVA, f value of 0.667 and p values of 0.603 were obtained. At 95% level of significance, there exist no significant difference between the porosity of the zones.
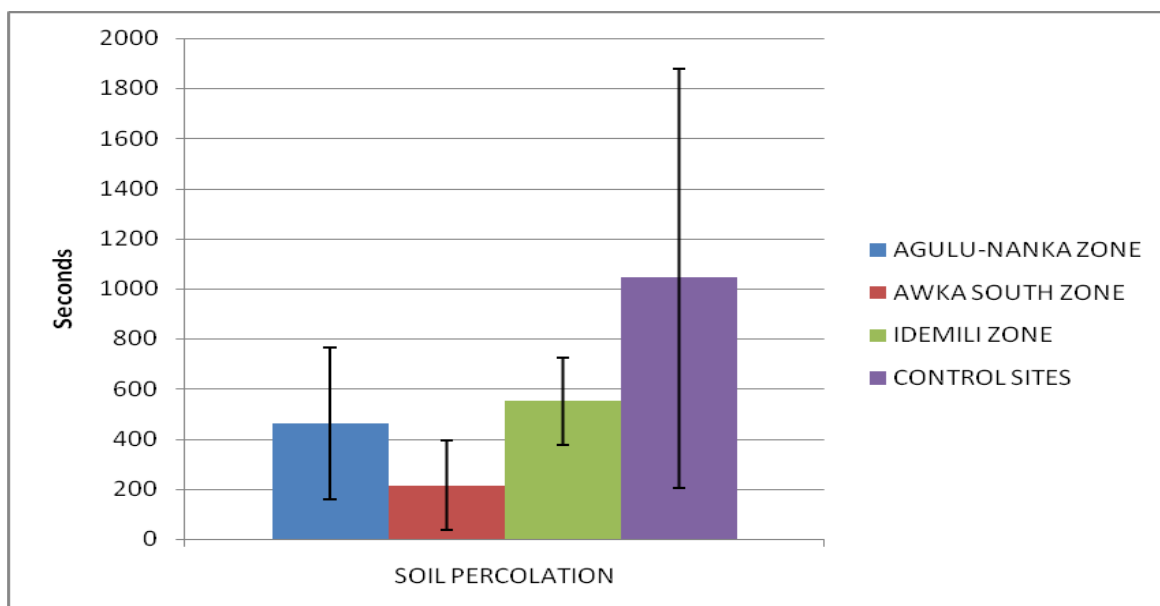

Figure 10: Plot of Mean ± SEM values for soil percolation of the zones

4.3.2 Soil temperature:

The Mean ± SEM values of soil temperatures of area under the sun were taken at the shoulder level, surface level, 2", 4" and 6" into the soils depths at different zones respectively thus; Agulu-Nanka (34.67 ± 1.76 °C, 32 ± 4.16 °C, 29.33 ± 2.91 °C, 28.67 ± 2.91 °C, 27 ± 2.89°C), Awka South (35 ± 1°C, 36 ± 2 °C, 34 ± 0 °C, 32.5 ± 0.5 °C, 31 ± 1°C), Idemili (33.33 ± 1.45°C, 34.67 ± 1.76 °C, 31.33 ± 0.67 °C, 30 ± 0 °C, 29.33 ± 0.67°C), and Control (36 ± 0°C, 37 ± 1 °C, 34 ± 2 °C, 31 ± 1 °C, 30 ± 0 °C) were as shown in Figure 11a while that of soil temperatures of area under the shade were taken too at the shoulder level, surface level, 2", 4" and 6" into the soils depths Agulu-Nanka (32 ± 1.15 °C, 31.33 ± 1.76 °C, 31.33 ± 2.9°C, 30.67 ± 2.4 °C, 28.67 ± 2.4°C), Awka South (34 ± 2 °C, 33.5 ± 0.5 °C, 34 ± 2 °C, 33 ± 1 °C, 32 ± 0°C), Idemili (31.33 ± 1.33 °C, 30.33 ± 0.33 °C, 28.33 ± 0.33 °C, 28 ± 0 °C, 28.67 ± 0.88°C), and Control (34 ± 0°C, 33 ± 1 °C, 30 ± 0 °C, 29 ± 1 °C, 28 ± 0 °C) were as shown in figure 11b (See Appendix X for details). When the temperature of the different depths of the soils of area under the sun and area under the shade in the zones were compared using oneway ANOVA, at 95% level of significance, there exist no significant difference between the temperature of the different depths of these zones.
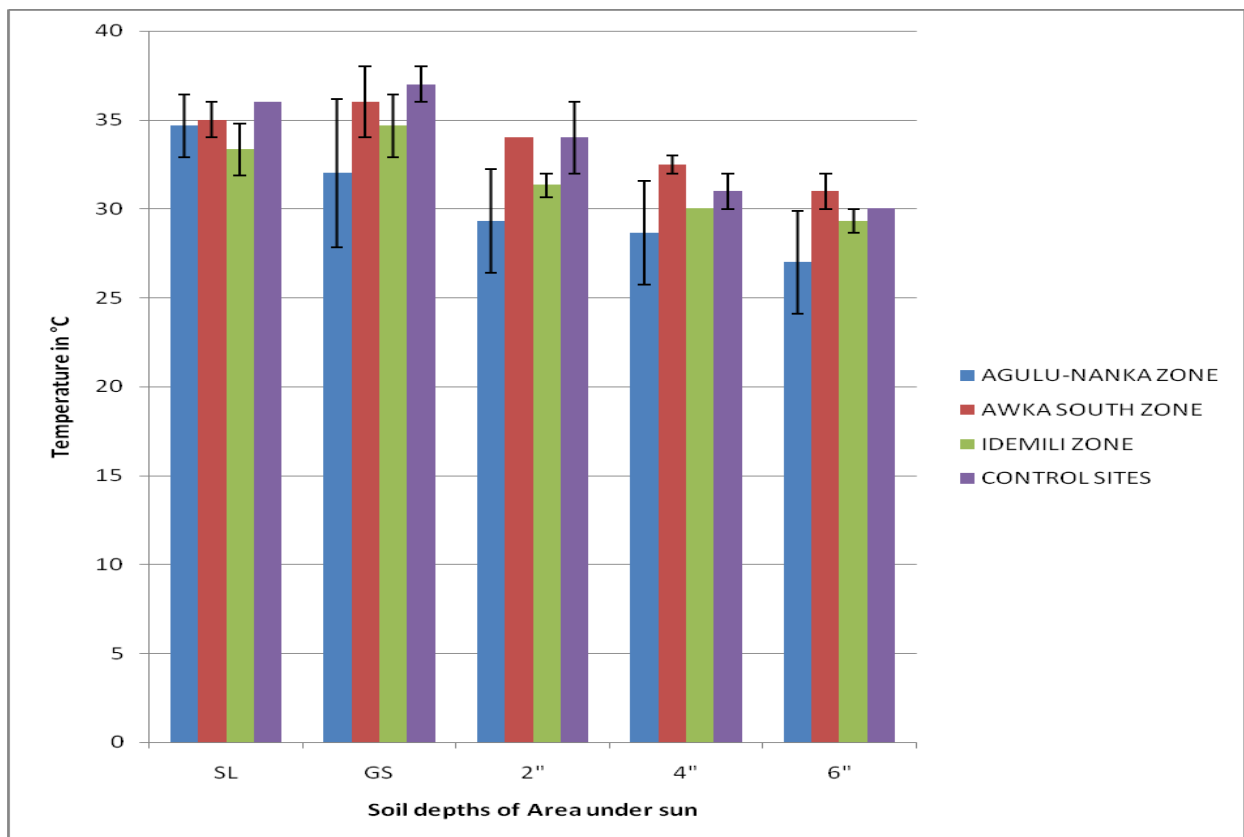

Figure 11a: Shows soil temperature of area under the sun at different soil depths of the zones.
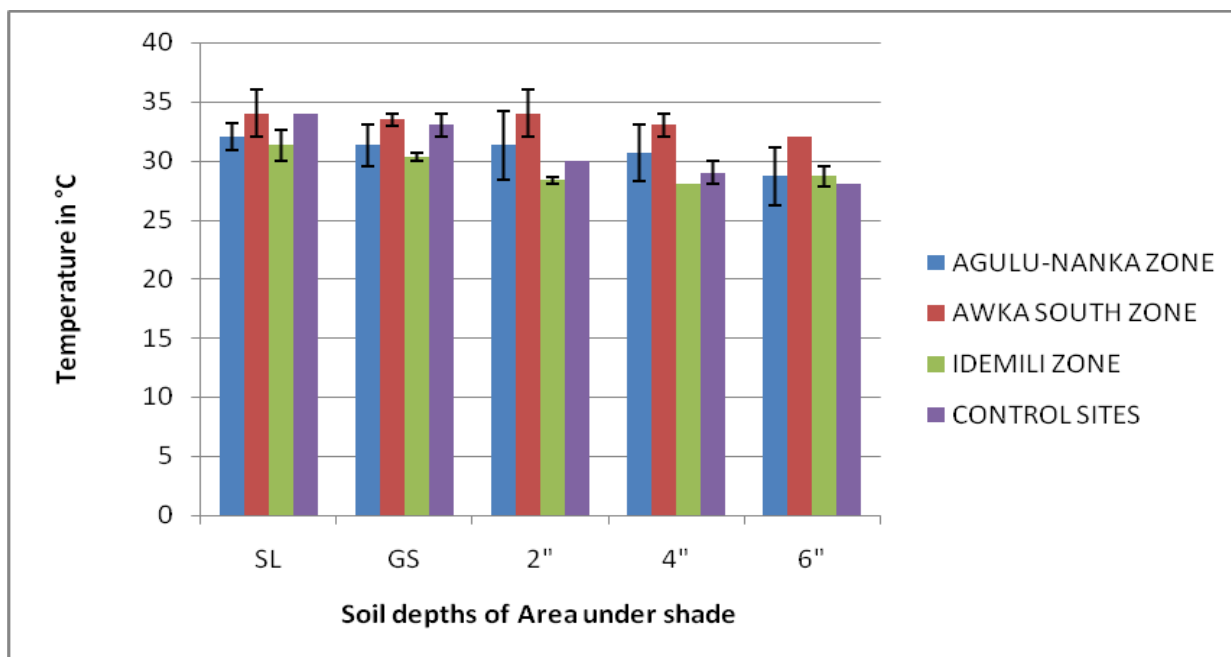
Figure 11b: Shows soil temperature of area under the shade at different soil depths of the zones.

4.3.3 pH value of soils:

The results of the pH of the soil zones and horizonation are shown in figure 12 (See Appendix XI for details). The Mean ± SEM value for Agulu Nanka zone (6.88 ± 0.11), Awka South zone (6.78 ± 0.23), Idemili (7.18 ± 0.33) and Control (7.2 ± 0.1). The Agulu-Nanka and Awka South zones have pH tilt to acidic (low) but all still are within the neutral pH range. When the pH of the zones were compared using oneway ANOVA, f value of 0.753 and p values of 0.560 were obtained. At 95% level of significance, there exist no significant difference between the pH values of the zones.
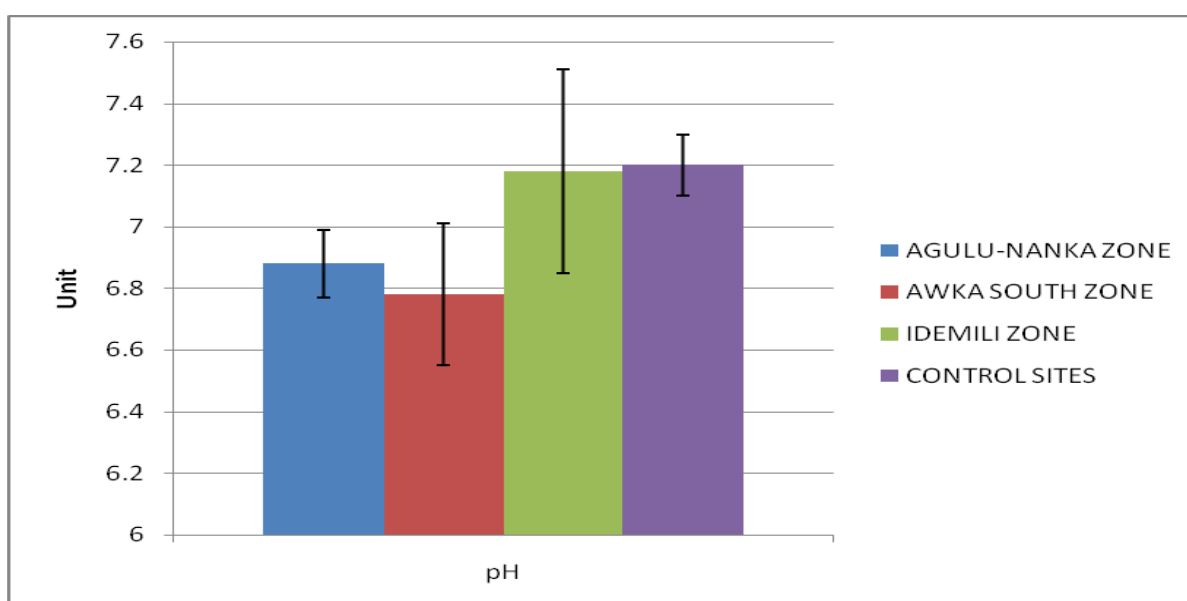

Figure 12: Plot of Mean ± SEM values for soil pH of the zones.

4.3.4 Soil resistivity:

The results of the soil resistivity (which is the inverse of soil conductivity) of the zones are shown in Figure 13 (See Appendix XII for details). The Mean ± SEM value for the zones; Agulu-Nanka (0.02 ± 0.01cm/µs), Awka South (0.02 ± 0.02cm/µs), Idemili (0.02 ± 0.02cm/µs) and Control (0.1 ± 0.01cm/µs). The results indicates that the conductivity of the control is lower when compared with the value of the other zones. When the resistivity of the zones were compared using oneway ANOVA, f value of 3.024 and p values of 0.115 were obtained. At 95% level of significance, there exist no significant difference between the resistivity of the zones.
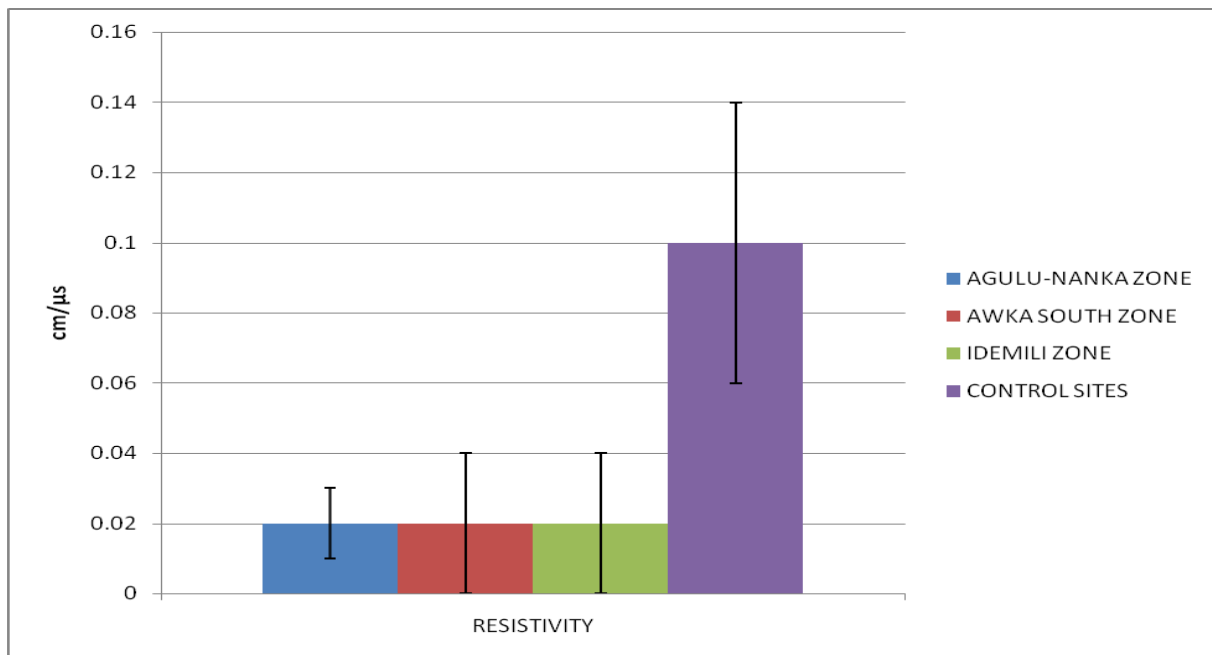

Figure 13: Plot of the Mean ± SEM of soil resisitivity of the zones.

4.3.5 Soil Organic Matter (SOM) and Loss on Ignition (LOI):

Figure 14 shows the plot of the Mean ± SEM value of Soil Organic Matter (SOM) and Percentage Loss on Ignition (LOI) of the zones; Agulu-Nanka (6.67 ± 3.71%, 49.17 ± 4.88%), Awka South (4 ± 2%, 20 ± 19%), Idemili (8.27 ± 5.94%, 27.5 ± 11.51%) and Control (3 ± 1%, 10 ± 5%) respectively (See Appendix XIII for detailed information on SOM and Appendix XIV for LOI data). From the mean values above, we observed that Idemili zone has higher SOM while LOI is higher in Agulu-Nanka zone. When the SOM and LOI of the zones were compared using oneway ANOVA, f values of 0.280 and 2.468 and p values of 0.838 and 0.16 were obtained respectively. At 95% level of significance, there exist no significant difference between the SOM and LOI values of the zones.
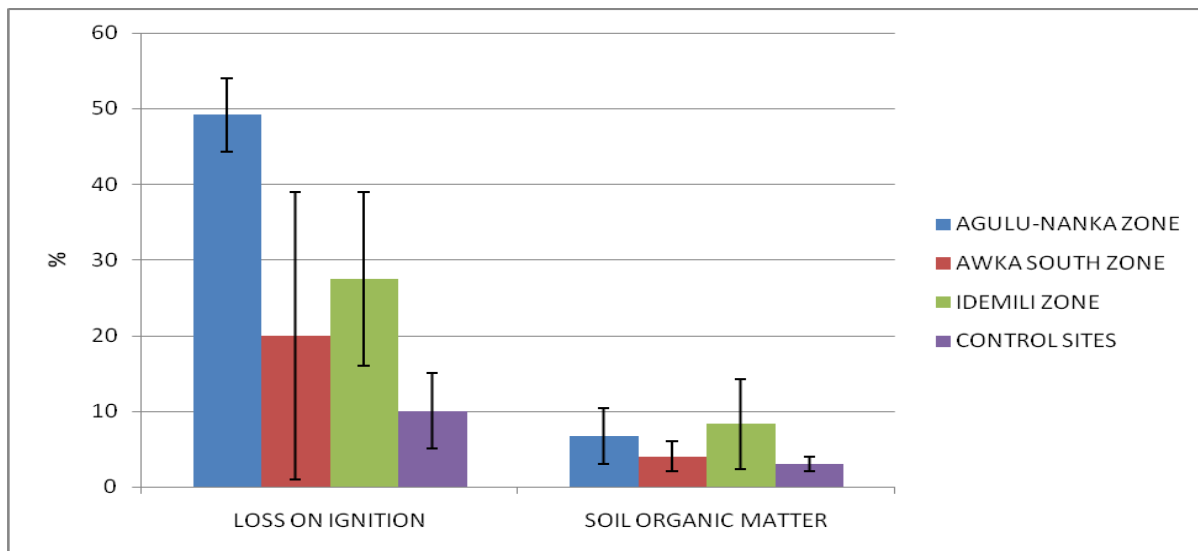
Figure 14: Plot of the Mean ± SEM of SOM and LOI of the zones.

4.3.6 Cation Exchange Capacity (CEC):

Figure 15 shows the plot of the Mean ± SEM value of CEC of the zones; Agulu-Nanka (1.77 ± 0.31cmol/kg), Awka South (0.25 ± 0.04cmol/kg), Idemili (7.91 ± 6.69cmol/kg) and Control (0.24 ± 0cmol/kg). The results suggest that the values of Idemili zone are higher than the other zones (See Appendix XV for details). When the CEC of the zones were compared using oneway ANOVA, f value of 0.799 and p values of 0.538 were obtained. At 95% level of significance, there exist no significant difference between the CEC of the zones.
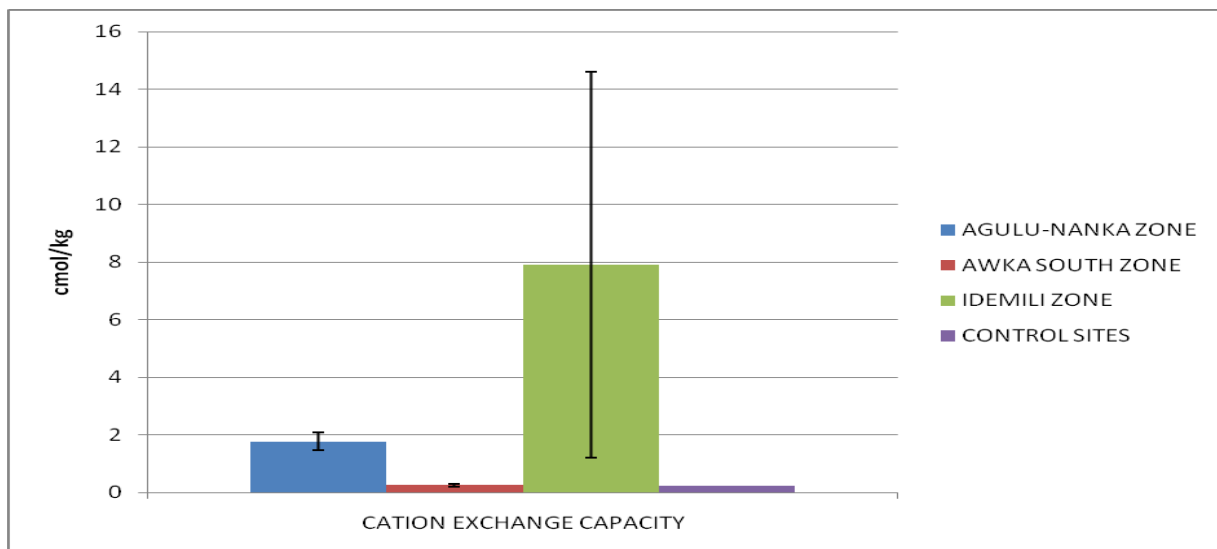

Figure 15: Plot of the Mean ± SEM of CEC of the zones.

4.3.7 Base Saturation:

The results of the base saturation of the zones are shown in figure 16 (See Appendix XVI for details). The mean ± SEM value for these zones were; Agulu-Nanka (101.44 ± 1.25%), Awka South (108.58 ± 1.79%), Idemili (100.17 ± 0.08%) and Control (101.83 ± 0.03%) and Awka

South Zone showed higher in Base Saturation when compared with the value of the other zones. When the base saturation of the zones were compared using oneway ANOVA, f value of 0.11.729 and p values of 0.006 were obtained. At 95% level of significance, there exist high significant (P< 0.01) difference between the base saturation of the zones.
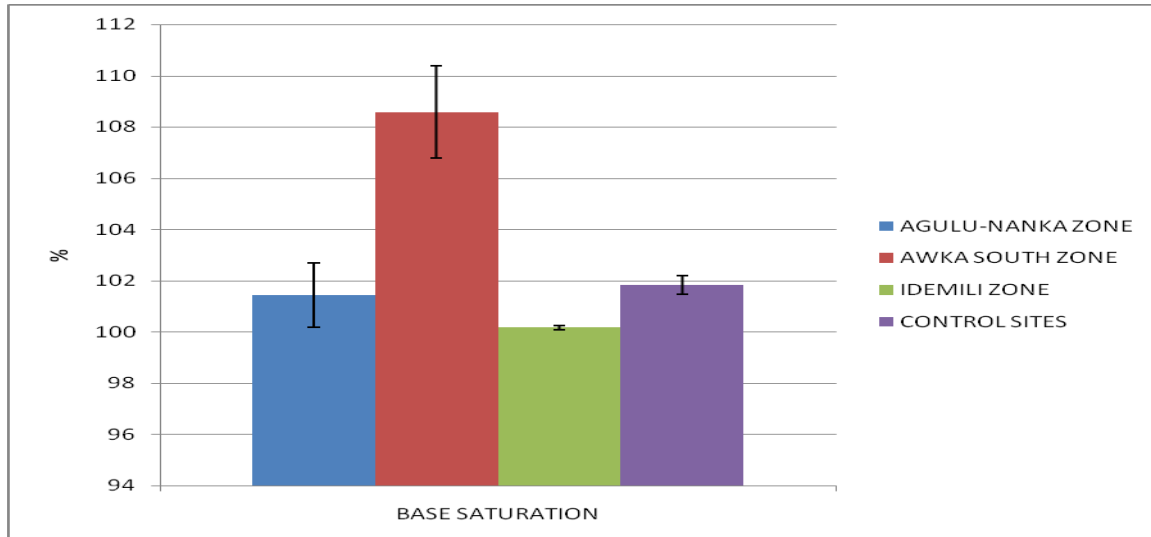
Figure 16: Plot of the Mean ± SEM of base saturation of the zones.

4.3.8 Soil Rheology:

The results of the soil rheology of the zones were shown in figure 17 (See Appendix XVII for details). The mean ± SEM value for the zones; Agulu-Nanka (0.09 ± 0.004pa.s), Awka South (0.44 ± 0.36pa.s), Idemili (0.08 ± 0.01pa.s) and Control (0.08 ± 0.002pa.s). Awka South zone showed the highest rheology when compared to the other zones. When the rheology of the zones were compared using oneway ANOVA, f value of 1.579 and p values of 0.29 were obtained. At 95% level of significance, there exist no significant difference between the rheology of the zones.
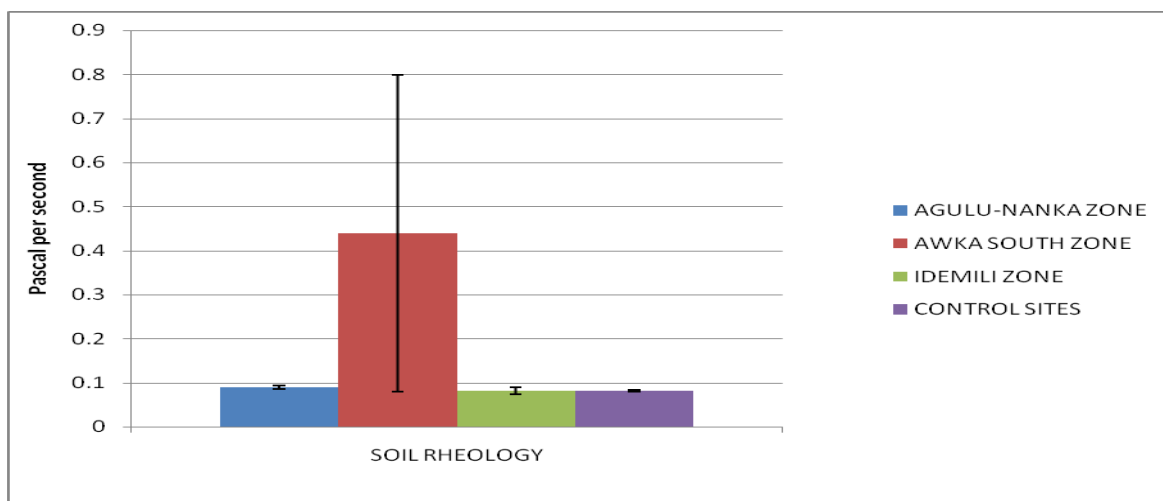
Figure 17: Plot of the Mean ± SEM of soil rheology for the zones.

4.4 SOIL MINERALS

4.4.1 Essential elements:

The results of the essential elements were as presented in figures 18 and 19. The Mean ± SEM values of these elements (sodium, calcium, magnesium and potassium) for the zones; Agulu-Nanka (404.83 ± 70.82ppm, 3.58 ± 2.77ppm, 4.15 ± 1.21ppm, 0.08 ± 0.05ppm), Awka South (38.1± 6.63ppm, 4.38 ± 1.65ppm, 5.84 ± 2.46ppm, 7.72 ± 2.68ppm), Idemili (332.9 ± 142.75ppm, 0.77 ± 0.37ppm, 5.84 ± 2.48ppm, 5.05 ± 1.69ppm) and Control (13.79 ± 5.89ppm, 0.89 ± 0.16ppm, 13.79 ± 5.89ppm, 9.04 ± 0.44ppm) respectively (See Appendix XVIII for details of the values of these essential elements). When the essential elements (sodium, calcium, magnesium and potassium) of the zones were compared using oneway ANOVA, f values of (3.810, 0.935, 7.531 and 1.934) and and p values of (0.077, 0.480, 0.019 and 0.225) were obtained respectively. At 95% level of significance, there exist no significant difference between the esential elements of the zones but there is a significant difference between the magnesium of the zones.
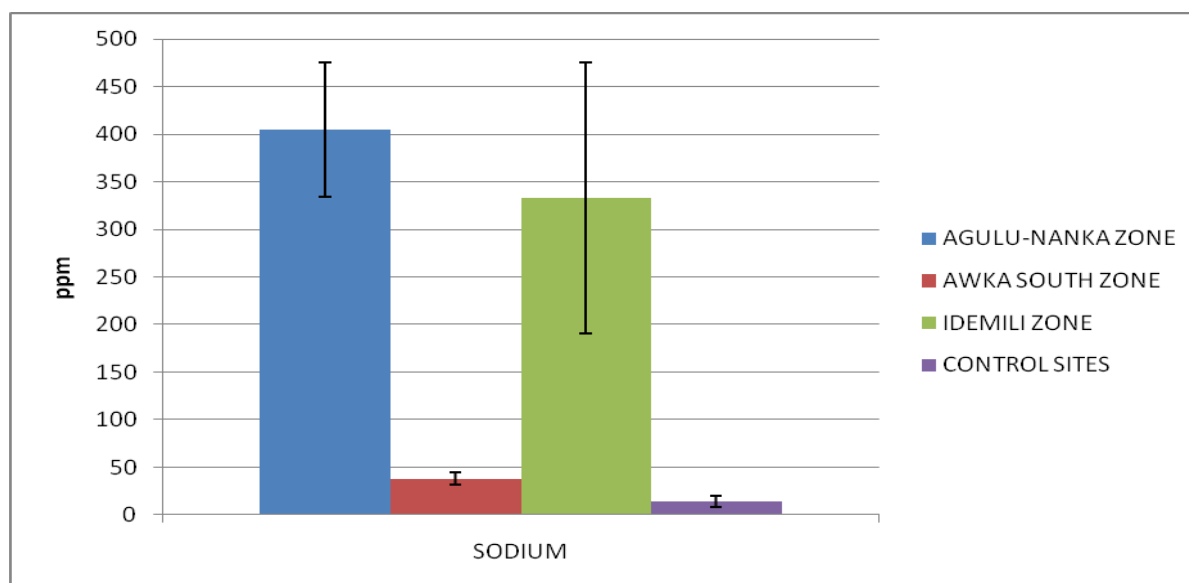
Figure 18: Mean ± SEM of sodium for the zones.
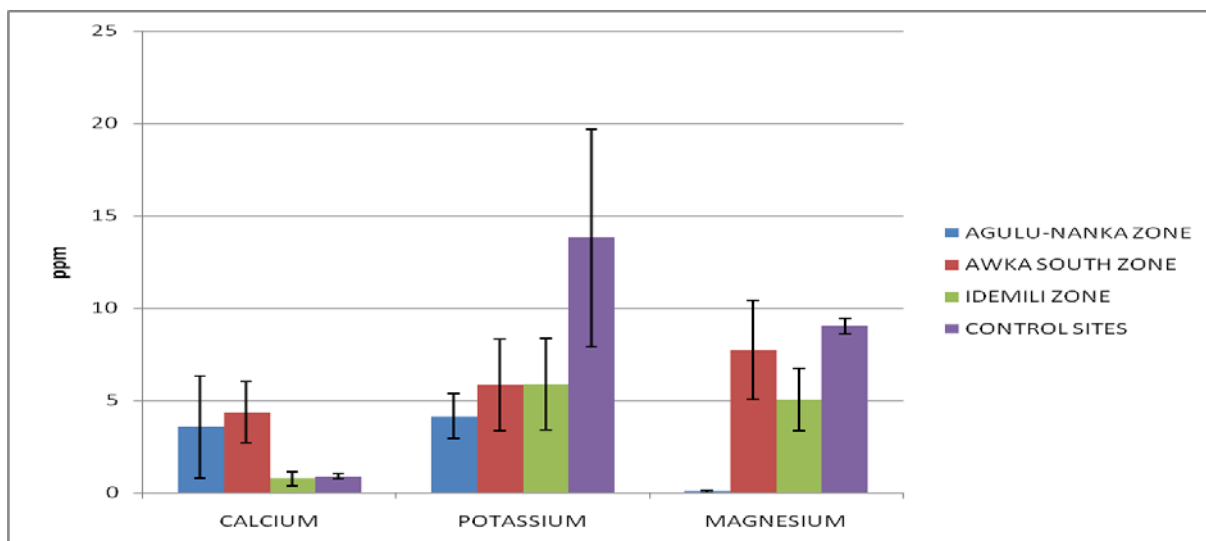
Figure 19: Mean ± SEM of calcium, potassium and magnesium for the zones.

4.4.2 Trace elements:

The Mean ± SEM values of these trace elements (copper, zinc, manganese and cobalt) for the zones; Agulu-Nanka (3.11 ± 0.22ppm, 107.61 ± 4.75ppm, 0.67 ± 0.67ppm, 0.19 ± 0.01ppm), Awka South (18.33 ± 13ppm, 103.56 ± 59.55ppm, 11 ± 3ppm, 0.17 ± 0.03ppm), Idemili (11.11 ± 4.7ppm, 77.56 ± 20.25ppm, 2.67 ± 2.67ppm, 0.07 ± 0.07ppm) and Control (20.67 ± 4.76ppm, 11.96 ± 4.95ppm, 16 ± 16ppm, 0.19 ± 0.07ppm) respectively.. Figures 20 and 21 depict the graphical representation of the Mean ± SEM of the trace elements (See Appendix XIX for details of the values of these trace elements). When the trace elements (copper, zinc, manganese and cobalt) of the zones were compared using oneway ANOVA, f values of (1.826, 2.6, 1.276 and 1.506) and and p values of (0.243, 0.147, 0.364 and 0.306) were obtained respectively. At 95% level of significance, there exist no significant difference between the trace elements of the zones.
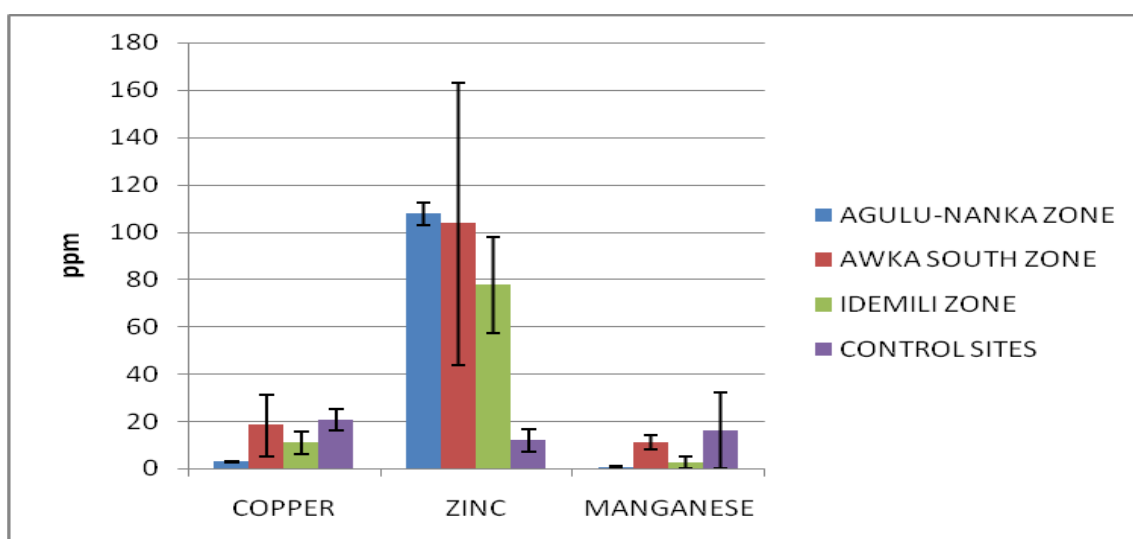
Figure 20: Mean ± SEM of zinc, copper and manganese for the zones.
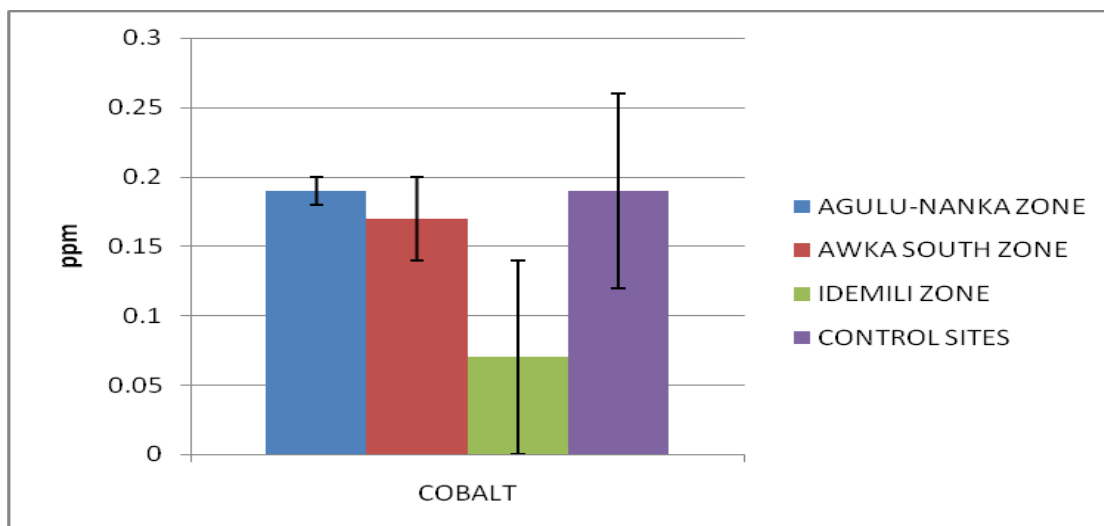
Figure 21: Mean ± SEM of Cobalt for the zones.

4.4.3 Heavy metals:

Figures 22 and 23 shows the plot of the Mean ± SEM value of the heavy metals (cadmium, nickel, chromium and lead) for the zones; Agulu-Nanka (0 ± 0ppm, 0.21 ± 0.08ppm, 82.67 ± 12.72ppm, 0.5 ± 0.35ppm), Awka South (0 ± 0ppm, 0.05 ± 0.01ppm, 108 ± 8ppm, 0.16 ± 0.05ppm), Idemili (0 ± 0ppm, 0.03 ± 0.03ppm, 86.67 ± 7.42ppm, 4.48 ± 4.37ppm) and Control (0.02 ± 0.02ppm, 0.02 ± 0.02ppm, 94 ± 2ppm, 2.73 ± 2.55ppm) (See Appendix XX for details). When the heavy metals (cadmium, nickel, chromium and lead) of the zones were compared using oneway ANOVA, f values of (1.488, 19.966, 1.197 and 0.513) and and p values of (0.310, 0.002, 0.388 and 0.688) were obtained respectively. At 95% level of significance, there exist no significant difference between the heavy metals of the zones but a high significant difference was observed with the nickel content of the zones.
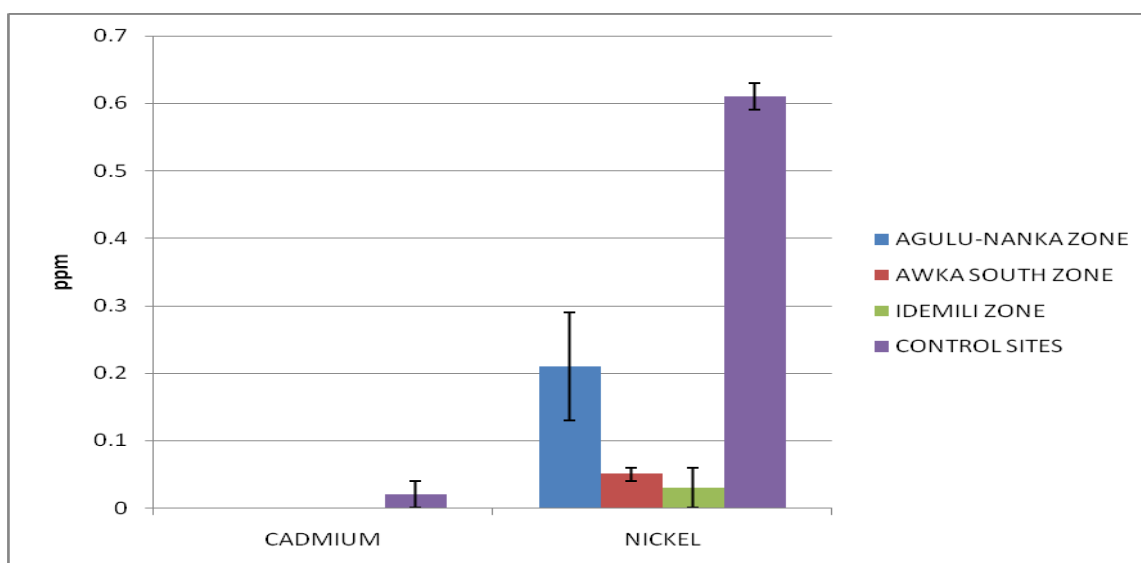
Figure 22: Mean ± SEM of cadmium and nickel for the zones.
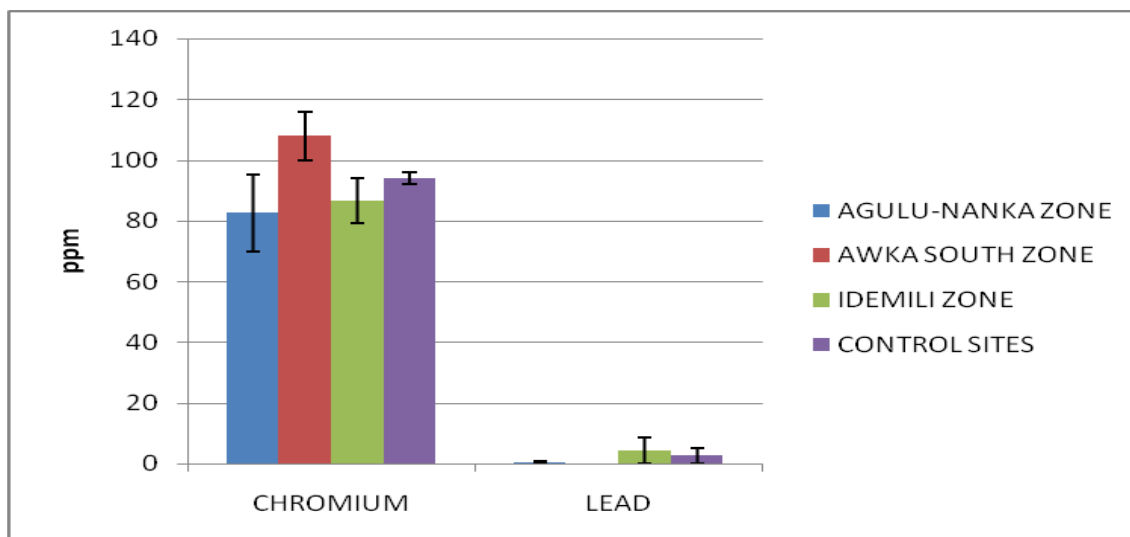
Figure 23: Mean ± SEM of chromium and lead for the zones.

4.4.4 Other metals:

The Mean ± SEM values of the other metals (silver, iron and aluminium) for the zones; Agulu-Nanka (0.76 ± 0.08ppm, 12.4 ± 3.63ppm, 7.99 ± 2.87ppm), Awka South (0.35 ± 0.35ppm, 5.7 ± 3.54ppm, 8.19 ± 3.29ppm), Idemili (1.27 ± 0.3ppm, 10.12 ± 3.26ppm, 11.44 ± 6.14ppm) and Control (9.57 ± 4.13ppm, 7.95 ± 6.82ppm, 2.44 ± 2.44ppm). Figures 24 depicts the graphical representation of the Mean ± SEM of the other metals (See Appendix XXI for details of the values of the other elements. When the other metals (silver, iron and aluminium) of the zones were compared using oneway ANOVA, f values of (7.036, 0.461 and 0.631) and and p values of (0.022, 0.719 and 0.621) were obtained respectively. At 95% level of significance, there exist no significant difference between the other metals of the zones but there exist a significant difference with the silver content of the zones .
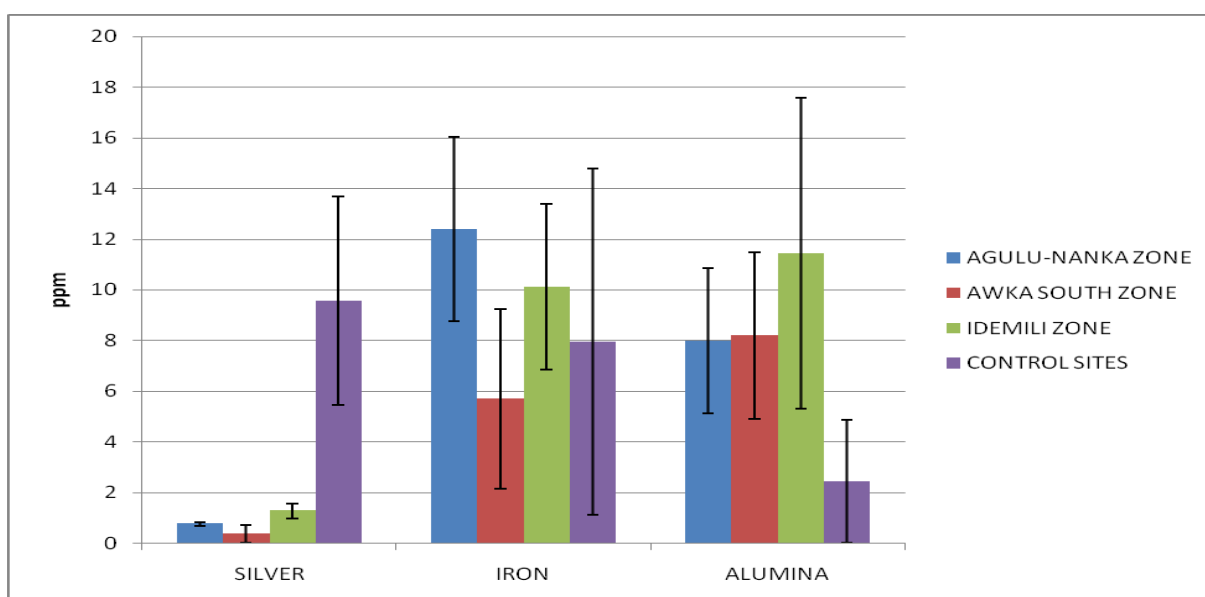
Figure 24: Mean ± SEM of silver, iron and aluminium for the zones.

4.4.5 Metalloids:

The results of the Metalloid (Silicate) of the zones are shown in figure 25 (See Appendix XXII for details). The mean ± SEM value for Agulu-Nanka (8.21 ± 0.63ppm), Awka South (6.48 ± 0.67ppm), Idemili (6.93 ± 0.69ppm) and Control (3.71 ± 0.49ppm) were represented graphically below. When the metalloid (Silicate) of the zones were compared using oneway ANOVA, f values of 7.562 and and p values of 0.018 were obtained. At 95% level of significance, there exist significant difference between the silicate of the zones.
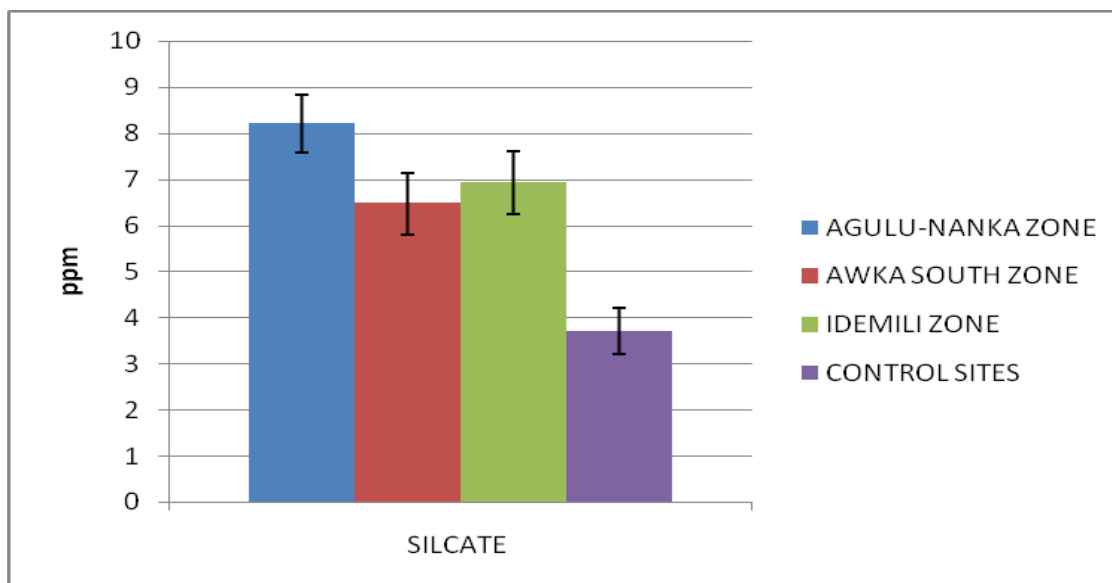
Figure 25: Mean ± SEM of Silicate for the zones.

**4.4.6 Statistical analysis of results grouped according to zones:**

Oneway analysis of variance (ANOVA) is a quick test to ascertain the signifacant difference existing between the various parameters considered in the chemistry and elemental characteristics within the zones to which these soil samples are found or located. However, multiple comparism of analysis of variance (MANOVA) was further used to consider significance between groups at 95% confidence level. See Appendix XXV for table of statistical analysis for both zones.

4.5 POOLING OF SAMPLES INTO ERODED AND NON-ERODED SITE.

When the results of the zones were considered and analysed statistically, the results could not critically answer our objectives and provide substantial evidence to causes of soil erodibility so it became imperative that a pooled sample results of the eroded and non-eroded sites were compared for further insight and the outcome of that is thus presented;

4.6 Soil colour:

Table 3: MUNSELL soil colour chart: This separates hue, value and chroma into perceptual uniform and independent dimensions, and systematically illustrate the colours in three dimensional space.

S/ No	SOIL SAMPLE	TOP SOIL	SUB SOIL	UNDERLYING ROCKS AND STONES
1	Agu-Awka	**REDDISH BROWN** HUE 5YR 4/3	**RED** HUE 10R 4/8	**RED** HUE 10R 5/8
2	Agulu	**BROWN** HUE 7.5YR 5/4	**LIGHT RED** HUE 2.5YR 5.5/8	**LIGHT REDDISH BROWN** HUE 2.5YR 6/4
3	Nanka	**REDDISH YELLOW** HUE 5YR 6.5/6	**LIGHT REDDISH BROWN** HUE 5YR 6/4	**YELLOW** HUE 2.5Y 8/6
4	Ekwulobia	**REDDISH BROWN** HUE 10R ¾ DARK	**RED** HUE 10R 4/8	**PINKISH WHITE** HUE 5YR 8/2
5	Ogidi	**DUSKY RED** HUE 10YR 3/2	**YELLOW** HUE 10YR 8/6	**LIGHT REDDISH BROWN** HUE 2.5YR 6/6
6	Nkpor	**YELLOWISH RED** HUE 5YR 4.5/6	**RED** HUE 10R 5/8	N.A
7	Agu-Awka (Burrow pit)	**RED** HUE 2.5YR 4/6	**LIGHT RED** HUE 10R 6/6	**PINK** HUE 5YR 8/4
8	Odekpe (Control)	**YELLOWISH BROWN** HUE 10YR 5/4	N.A	N.A
9	Igbariam (Control)	**REDDISH BROWN** HUE 5YR 4/4	N.A	N.A
10	Alor (Control)	**REDDISH BROWN** HUE 5YR 3.5/4	N.A	N.A

4.7 SOIL MECHANICS

4.7.1 Relative size of soil particles:

The results of the relative size of soil particles; sand, silt and clay of the Top Soils are shown in figure 26 (See Appendix II for details).

The mean ± SEM value for percentage sand is highest in eroded sites (81.33 ± 4.38%) when compared to non-eroded site (79.04 ± 1.51%). When the percentage sand of the eroded sites and non eroded sites were compared using student t- test, a t value of 0.327 and a p value of 0.752 were obtained. At 95% level of significance, there exist no significance difference between the percentage sand of the two sites.

The mean ± SEM value for percentage silt is lesser in eroded sites (7.58 ± 2.59%) when compared to non-eroded site (10.02 ± 3.71%). When the percentage silt of the eroded sites and non eroded sites were compared using student t- test, a t value of -0.523 and a p value of 0.615 were obtained. At 95% level of significance, there exist no significance difference between the percentage silt of the two sites.

The mean ± SEM value for percentage clay is lesser in eroded sites (11.08 ± 2.98%) when compared to non-eroded site (10.88 ± 4.71%). When the percentage clay of the eroded sites and non eroded sites were compared using student t- test, a t value of 0.038 and a p value of 0.971 were obtained. At 95% level of significance, there exist no significance difference between the percentage clay of the two sites.
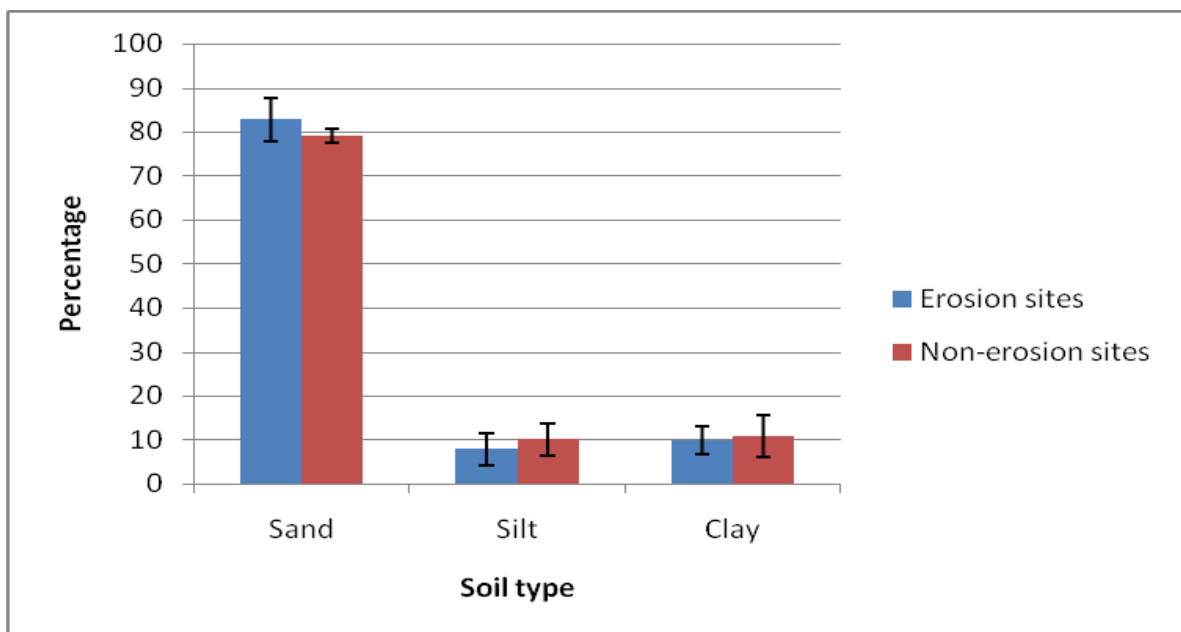
Figure 26: Plot of the Mean ± SEM of the relative size of soil particles of eroded sites and non-eroded sites measured in percentage.

4.7.2 Soil sedimentation:

Figure 27 shows the plot of the mean ± SEM value of soil sedimentation of the top soils of the eroded sites (0.61 ± 0.37sec, 0.62 ± 0.38sec, 0.57 ± 0.39sec) and non-eroded sites (0.86 ± 0.65sec, 0.45 ± 0.24sec, 1.14 ± 0.84sec) for 5seconds, 10seconds and 20seconds respectively (See Appnedix III for detailed soil sedimentation values). When the sedimentation values of the eroded sites and non eroded sites were compared using students t test, t values of -0.343, 0.274 and -0.716 and p values of 0.740, 0.791 and 0.494 were obtained respectively. At 95% level of significance, there exist no significance difference between the cumulative soil sedimentation values of the two sites.
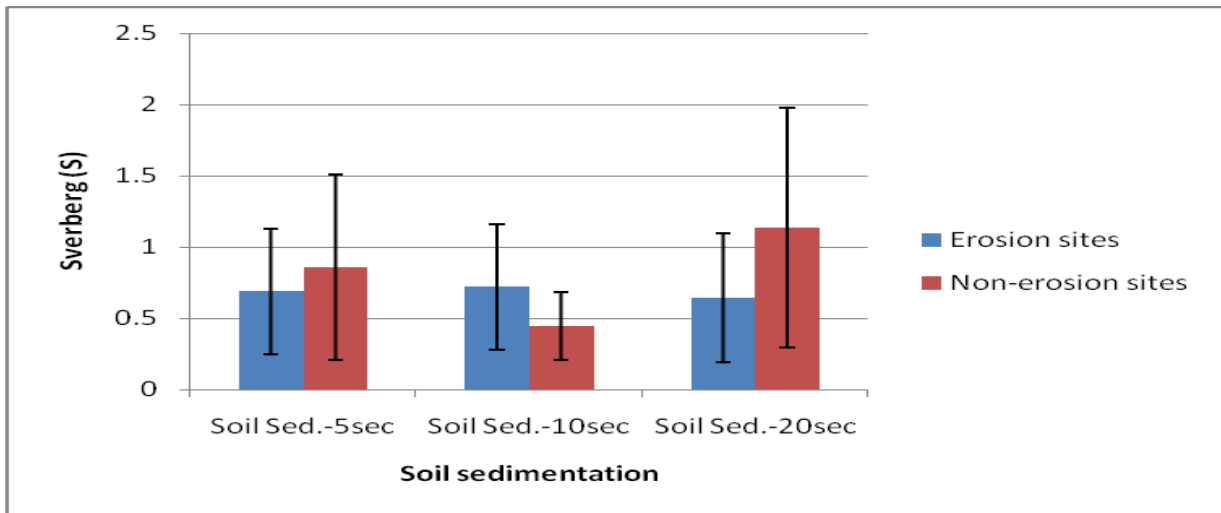
Figure 27: Plot of the Mean ± SEM of soil sedimentation of the eroded and non-eroded sites measured in seconds cumulatively.

4.7.3 Natural moisture and CBR:

Figure 28 shows the plot of the mean ± SEM value of natural moiture and California Bearing Ratio (CBR) of the eroded sites (8.29 ± 0.94%, 40.71 ± 7.14%) and non-eroded sites (6.12 ± 1.23%, 47.67 ± 2.03%) respectively (See Appendix IV for detailed information on natural moiture, Appendix V for CBR tables and Appendix XXIII for CBR detailed plot). From the mean values above, we observed that the natural moisture content is higher in eroded sites than non-eroded sites while the CBR value is higher in non-eroded sites than eroded sites. When the natural moiture content and the CBR of the eroded sites and non eroded sites were compared using students t test, t values of 1.313 and -0.612 and p values of 0.225 and 0.558 were obtained respectively. At 95% level of significance, there exist no significant difference between the natural moisture content of the two sites as well as the CBR values of the two sites.
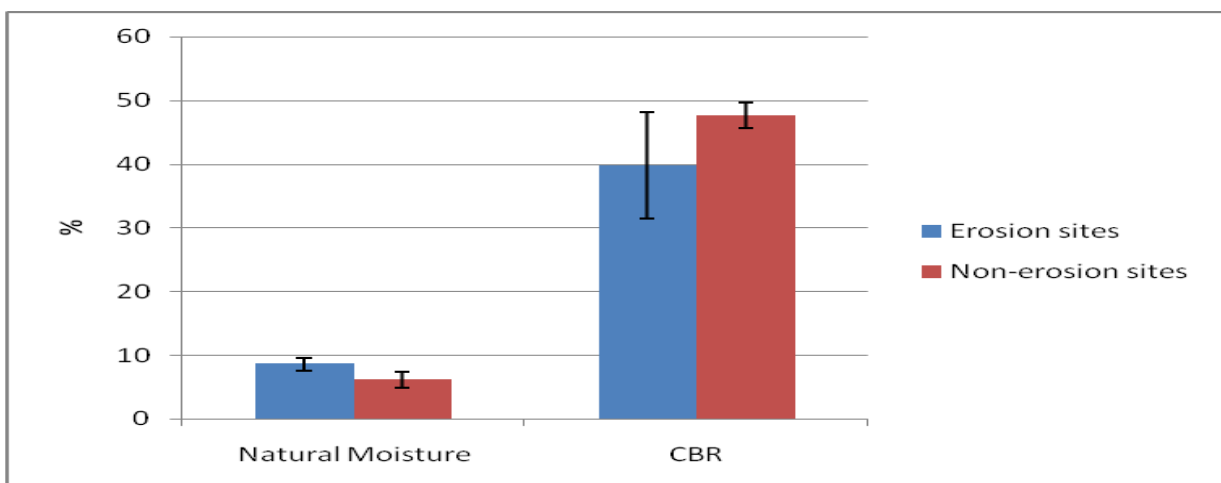
Figure 28: Plot of the Mean ± SEM of the natural moisture content and california beraing ratio of the eroded and non-eroded sites measured in percentages.

4.7.4 Soil densities:

The Mean ± SEM values of soil pore densities and bulk densities of the eroded sites (1.19 ± 0.05 g/cm³, 1.18 ± 0.04 g/cm³) and non-eroded sites (1.03 ± 0.09g/cm³, 1.06 ± 0.06g/cm³) were as shown in figure 29 (See Appendix VI for details). In all cases, the values of the densities from the eroded sites were slightly higher than the non-eroded sites. When the pore density and bulkdensity of the eroded sites and non eroded sites were compared using students t test, t values of 1.705 and 1.835 and p values of 0.127 and 0.104 were obtained respectively. At 95% level of significance, there exist no significant difference between the pore density and bulk density of the two sites independently.
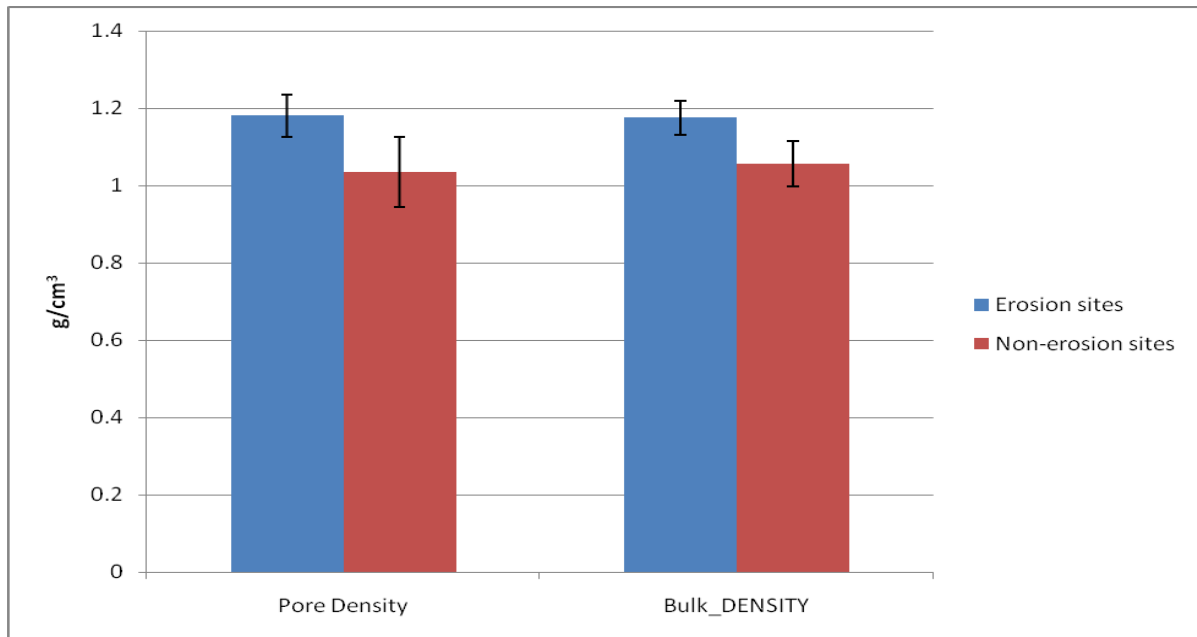
Figure 29: Plot of the Mean ± SEM of the pore density and bulk density of the eroded sites compared with the non-eroded sites.

4.7.5 Porosity:

Figure 30 shows the Mean ± SEM of the soil porosity of the eroded sites (0.16 ± 0.01) and non-eroded sites (0.18 ± 0.02). From the plot, we observed that the values of the porosity of the non-eroded site is slightly higher than the eroded sites (See Appendix VII for details). When the porosity of the eroded sites and non eroded sites were compared using students t test, t values of -0.676 and p values of 0.518 were obtained. At 95% level of significance, there exist no significant difference between the porosity of the two sites.
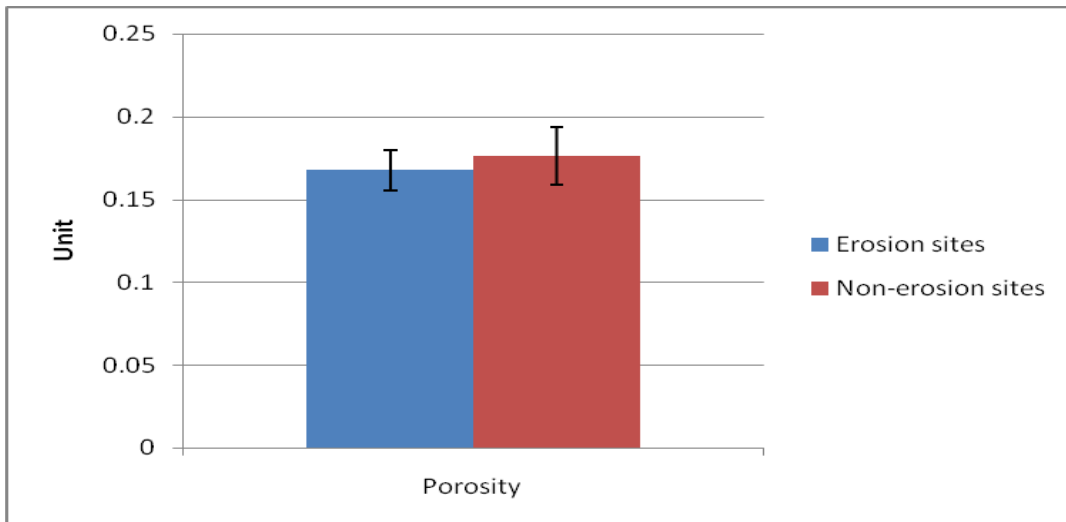
Figure 30: Plot of the Mean ± SEM of the porosity of the eroded site compared
        with non-eroded sites.

4.7.6 Compaction:

The Mean ± SEM plot of the compaction values; MDD (Maximum Dry Density in kg/m^3) and OMC (Optimum Moisture Contentin %) of the top soils were plotted from the results of the eroded sites and non-eroded sites as shown in figure 31 below. Their values are (1.84 ± 0.05g/cm^3, 12.77 ± 1.31%) and (1.79 ± 0.07g/cm^3, 14.31 ± 2.52%) respectively for eroded sites and non eroded sites (See Appendix VIII for details of both MDD and OMC). When the Compaction_MDD and Compaction_OMC of the eroded sites and non eroded sites were compared using students t test, t values of 0.812 and -0.734 and p values of 0.440 and 0.484 were obtained respectively. At 95% level of significance, there exist no significant difference between the Compaction_MDD and Compaction_OMC content of the two sites independently.
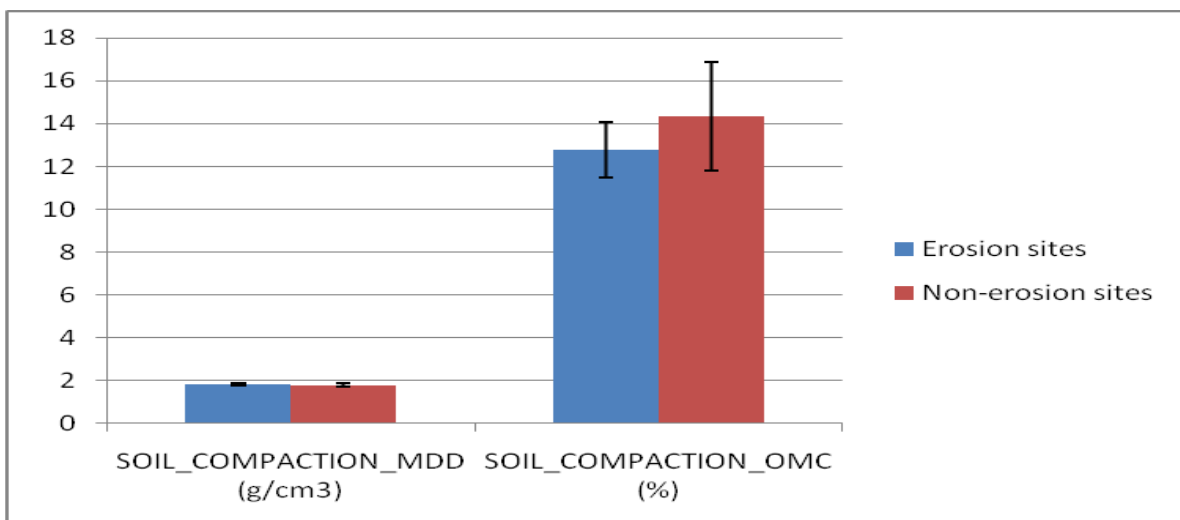
Figure 31: Plot of Mean ± SEM values for compaction_MDD and compaction_OMC.

Table 4: ATTERBERG LIMIT TEST

S/No	SOIL SAMPLE	TOP SOIL	SUB SOIL	UNDERLYING ROCKS AND STONES
1	Agu-Awka	NP	NP	NP
2	Agulu	NP	NP	NP
3	Nanka	NP	NP	NP
4	Ekwulobia	NP	NP	NP
5	Ogidi	NP	NP	NP
6	Nkpor	NP	NP	N. A
7	Agu-Awka(Burrow pit)	NP	NP	NP
8	Odekpe (Control)	P	N.A	N.A
9	Igbariam (Control)	NP	N.A	N.A
10	Alor (Control)	NP	N.A	N.A

Legend: N.A= Not available; because the soil profile section is not exposed,
P= Plastic, NP = Non Plastic

The table above shows atterberg limit or elasticity limit of the soils from the sites. When soils are non plastic, it is an indication of non cohesiveness of the soils.

4.8 SOIL PHYSICOCHEMICAL PROPERTIES:

4.8.1 Soil texture: The major soil textural classes can be defined by the percentages of sand, silt and clay according to the heavy boundary lines from textural triangle (Agronomy Guide, 2013-2014) as well as squeeze hand test. Table 5 shows the soil texture of both eroded and non eroded sites at the different layers or zones within the area sampled.

Table 5: Soil texture of soil horizonation of eroded sites and non-eroded sites.

S/No	SOIL SAMPLE	TOP SOIL	SUB SOIL	UNDERLYING ROCKS AND STONES
1	Agu-Awka	Loamy sand	Loamy sand	Sandy loam
2	Agulu	Loamy sand	Sandy clay loam	Sandy loam
3	Nanka	Sandy clay loam with particles of stones	Sandy clay loam	Sandy soil
4	Ekwulobia	Sandy loam soil	Sandy loam soil	Loamy sand
5	Ogidi	Sand with particles of stones	Sandy soil	Sandy soil
6	Nkpor	Sandy soil with particles of stones	Sandy soil	N.A
7	Agu-Awka (Burrow pit)	Sandy loam soil	Sandy clay loam soil	Sandy clay loam soil
8	Odekpe (Control)	Clay and mouldy soil	N.A	N.A
9	Igbariam (Control)	Sandy loam soil	N.A	N.A
10	Alor (Control)	Loamy sand soil	N.A	N.A

4.8.2 Soil percolation:

Figure 32 shows the plot of the Mean ± SEM value of soil percolation of the eroded sites (466.76 ± 144.79sec) and non-eroded sites (763.0 ± 558.50sec). The results suggest that the values of the non-eroded sites are higher than the eroded sites (See Appendix IX for details). When the soil percolation of the eroded sites and non eroded sites were compared using students t test, t values of –0.732 and p values of 0.485 were obtained. At 95% level of significance, there exist no significant difference between the soil percolation values of the two sites.


Figure 32: Plot of Mean ± SEM values for soil percolation of the eroded sites and non-eroded sites

4.8.3 Soil temperature:

The Mean ± SEM values of soil temperatures of area under the sun and area under the shade were taken at the shoulder level, surface level, 2", 4" and 6" into the soils of the eroded sites (32 ± 1.03 ºC, 31.33 ± 0.99 ºC, 31 ± 1.77 ºC, 30.33 ± 1.41 ºC, 29.5 ± 1.20ºC) and non-eroded sites (34 ± 0ºC, 32.33 ±0.88 ºC, 29.67 ± 0.33 ºC, 28.67 ± 0.67 ºC, 27.67 ± 0.33 ºC) were as shown in figure 33 (See Appendix X for details). From the result shown in the figure below on area under the shade, we observed that temperature above the soil surface is higher in the soils of the eroded sites than soils in the non-eroded sites. The same result reflects for soils under the sun. When the soil temperature of the eroded sites and non eroded sites were compared using students t test, at all the soil depths within the A-Horizon, at 95% level of significance, there exist no significant difference between the soil temperature at all soil depths within the A-Horizon of the two sites.
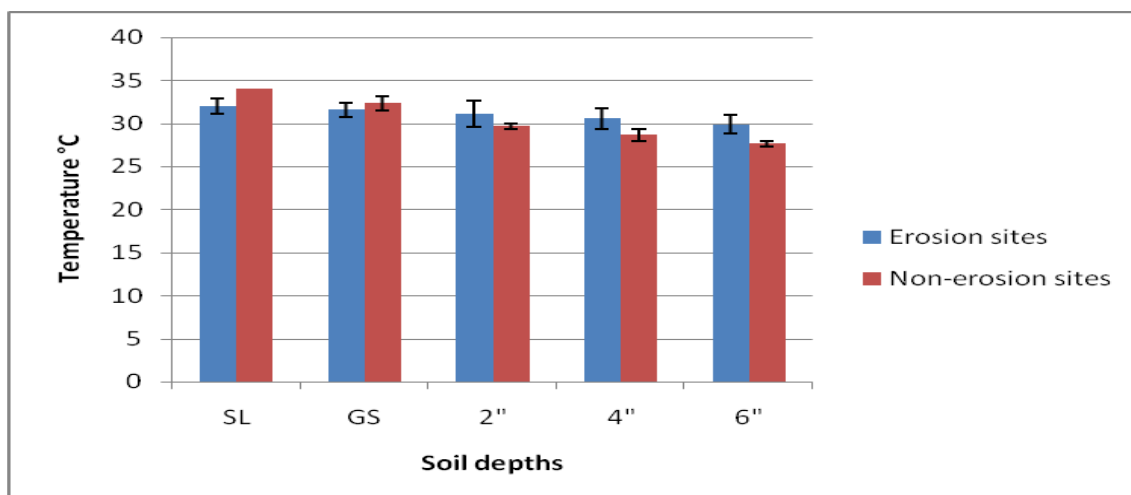
Figure 33: Shows soil temperature of area under the sun and area under the shade at different soil depths; both the eroded sites and non-eroded sites.

4.8.4 pH value of soils:

The results of the pH of the top soils are shown in figure 34 (See Appendix XI for details).

The Mean ± SEM value for eroded site (6.85 ± 0.13) is lower when compared with the value of the non-eroded site (7.34 ± 0.15) but both are still within the neutral pH range. When the pH of the eroded sites and non eroded sites were compared using students t test, t values of -2.288 and p values of 0.051 were obtained. At 95% level of significance, there exist significant difference between the pH of the two sites.
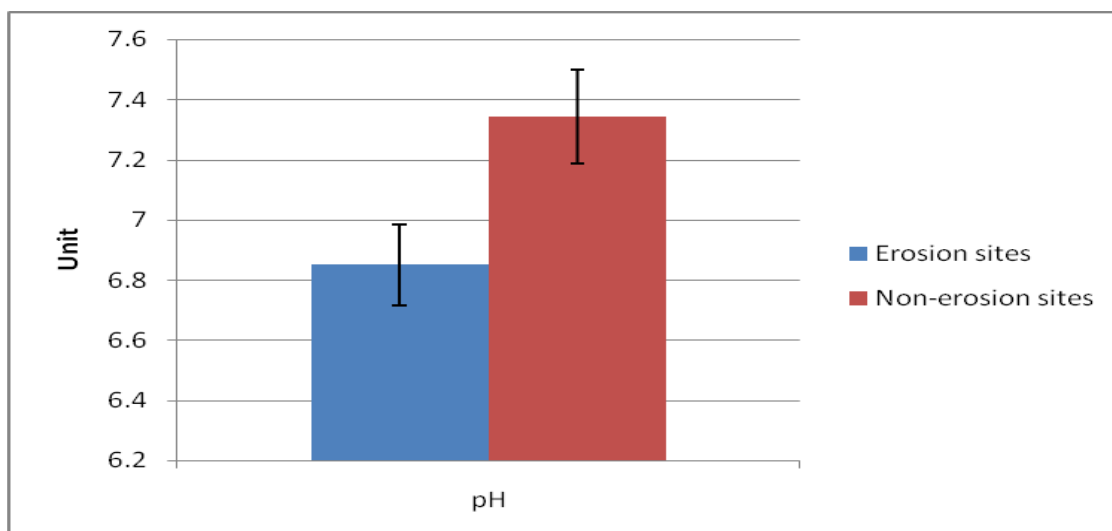
Figure 34: Plot of Mean ± SEM values for soil pH of the eroded sites and non-eroded sites

4.8.5 Soil resistivity:

The results of the soil resistivity (which is the inverse of soil conductivity) of the top soils are shown in figure 35 (See Appendix XII for details). The mean ± SEM value for eroded site (0.02 ± 0.01cm/µs) is lower when compared with the value of the non-eroded site (0.07 ± 0.04cm/µs). When the resistivity of the eroded sites and non eroded sites were compared

using students t test, t values of -1.741 and p values of 0.120 were obtained. At 95% level of significance, there exist no significant difference between the resistivity of the two sites.
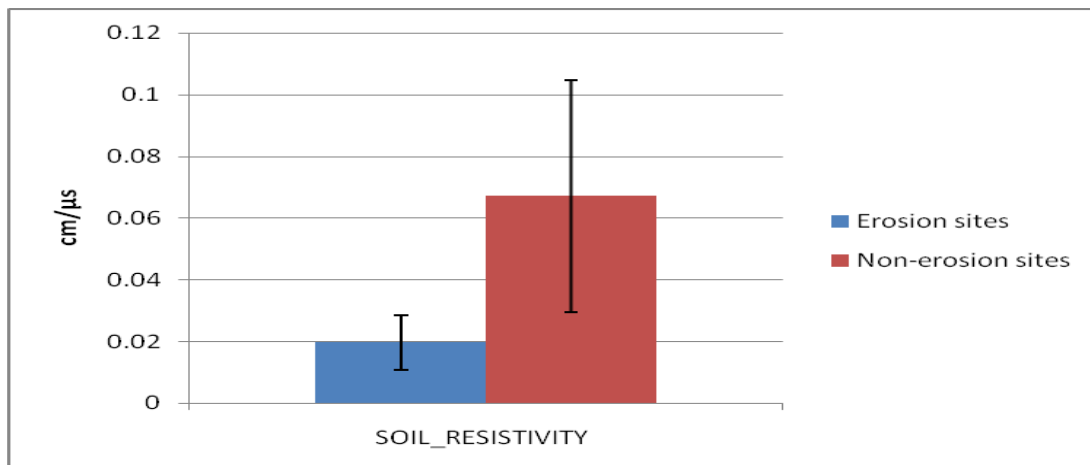
Figure 35: Plot of the Mean ± SEM of soil resisitivity of the eroded sites and non-eroded sites.

4.8.6 Soil Organic Matter (SOM) and Loss on Ignition (LOI):

Figure 36 shows the plot of the Mean ± SEM value of Soil Organic Matter (SOM) and Percentage Loss on Ignition (LOI) of the eroded sites (7.43 ± 2.61%, 36.43 ± 7.66%) and non-eroded sites (2.27 ± 0.93%, 11.67 ± 3.33%) respectively (See Appendix XIII for detailed information on SOM and Appendix XIV for LOI data). From the mean values above, we observed that both the SOM and LOI are higher in eroded sites than non-eroded sites. When the SOM and LOI of the eroded sites and non eroded sites were compared using students t test, t values of 1.240 and 2.016 and p values of 0.250 and 0.079 were obtained. At 95% level of significance, there exist no significant difference between the SOM nor the LOI of the two sites.
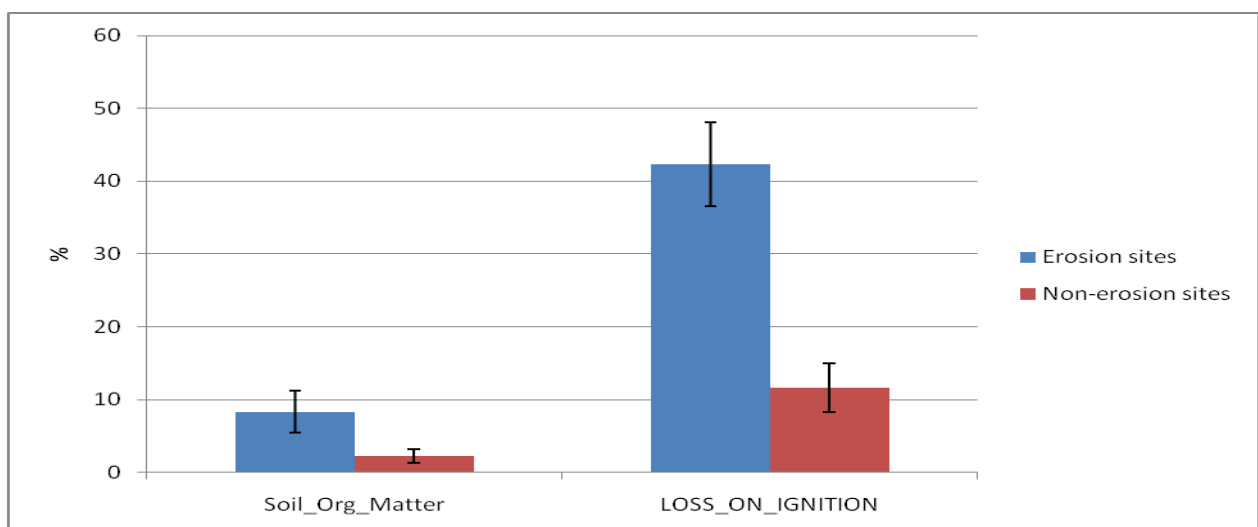
Figure 36: Plot of the Mean ± SEM of SOM and LOI of both the eroded sites and non-eroded sites.

4.8.7 Cation Exchange Capacity (CEC):

Figure 37 shows the plot of the Mean ± SEM value of CEC of the eroded sites (4.17 ± 2.87cmol/kg) and non-eroded sites (0.29 ± 0.05cmol/kg). The results suggest that the values of the eroded sites are higher than the non-eroded sites (See Appendix XV for details). When the CEC of the eroded sites and non eroded sites were compared using students t test, t values of 0.856 and p values of 0.417 were obtained. At 95% level of significance, there exist no significant difference between the CEC of the two sites.
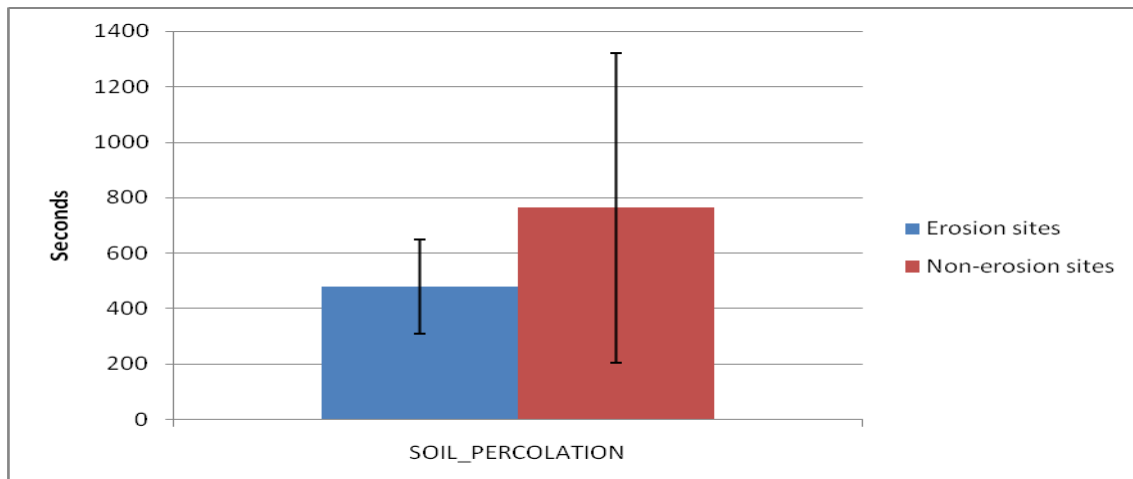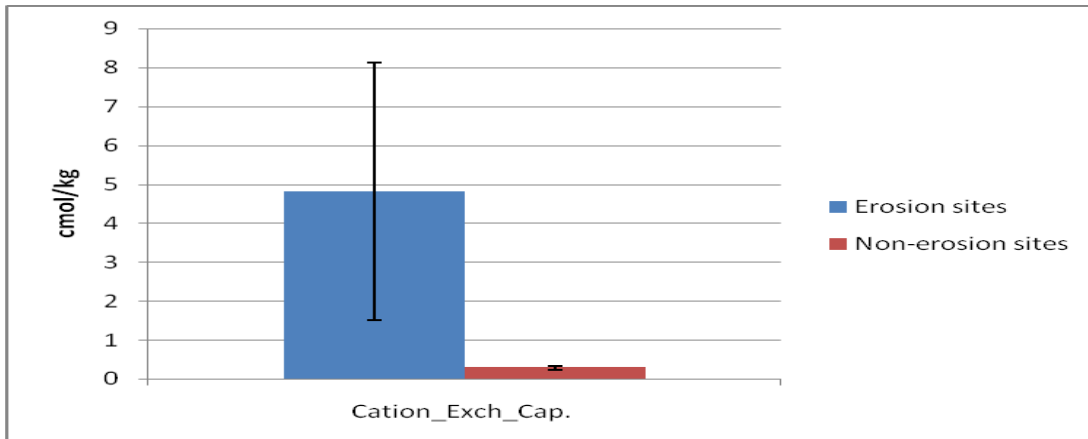

Figure 37: Plot of the Mean ± SEM of CEC of the eroded sites and non-eroded sites.

4.8.8 Base Saturation:

The results of the base saturation of the top soils are shown in figure 38 (See Appendix XVI for details). The mean ± SEM value for eroded site (103 ± 1.56%) is higher when compared with the value of the non-eroded site (101.33 ± 0.55%). When the Base saturation of the eroded sites and non eroded sites were compared using students t test, t values of 0.711 and p values of 0.498 were obtained. At 95% level of significance, there exist no significant difference between the base saturation of the two sites.
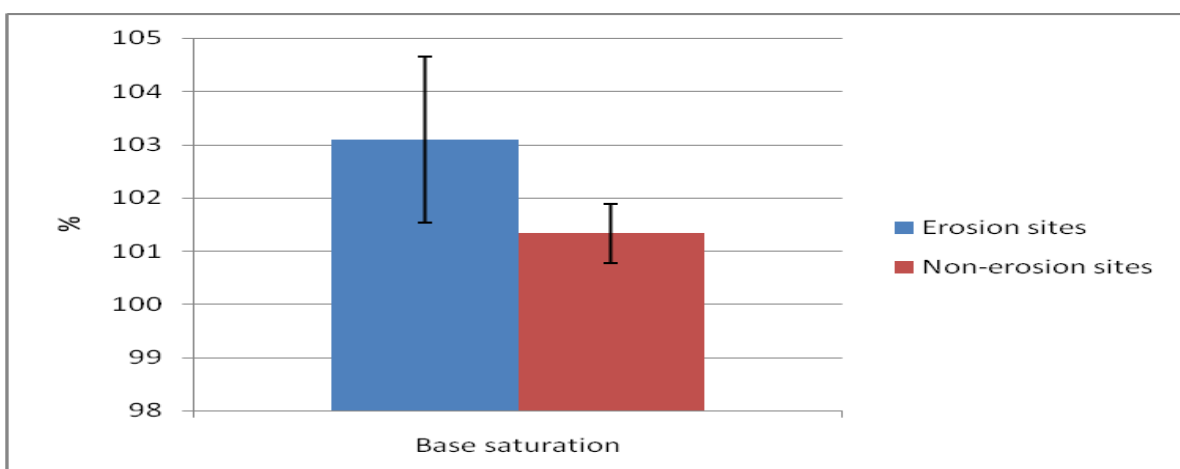
Figure 38: Plot of the Mean ± SEM of base saturation of the eroded sites and non-eroded sites

4.8.9 Soil Rheology:

The results of the soil rheology of the top soils are shown in figure 39 (See Appendix XVII for details). The mean ± SEM value for eroded site (0.09 ± 0.002pa.s) is higher when compared with the value of the non-eroded site (0.08 ± 0.005pa.s). When the rheology of the eroded sites and non eroded sites were compared using students t test, t values of 1.834 and p values of 0.104 were obtained. At 95% level of significance, there exist no significant difference between the rheology of the two sites.
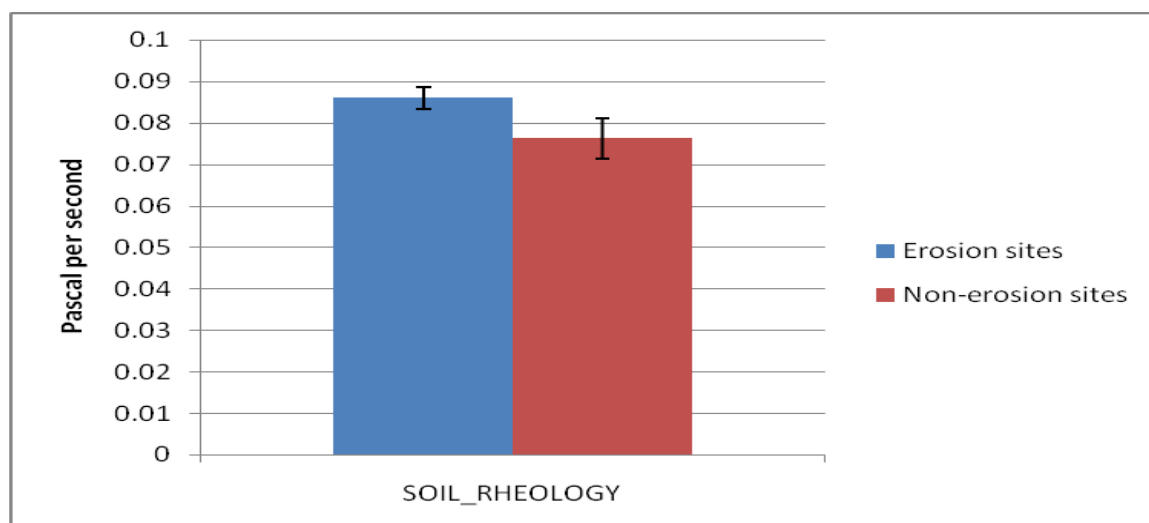

Figure 39: Plot of the Mean ± SEM of soil rheology for the eroded sites and non-eroded sites

4.9 SOIL MINERALS

4.9.1 Essential elements:

The results of the essential elements were as presented in figures 40 and 41. The Mean ± SEM values of these elements (sodium, calcium, magnesium and potassium) are 366.21± 75.41ppm, 2.38 ± 1.39ppm, 2.05 ± 0.97ppm, 6.21 ± 1.11ppm for eroded sites and 36.03 ± 6.48ppm, 1.08 ± 0.22ppm, 8.73 ± 0.40ppm, 9.56 ± 5.42ppm for non-eroded sites (See Appendix XVIII for details of the values of these essential elements). When the essential elements (sodium, calcium, magnesium and potassium) of the eroded sites and non eroded sites were compared using students t test, t values of (2.287, 0.888, -2.385, and -1.037) and p values of (0.051, 0.401, 0.044, and 0.330) were obtained. At 95% level of significance, there exist no significant difference between the calcium and potassium of the two sites but significant difference was observed between sodium and between magnesium of the two sites.
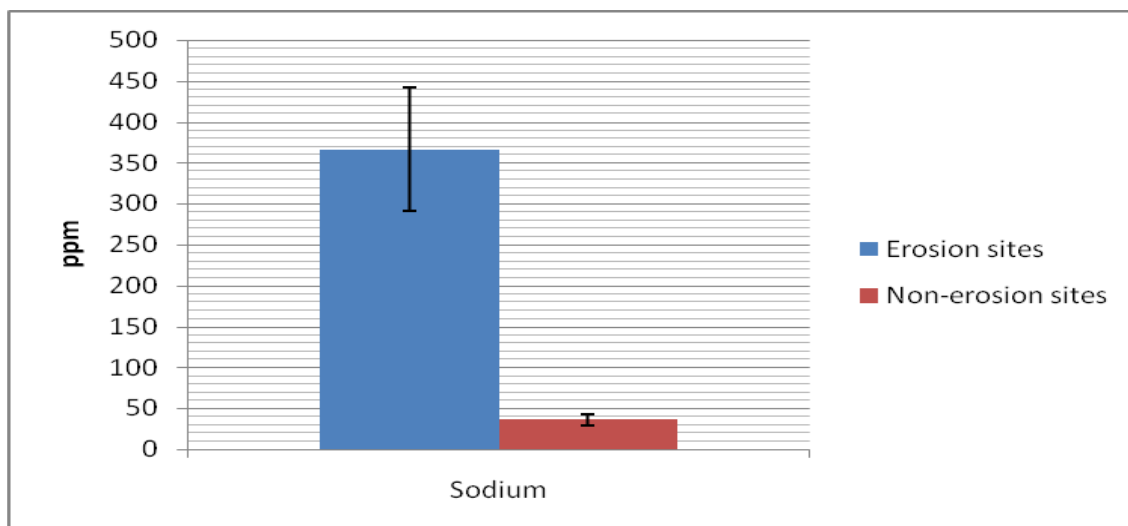
Figure 40: Mean ± SEM of sodium for the eroded sites and non-eroded sites.
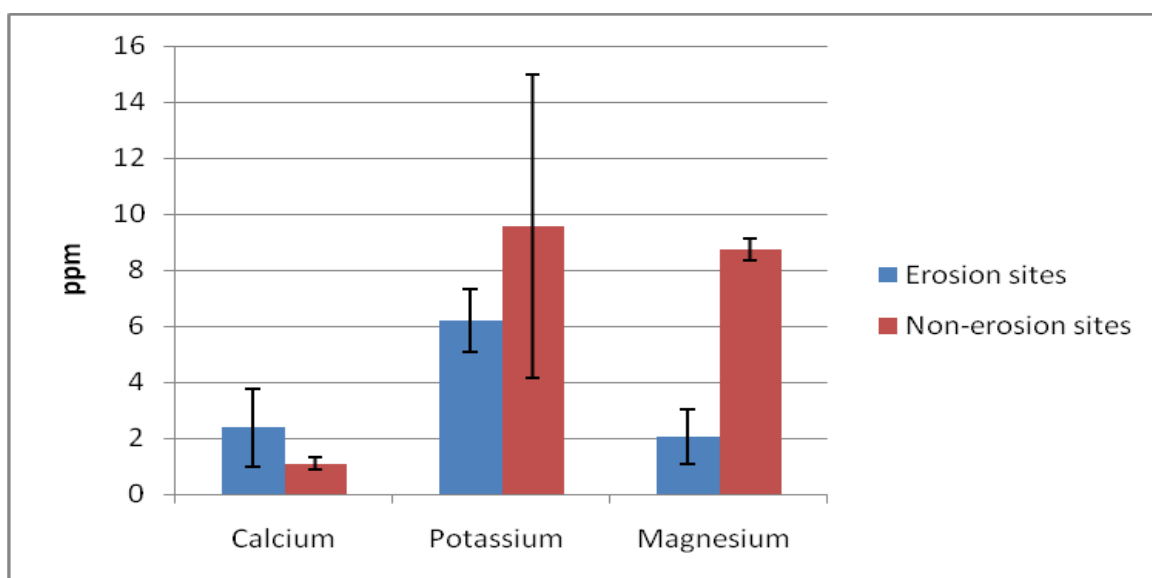
Figure 41: Mean ±SEM of calcium, potassium & magnesium of the eroded and non-eroded site

4.9.2 Trace elements:

The Mean ± SEM values of these trace elements (zinc, copper, manganese and cobalt) are 105.33 ± 16.24ppm, 4.67 ± 1.0ppm, 3 ± 1.61ppm, 0.13 ± 0.04ppm for eroded sites and 36.85 ± 25.05ppm, 20.44 ± 2.70ppm, 10.67 ± 10.67ppm, 0.19 ± 0.04ppm for non-eroded sites. Figures 42 and 43 depict the graphical representation of the Mean ± SEM of the trace elements (See Appendix XIX for details of the values of these trace elements). When the trace elements (copper, zinc, manganese and cobalt) of the eroded sites and non eroded sites were compared using students t test, t values of (2.005, -1.877, -0.850, and -1.033) and p values of (0.08, 0.097, 0.420, and 0.332) were obtained. At 95% level of significance, there exist no significant difference between the trace elements of the two site.
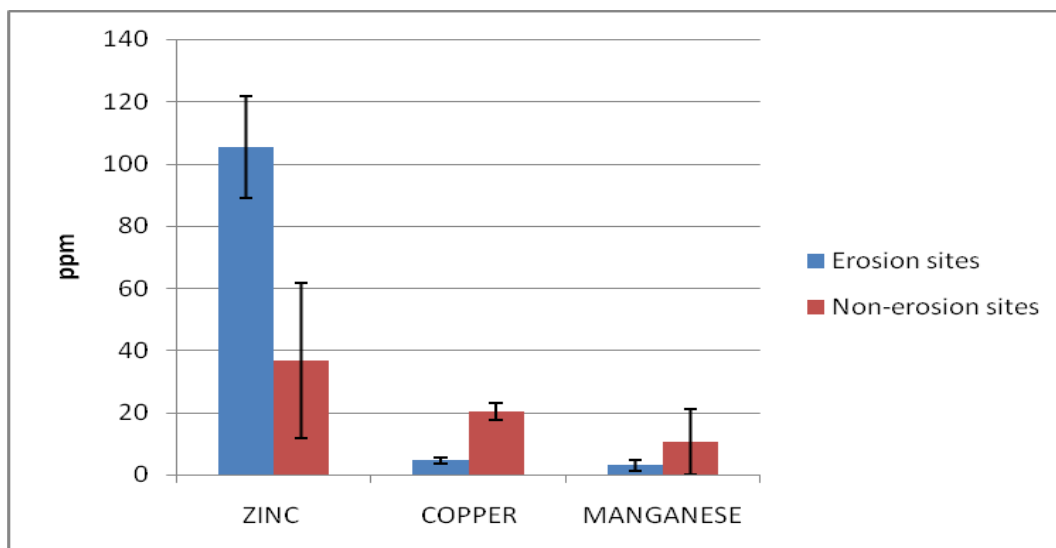
Figure 42: Mean ± SEM of zinc, copper and manganese for the eroded sites and non-eroded sites.
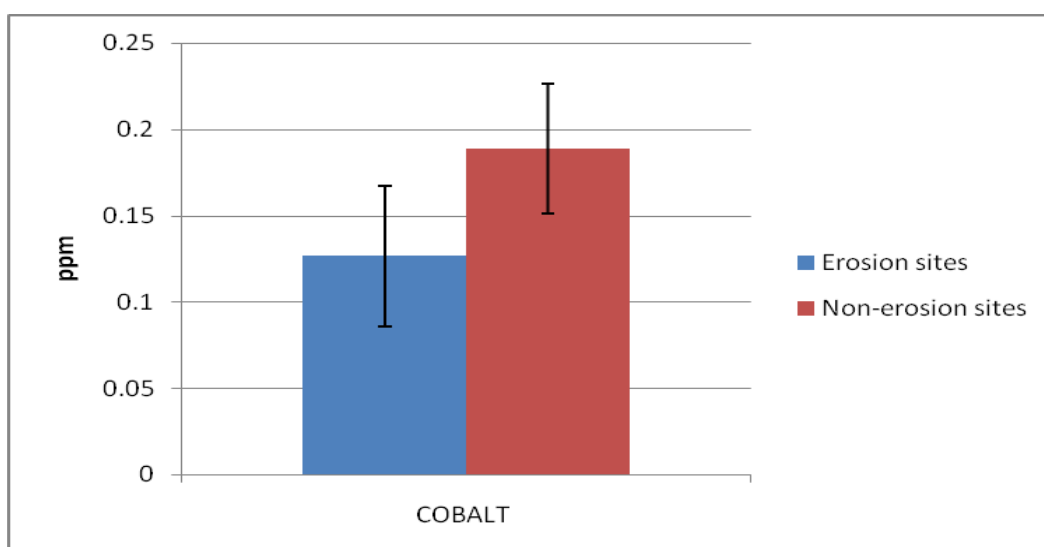
Figure 43: Mean ± SEM of cobalt for the eroded sites and non-eroded sites.

4.9.3 Heavy metals:

Figures 44 and 45 show the plot of the Mean ± SEM value of the heavy metals (cadmium, nickel, chromium and lead) for the eroded sites (0 ± 0ppm, 0.11 ± 0.06ppm, 88 ± 8.39ppm, 0.32 ± 0.18ppm) and non-eroded sites (0.01 ± 0.01ppm, 0.44 ± 0.17ppm, 94.67 ± 1.33ppm, 6.22 ± 3.79ppm). The results suggest that in all the heavy metals analysed, the values of the eroded sites is lesser than the non-eroded sites (See Appendix XX for details). When the heavy metals (cadmium, nickel, chromium and lead) of the eroded sites and non eroded sites were compared using students t test, t values of (-2.431, -2.556, -0.428, and -2.602) and p values of (0.041, 0.034, 0.680, and 0.032) were obtained. At 95% level of significance, there exist significant difference between the heavy metals of the two sites but for cadmium where no significant difference was not observed.
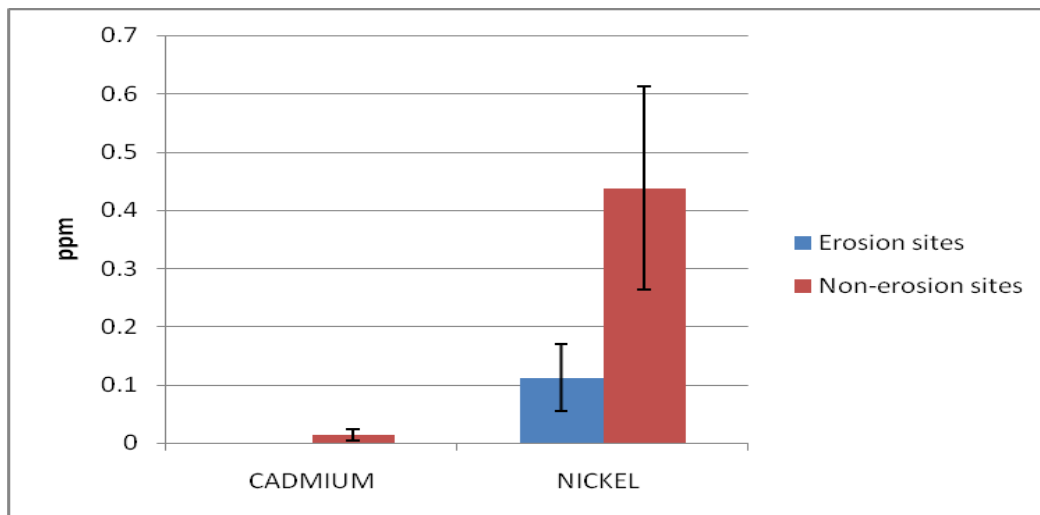
Figure 44: Mean ± SEM of cadmium and nickel for the eroded sites and non-eroded sites.
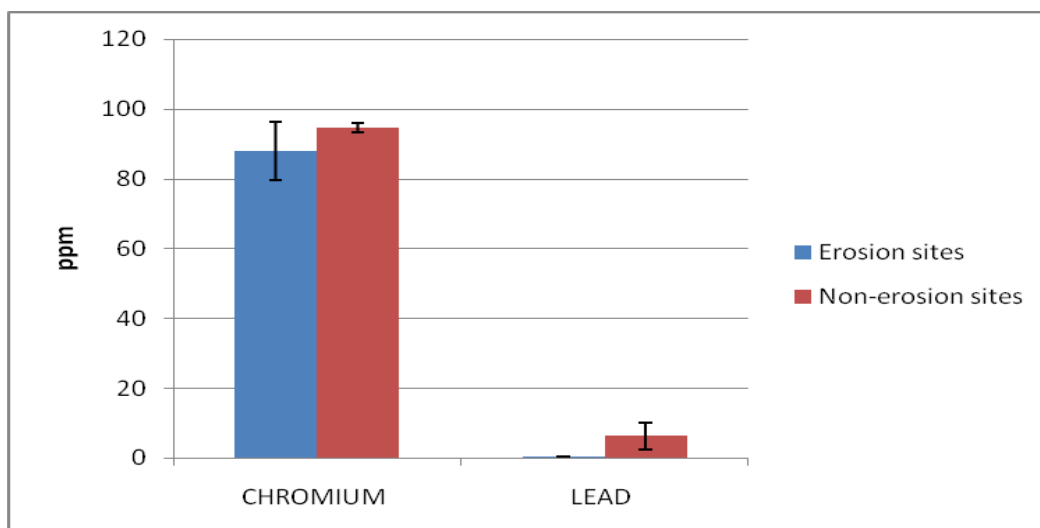
Figure 45: Mean ± SEM of chromium and lead for the eroded sites and non-eroded sites.

4.9.4 Other metals:

The Mean ± SEM values of the other metals (silver, iron and aluminium) are 0.95 ± 0.19ppm, 10.22 ± 2.70ppm, 10.53 ± 2.70ppm for eroded sites and 6.75 ± 3.69ppm, 8.09 ± 3.94ppm, 1.62 ± 1.62ppm for non-eroded sites. Figure 46 depicts the graphical representation of the Mean ± SEM of the other metals (See Appendix XXI for details of the values of the other elements). The results show that iron and aluminium are higher in the eroded sites than non-eroded sites while silver is higher in the non-eroded sites than the eroded sites. When the other metals (silver, iron, and aluminium) of the eroded sites and non eroded sites were compared using students t test, t values of (-2.660, 0.461, and 2.421) and p values of (0.029, 0.657, and 0.042) were obtained. At 95% level of significance, there exist no significant difference between iron of the two sites but significant difference was observed between silver and between aluminium of the two sites.
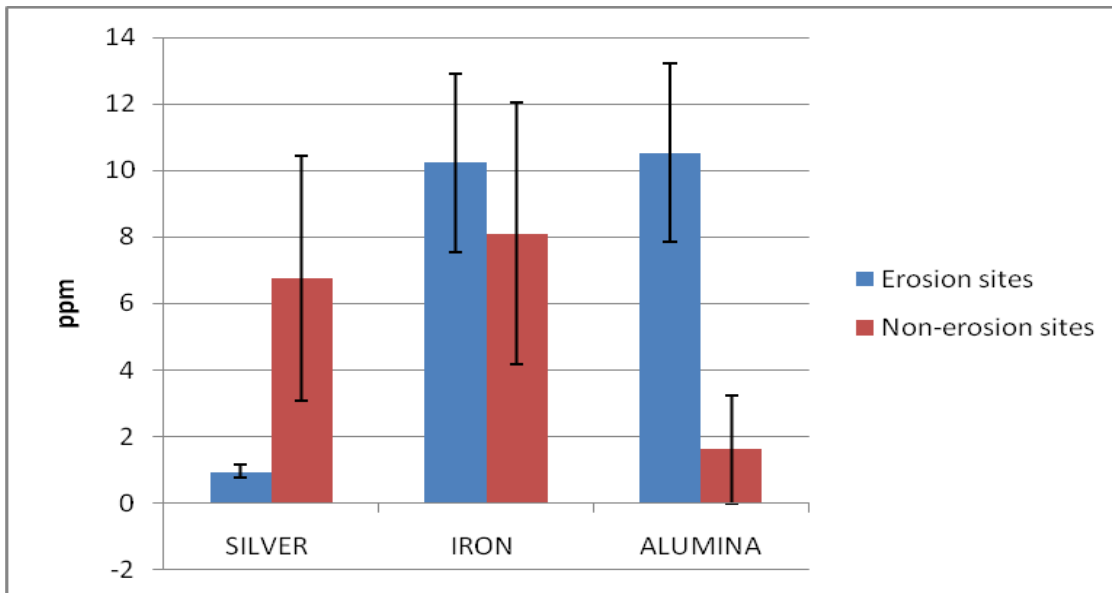
Figure 46: Mean ± SEM of silver, iron and aluminium for the eroded sites and non-eroded sites.

4.9.5 Metalloids:

The results of the metalloid (silicate) of the top soils are shown in figure 47 (See Appendix XXII for details). The mean ± SEM value for eroded site (7.40 ± 0.49ppm) is higher when compared with the value of the non-eroded site (5.20 ± 1.52ppm). The result suggests that silicate is higher in the eroded sites than the non-eroded sites. When the metalloid; silicate of the eroded sites and non eroded sites were compared using students t test, t value of 1.671 and p value of 0.133 were obtained. At 95% level of significance, there exist no significant difference between the silicate of the two sites.
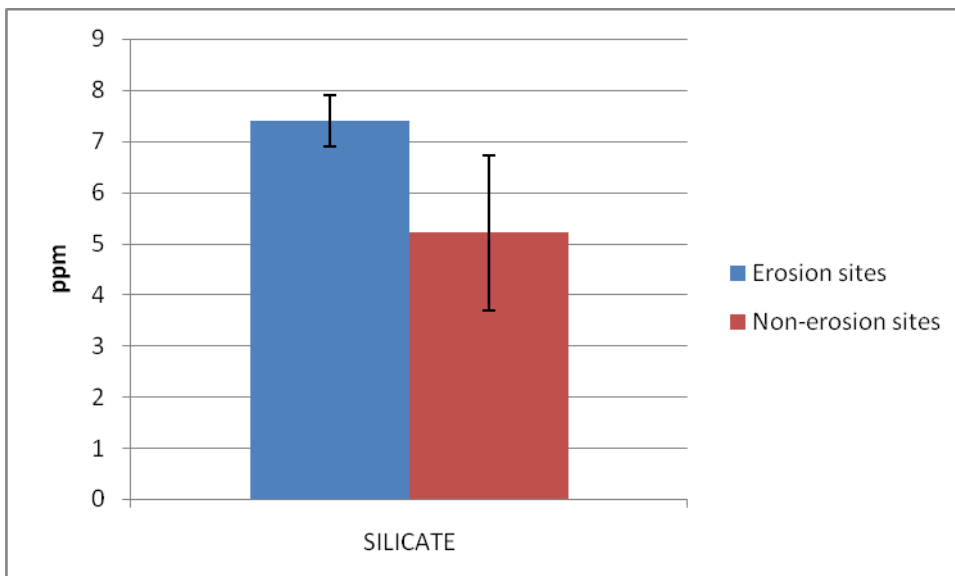

Figure 47: Mean ± SEM of silicate for the eroded sites and non-eroded sites.

4.9.6 Testing of Research Hypothesis:

Hypothesis one:

H_0: There is a significant difference in soil biochemical properties among the soil blocks in Anambra State.

H_1: There is no significant difference in soil biochemical properties among the soil blocks in Anambra State.

The hypothesis was tested using one way analysis of variance at $P < 0.05$ significance level.

Results:

One way analysis of variance was conducted to see if there is a significant difference in soil biochemical parameters among the soil blocks in Anambra State. The results show that there are no significant difference in soil biochemical properties among the soil zones; pH (f= 0.75, p= 0.56) figure 12, loss on ignition (f= 2.47, p= 0.16) fig 14, soil organic matter (f= 0.28, p= 0.84) figure 14, cation exchange capacity (f= 0.80, p= 0.54) figure 15, essential elements of the zones (except magnesium) figures 18 & 19, trace elements of the zones figures 20 & 21, other metals of the zones (except nickel and silver) figures 22, 23, & 24. This implies that there is no significant difference in soil biochemical properties of the zones. We therefore reject the null hypothesis (H_0) and accept the alternate hypothesis (H_1).

Hypothesis two:

H_0: Soil erosion has effect on soil biochemical and edaphic factors

H_1: Soil erosion has no effect on soil biochemicals and edaphic factors.

The hypothesis was tested using paired sample students' t test at $p < 0.05$ significance level.

Results:

Paired sample t test was conducted to see if there is a significant difference on soil biochemicals and edaphic factors using pooled samples from the eroded and non-eroded sites; The results show that there are no significant difference on soil biochemicals and edaphic factors of the eroded and non-eroded sites (two sites); relative size of soil particles (fig 26), natural moisture (fig. 28), CBR (fig. 28), Soil densities (fig. 29), Compaction (fig. 31), percolation (fig. 32), {except pH (t= 2.29, p= 0.05) fig 34}, loss on ignition (t= 2.02, p= 0.08) fig 36, soil organic matter (t= 1.24, p= 0.25) fig. 36, cation exchange capacity (t= 0.86, p= 0.42) fig. 37, soil rheology (t= 1.83, p= 0.10) fig. 39, essential elements of the two sites (except sodium and magnesium) figures 40 & 41, trace elements of the two sites figures 42 & 43, other metals of the two sites (except alumina and silver) figures 46 & 47. This implies that there is no significant difference in soil biochemicals and edaphic factors of the two sites. We therefore reject the null hypothesis (H_0) and accept the alternate hypothesis (H_1).

Hypothesis three:

H$_0$: There is a relationship between soil edaphic factors and biochemical properties.

H$_1$: There is no relationship between soil edaphic factors and biochemical properties.

The hypothesis was tested using correlational analysis at $p < 0.05$ significance level.

Results:

Correlational analysis or dependence consideration of data expresses statistical relationship between two sets of data or variables. It equally quantify the extent of the relationship between the variables. The correlational coefficient of biochemical properties against soil edaphic factors are shown in tables 6, 7 and 8. See Appendix XXIV for detailed correlational analysis of the data.

Table 6: Correlation coefficient of essential elements vs other soil edaphic properties.

Essential minerals	Edaphic parameters	Correlation co-eff	Significance
Calcium	Silt	*0.643	0.045
	Base saturation	*0.658	0.039
Potassium	Sedimentation_5sec	*0.693	0.026
	Sedimentation_20sec	*0.741	0.014
	Compaction_OMC	*0.808	0.005
	Pore density	*-0.723	0.18
	Percolation	*0.705	0.023
	Resistivity	*0.739	0.015
Sodium	CBR	*-0.709	0.022
	Loss on Ignition	*0.658	0.038
Magnesium	Loss of Ignition	**-0.917	0

Table 7: Correlation coefficient of trace elements vs other soil edaphic properties.

Trace elements	Correlated parameters	Correration co-efficient	Significance
Copper	Loss on ignition	**-0.820	0.004
Zinc	Resistivity	**-0.810	0.005
	Loss on ignition	**0.774	0.009
Cobalt	Sand	*-0.749	0.013
	Silt	*0.695	0.026
	Sedimentation_5sec	*-0.716	0.02
	Sedimentation_10sec	**-0.782	0.008

Table 8: Correlation coefficient of other metals vs other soil edaphic parameters compared.

Metals	Cor. edaphic parameter	Correlation co-efficient	Significance
Silver	Pore density	*-0.730	0.016
	Bulk density	*-0.645	0.044
	Percolation	*0.726	0.017
Aluminium	Silt	*-0.633	0.05
	Natural moisture	*0.677	0.032
Lead	Rheology	*-0.690	0.027

Note: Negative correlation coefficient signifies that as one is increasing, the other is decreasing (inversely proportional) while positive correlation coefficient show both parameters are either increasing or decreasing simultaneously (directly proportional).

* Significant (P <0.05).
** Highly significant (P <0.01)

From the tables above,
  i. Calcium correlates directly with silt and base saturation.
  ii. Potassium correlates directly with sedimentation, compaction_omc, soil densities, percolation and resistivity.
 iv. Sodium and zinc have direct correlation with loss on ignition, while magnesium and copper have inverse relationship with loss on ignition.
  iv. Both potassium and silver show inverse realtionship with soil densities.
  v. Lead shows inverse relationship with rheological properties of the soils.

Since there is a considerable correlation between soil edaphic factors and biochemical properties, we accept the hypothesis.

CHAPTER 5

5.0 DISCUSSION

The earth, our unique home in the vastness of the universe is in serious crises as depletion of the ozone layers in the upper atmosphere is threatening us with overload of ultraviolet radiation (Brady and Weil, 1999), erosion and its deleterious consequence is wearing away our habitation and the capacity of soils to produce food being fastly degraded even as the number of people needing food and land mass for habitation is increasing exponentially.

In this study, the soil chemistry and edaphic factors as well as rheological properties as possible deterministic features for predicting soil erodibility in Anambra state were carried out by taking a vast measure of the soils characteristics and properties considered to contribute to erosion. Though, a lot of work has been done on soil with respect to Agriculture and Engineering but literature is largely scanty on the erodibility factors as a measure to the checking or preventing erosion.

The result of relative size of soil particles in Anambra state reveals a higher mean values of sand (82.74 ± 4.92 and 79.04 ± 1.51) when compared to silt and clay from both the eroded and non-eroded sites respectively and even when the soils were grouped into zone; (91.56 ± 4.85% to 74.58 ± 4.97%). There exists no significant difference (p< 0.05) between these variables for sand, silt and clay (figures 4 and 26). This agrees with earlier observation of Obasi (2013) in his works from southern Nigeria who stated that percentage of sand composition ranges from 71% to 85%. The mean values for percentage silt were (11.08 ± 2.98%) and (10.88 ± 4.71%) and percentage clay (11.08 ± 2.98%) and (10.88 ± 4.71%) for the eroded and non-eroded sites. Though sand is believed to enhance drainage (infiltration) and so does not allow overland flowing of water yet these areas are still susceptible to soil erosion. Onwuka, *et al* (2012) stated that high sand composition implies low binding factor with the soils which explains unconsolidated, friable and loose nature of the rocks which enhances erodibility. Table 5 shows the soil texture within Anambra State depicting the fact that the soils of Anambra State is predominantly sandy which is in conformity with the characteristics of tropical rainforest; it gets saturated easily and becomes vulnerable to runoff and concentrated runoff leads to erosion (Egboka, 1993., Mirsal, 2008., Obasi, 2013., Rainforest Conservation Fund, 2013).

Due to the soil texture (table 5), sedimentation rate of the different soils; eroded and non-eroded as well as sample grouping into zones did not equally show any significant difference ($p < 0.05$). Fig. 3 shows the depth or the extent of erosion in Anambra state, an effect of these factors.

There was no significant difference ($p < 0.05$) with the natural moisture content as well as the California Bearing Ratio of both the eroded sites and non-eroded sites. When further analysed according to zones, there still exist no significant difference ($p < 0.05$) indicating that Anambra State; a tropical rainforest has almost equal rainfall pattern, temperature and soil texture. The soil natural moisture is averaged ($6.12 \pm 1.23\%$ and $8.29 \pm 0.94\%$) for non-eroded and eroded sites showing that the eroded sites has higher degree of water retention, a factor that encourages higher overland water flow once rainfall above the land capacity falls.

The CBR used for measuring the load-bearing capacity of soils was employed to ascertain the strenght of the soils within these study sites. It therefore proves that the harder the surface, the higher the CBR rating. A CBR of 3 equates to tilled farmland, a CBR of 4.75 equates to turf or moist clay, while moist sand may have a CBR of 10. High quality crushed rock has a CBR over 80. Soils are classified as non-weak soil if the average soaked CBR is high; within the ranges of 5.5 to 15.4 (Ekeocha and Akpokodje, 2014) agreeing with the earlier ranges of non-weak soils. The CBR results of the eroded and non-eroded sites ($40.71 \pm 7.14\%$ and $47.67 \pm 2.03\%$) (Fig. 28) were well above these ranges even when grouped into zones ranges from $30.67 \pm 10.41\%$ to $59.5 \pm 13.5\%$ (Fig. 6). This proves that all soils samples tested have high CBR rating. This should have prevented erosion but for the atterberg limit which shows non plasticity for all the samples but one (Table 4). This result conforms with Ekeocha and Akpokodje's (2014) explaination of widespread failure of the area with high CBR rating but low atterberg values. Onwuka *et al* (2012) is of the same view that non plastic values or low plasticity can cause breakdown and dismantling of the soil particles consequently leading to serious erosion if unguarded urbanization kicks off in the area. Similarly, the values of rheology or rheological properties showed no significance difference ($p < 0.05$) when statistically analysed. The rheology of the eroded site (0.09 ± 0.002pa.s) is higher when compared with the value of the non-eroded site (0.08 ± 0.005pa.s). Soil classification as zones proved too that there is no significant difference ($p < 0.05$) with the soil rheological properties of the zones. Non plasticity of soils reduces the binding capacity of soils (aggregate stability) thereby enhancing erodibility.

Figures 31 and 9 represent the values of the Compaction_MDD and Compaction_OMC (1.84 $\pm$ 0.05g/cm^3, 12.77 $\pm$ 1.31%) and (1.79 $\pm$ 0.07g/cm^3, 14.31 $\pm$ 2.52%) respectively for eroded sites and non eroded sites and for the zones; Agulu-Nanka (1.92 $\pm$ 0.05g/cm^3, 11.54 $\pm$ 1.16%), Awka South (1.90 $\pm$ 0.04g/cm^3, 11.76 $\pm$ 0.06%), Idemili (1.97 $\pm$ 0.05g/cm^3) and Control (1.76 $\pm$ 0.11g/cm^3, 15.76 $\pm$ 3.6%). A critical look at the figures (Appendix VIII) suggest that eroded sites have higher Compaction_MDD value but lesser Compaction_OMC values; an indication expressing the fact that both are inversely related. The erodibility of a soil increases with increased compaction because it reduces water infiltration (affects soil available water) by closing pore spaces thereby increasing surface runoff. According to Ekeocha and Akpokodje (2014), in their work, compaction_MDD range of 1.76 to 2.03g/cm^3 was obtained from subgrade soils in Benue trough of southeastern Nigeria while our result was 1.76g/cm^3 for control to 1.97g/cm^3 for Idemili (erosion status classified as severly gullied). It shows therefore that Anambra State soils are in accordance with Federal Government specification for non-weak soils (Onwuka *et al*, 2012). This implies that high compaction values for Anambra State soils depict high susceptibility to erosion. Though compaction_MDD is negatively correlated with natural moisture but in our result, the statistical analysis of the correlation shows no significance difference ($p < 0.05$). Erodibility increases with increasing compaction value which results to an increase in bulk density but decrease in atterberg limit against (Onwuka, *et al*., 2012) submission that low bulk density increases susceptibility to erosion. This is dependent on soil texture as fine textured surface soils such as silt loams, clays and clay loams generally have lower bulk densities than sandy soils which our soil samples are predominantly made of (Table 5). The results of the statistical analysis indicated no significant difference ($p < 0.05$) with the eroded and non-eroded sites of the soils and further analysis with ANOVA of the zones revealed that only the particle density has a significant difference ($p < 0.05$). There exist no significant difference with both bulk density and pore density or pore spaces.

Porosity is synonymous to pore spaces and is inversely proportional to bulk density (Agronomy Guide, 2013-2014). The result of the mean values for porosity of the eroded to non-eroded sites ranges between 12% and 22% and for the zones, from 15% to 18%. Statistical analysis shows that there exist no significant difference with respect to the sites as well as the zones. This implies that the degree of soil porosity is not very high due to high compaction of the soils even though the soil is predominantly sandy. Due to high moisture content of friable soils of tropical rainforest of which Anambra State fell into, and due to

laterization of this subsoils, saturation of the soils was easy leading to overland flow of floods and consequently erodibility of the soils. It disagrees with Onwuka *et al.,* (2012) that porosity is high (32% to 40%) leading to high water infiltration and low water holding capacity which results in lubrication of existing cracks causing wearing away and cutting of layers during rainy seasons. The mean ± SEM of percolation rate of the eroded soils (466.76 ± 144.79sec) and non-eroded sites (763.0 ± 558.50sec) were compared and analysed using student t test and it showed that there exist no significant difference between the two sites although the non-eroded sites has higher mean values for percolation meaning that it takes longer time for water to percolate in those area. The result was further grouped into zones; Agulu-Nanka (462.11 ± 304.22sec), Awka South (214.5 ± 178.17sec), Idemili (551.67 ± 174.33sec) and Control (1043 ± 837sec) and the results suggest that the values of the control are higher than the rest of the zones yet no significant difference ($p< 0.05$) was observed with the zones. This correlates with porosity and compaction of the soils.

The analysis of variance (ANOVA) with the temperature showed no significant difference ($p< 0.05$) and further analysis using multiple comparism (MANOVA) still showed no significant difference but a closer look at the figures (11a & b and 33) showed there was not much mean difference in the plot nor table of its values but the ranges of soil temperatures of area under the sun and area under the shade were taken at the shoulder level, surface level, 2", 4" and 6" into the soils of the eroded sites ($29.5 ± 1.20°C$ to $32 ± 1.03 °C$) and non-eroded sites ($27.67 ± 0.33 °C$ to $34 ± 0°C$) were as shown in figure 33. From the result shown in the figure 33 of area under the shade, we observed that temperature above the soil surface was higher in the soils of the eroded sites than soils in the non-eroded sites. The same result reflects for soils under the sun. This implies that the soils of Anambra State under tropical rainforest share same features.

The Mean ± SEM value of pH for eroded site (6.85 ± 0.13) was lower when compared with the value of the non-eroded site (7.34 ± 0.15) but both are still within the neutral pH range. At 5% level of significance, there exist significant difference between the pH of the two sites. Though, the pH of the eroded sites is slightly acidic but its acidic nature could enhance chemical reactions with certain minerals thereby weakening the soils structure and making it more susceptible to erodibility. Onwuka, *et al.,*(2012) observed a lower pH of between 5.2 and 5.4 in Nanka and Ekwulobia axis which made the soils easily detachable and could be transported from one location to another by agents of erosion. Statistical Analysis of Variance (ANOVA) of the pH of the zones (fig. 12) showed no significant difference ($p< 0.05$);

evidence that soil pH is a key factor in soil erodibility when eroded and non eroded sites were compared.

The results of the soil resistivity (which is the inverse of soil electrical conductivity) as shown in figure 35 revealed that soils of non-eroded sites have lower conductivity than the soils of the eroded sites. This was in line with soil pH values of the same sites. The results of the zones are shown in figure 12. The results indicated that the conductivity (inverse of resistivity) of the control was lower when compared with the value of the other zones. It therefore confirmed the soil chemistry linked to soil pH but no significant difference ($p < 0.05$) between the eroded and non-eroded sites as well as the zones were observed. Pairwise comparisons of mean values of the zones were conducted using multiple comparism (MANOVA) and there exists significant difference between the control and all the zones; Agulu-Nanka, Awka South, and Idemili. This again showed that the soil chemistry is a serious factor in soil erodibilty. Korkanc, *et al.,* (2008) explained that low electrical conductivity of soils indicates low possibility of a salinity problem.

Figure 37 shows the values of CEC of the eroded sites and non-eroded sites and the results suggest that the values of the eroded sites were higher than the non-eroded sites. At 95% level of significance, there exist no significant difference between the CEC of the two sites. Figure 15 depicting the results of the CEC of the zones suggest that the values of Idemili zone was higher than the other zones yet no significance difference was observed at $p < 0.05$. The CEC of soils commonly ranges from 3 to 50cmol/kg (Nwachokor, *et al.,*2009). It is important to note that earth materials that posses low CEC will have low water holding capacity and by implication low plasticity which were issues associated with sandy soils but clay soils have the reverse description (Ekeocha and Akpokodje, 2014). Anambra State with very low CEC fell within this category because of its sandy nature no wonder it is highly prone to erosion and this agrees with submission by Saidi (2012) that CEC values of the soils depend, among other properties, upon the mineralogical nature of clays and other electric surface charges developed by the organic matter.

The results of the base saturation of the top soils are shown in figure 38. The mean ± SEM value for eroded site was higher when compared with the value of the non-eroded site. At 5% level of significance, there exist no significant difference between the base saturation of the two sites. The results of the Base saturation grouped according to zones are as shown in figure 16. The mean ± SEM value for these zones; Agulu-Nanka, Awka South, Idemili and Control were analysed and it was observed that Awka South zone showed higher values of base saturation when compared with the value of the other zones. At 95% level of significance,

there exist high significant difference between the base saturation of the zones and further pairwise comparisons of mean values of the zones using multiple comparism (MANOVA) showed that there exists significant difference between the Awka South zones and all the zones; Agulu-Nanka, Idemili and even Control. The results of base saturation was low and it agrees with Nwachokor *et al.,*(2009) that high precipitation which is predominant with tropical rainforest can lead to leaching of basic cations from the soils and this enhances erodibilty. Onweremadu (2007) added that high rainfall amount, duration and intensity may have increased leaching of this basic cations even in clayed soils. He noted a significant relationship between exchange basic cations and sand, silt contents.

A close review of figures 36 and 14 show the plot of the Mean ± SEM value of Soil Organic Matter (SOM) of the eroded sites and non-eroded sites respectively. From the results, we observed that the SOM was higher in eroded sites than non-eroded sites. At 5% level of significance, there exist no significant difference between the SOM of the two sites. When grouped according to zones, we observed that Idemili zone has higher SOM. At 5% level of significance, there still exist no significant difference between the SOM values of the zones. Generally, the soil organic matter was very low no wonder the soils do not support economic crops that can help prevent erosion. This is in line with an earlier work by Onwuka, *et al.,*(2012) that the soils of the area cannot support the growth of economic trees with tap root systems which help in obstructing the denuding effects of agents of erosion and which explains the fraible nature of the soil. This poor soil organic matter could be linked among others to the top soil colouration (Table 3) and poor agricultural produce from this part of the country as it is responsible for the formation and stabilization of soil aggregates (Brady and Weil, 1999) though further added that there is no consistent relationship between soil colour and soil texture.

Loss on ignition (LOI) is a commonly used method for the estimation of sediment properties like water content, organic matter, inorganic carbon and minerogenic residues (Veres, 2002). The results of the LOI of the eroded sites were higher than that from the non-eroded sites yet there exist no significant difference (p< 0.05) between the two sites. The values of the Control were the least in the zones which represent the non-eroded sites in top soil and still show no significant difference (p< 0.05) when statistically analysed. Pairwise comparisons of mean values of the zones using multiple comparism (MANOVA) showed that there exists significant difference (p< 0.05) between the Agulu-Nanka zone and the Control. These results suggest that erodibility increases with decreasing loss on ignition. According to colloid-

moisture equivalent indice, soil erodibility increased because of decreasing loss on ignition and sand fractions of soil in rangeland. Korkanc, *et al.,* (2002) reported too that generally, when loss on ignition of the soils increase, erodibility decreases.

The elemental characteristics of the soils were separated into essential elements, trace elements, heavy metals, other metals and metalloids and their characteristic effects were observed with the eroded sites compared with non-eroded sites. They were further grouped into zones to ascertain the characteristic features of the soils of the different zones in Anambra State.

The soils of Anambra State showed a remarkable high mean value of sodium in the eroded sites (366.21 $\pm$ 75.41ppm) compared to non-eroded sites (36.03 $\pm$ 6.48) (Figure 40). When grouped into zones, it was observed that Agulu_Nanka and Idemili zones (Figure 18) described as most severely gullied erosion sites (Appendix I) showed high level of sodium. It may therefore be suggested that sodium plays a critical role in erodibility. There exist a significant difference ($p < 0.05$) between the eroded sites and non-eroded sites, and using MANOVA showed too a significant difference ($p < 0.05$) between Agulu-Nanka and Awka South zone., Agulu-Nanka zone and Control. Sodic soils (soils high in sodium) generally have poor drainage and are soil disperssant but in health, could be attributed to high blood pressure (BP) experienced in this part of the country as edible plants absorb them.

There exist no significant difference ($p < 0.05$) observed with calcium in the soils of the eroded and non-eroded sites nor with the zones. Despite the fact that the mean value of the eroded sites was about double the non-eroded sites and that there seemed to be a collaboration with sodium that higher calcium may be linked to erodibility of soils. Yet when the soils were grouped into zones, there still exist no significant difference ($p > 0.05$) between the zones.

Higher mean values of magnesium (figure 41) was observed in non-eroded sites compared to eroded sites and statistical analysis showed a significant difference ($p < 0.05$). It showed an inverse relationship with sodium and calcium. When further analysed using ANOVA, there exist a significant difference ($p < 0.05$) between the zones. Mulitiple analysis of variance (MANOVA) shows a high significant difference ($p < 0.01$) between Agulu-Nanka and Awka South zone, and between Agulu-Nanka zone and the Control. There exist also a significant difference ($p < 0.05$) between Agulu-Nanka and Idemili zone (Appendix XXV).

Potassium was higher in non-eroded sites to eroded sites (figure 41) and likewise highest in control under zones to the rest of the zones (figure 19). Though there exist no significant difference (p< 0.05) with either the eroded and non-eroded sites nor with the zones. There is a clear evidence from these that lower levels of potassium may be linked to erodibility.

Figures 40 and 41 depict the mean value relationship between the eroded sites and non-eroded sites with the non-eroded site showing a higher mean value for the essential minerals; sodium and calcium but lower mean values for magnesium and potassium. Pearson correlational analysis results showed significant correlation (p< 0.01 and 0.05) among these essential elements; sodium vs magnesium is negatively correlated, potassium vs silver is highly positively correlated, calcium vs base saturation is positively correlated, magnesium vs loss on ignition is highly negatively correlated, and some other soil properties (Table 6). This is evidence of the implication of the elements in soil erodibility. Onweremadu, (2007) reported that some of the cations of mineral weathering are basic and include Ca, Mg, Na and K; though used to determine base saturation. They have the greatest effect on the availability of plant nutrients and influence soil water content. He further explained that the ratio of Ca to Mg may be antagonistic depending on the soil type knowing that as sand increases, basic cations decrease. Observing the mean values of our work expressed an imbalance of Ca to Mg against the reports by Onweremadu (2007).

Results of the trace elements; zinc, copper, manganese and cobalt were analysed. Though the mean values of Zn from the eroded sites were higher than the non-eroded sites, and those of Cu, Co & Mn from the non-eroded sites were higher than the eroded sites (figures 42 & 43), none of these showed any statistical difference (p< 0.05). The results of the zones equally showed no significant difference (P < 0.05) (figures 20 & 21). The heavy metals; cadmium, nickel, and lead but chromium instead showed significant increase (p< 0.05) in the non-eroded sites possibly due to pollution contamination from the environment (Appendix XXIII) and the zones, only nickel showed a significant difference (p< 0.05) (Appendix XXV).

The results of the other metals; silver, iron and aluminium were subjected to student's t test to ascertain their significance in erodibility and it was observed that there were significant difference (p< 0.05) with silver higher in non-eroded sites while aluminium is higher in the eroded sites. Though iron values did not show any significant difference, it must be observed that high amount of iron and aluminium in these areas may have brought about calcification of subsoils due to oxidation reaction leading to laterification which enhances overland flow

without proper water seepage. This loosens the soil structure so that it can weather easily. Onwuka, *et al.,* (2012) reported further that such soils do not support plants with buttress roots consequently reducing soil organic matter which is a binding factor for the soils against erodibility.

Silicate results of the eroded sites though showed no significant difference ($p < 0.05$) with non-eroded sites, the mean values of both sites revealed that there was a higher silicate content in the eroded sites (figure 47). When analysed according to zones, there exist significant difference ($p < 0.05$) between the zones showing that high silicate level is implicated in soil erodibility (Appendix XXV). Pearson correlational analysis results showed significant correlation ($p < 0.01$ and 0.05) between silicon vs zinc (positively correlated) and silicon vs potassium, magnesium, manganese, cadmium, nickel and silver (negatively correlated) (Table 8). Onwuka, *et al.,* (2012) reported that their geologic formation reveals low clay, low plasticity, low water retaining capacity because silicates are clastic but inorganic sedimentary rock. The implication is high soil erodibility considering the high negative correlation with soil properties that increase soil strength and prevent erosion.

5.1 Conclusion: It will be a great challenge for the current generation to bring the global environment back into balance. Soil as a complex, multicomponent system of interacting materials and properties is reflected from the net effect of these interactions. It has been shown that the interplay between the level of organic matter, cation exchange capacity, base saturation and elemental characteristics of eroded soil strongly correlates with soil erodibilty factors. Most interestingly, Anambra State soils revealed amongst others that essential elements which are critical to plant growth are very necessary for increased physicochemical properties of soils that promote agriculture as well as contribute to soil strength. Knowing that the type and the amount of salt in a soil affects its pH and this determines what is soluble and therefore available in the soils (Conklin, 2005).

5.2 Suggestion for further research: Plants found around these eroded sites need to be studied to understand the uptake level of these nutrients and possible plants that will enhance increased uptake of sodium as the proportion found around eroded sites was significantly high. Both plants and organisms need to be used to ascertain the effect of these minerals on living system that consequently affect the soils of the area. Further studies on aggregate stability and humic substances will give credence to the contribution of soil organic matter of these eroded sites to soil susceptibility to erosion.

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GLOSSARY OF WORDS

Advection: The method of transport of solutes (dissolved contaminants) along stream lines at the average linear seepage flow velocity.

Aeoline soils: Soils transported by wind: loess.

Alluvial soils*:* Soils transported by rivers and streams: Sedimentary clays.

Bulk density: is the density of the particles which measures the average density of a large volume of the powder in a specific medium (usually air) or mass of a unit volume of dry soil (includes both solids and pores)

Fulvic acid: The fraction of humic substances that is soluble in water under all pH conditions.

Glacial soils: Soils transported by glaciers: Glacial till.

Humic acid: The fraction of humic substances that is not soluble in water under acidic conditions (pH‹ 2) but is soluble at higher pH values.

Humic Substances: A category of naturally occurring, biogenic, heterogeneous organic substances that can generally be characterized as being yellow to black in colour, of high molecular weight, and refractory.

Humin: The fraction of the humic substances that is not soluble in water any pH value.

Illite: is a layered alumino-silicate or phyllosilicate, a non-expanding, clay-sized, micaceous mineral.

Kaolinite: is a part of the group of industrial minerals, with the chemical composition $Al_2Si_2O_5(OH)_4$. It is a layered silicate mineral; clay mineral at that.

Lacustrine soils: Soils deposited in lake beds: Lacustrine silts and lacustrine clays.

Laterite: Deep brown soil of cellular structure, easy to excavate but gets hardened on exposure to air owing to the formation of hydrated iron oxides.

Loam: Mixture of sand, silt and clay size particles approximately in equal proportions; sometimes contains organic matter.

Loess: Uniform wind-blown yellowish brown silt or silty clay; exhibits cohesion in the dry condition, which is lost on wetting. Near vertical cuts can be made in the dry condition.

Marine soils: Soils deposited in sea beds: Marine silts and marine clays.

Montmorrillonite: is a group of minerals that typically form in microscopic crystals, forming very soft phyllosilicate; clay.

Pedology: The scientific study of soil as soil is a link between the living and non living components of terrestial ecosystem.

Percolation: is the movement of water through the soil. Measuring the percolation rate will help determine if the soil drains fast enough.

SC Piedmont: South Carolina Piedmont is a census designated place (CDP) along the Saluda River in Anderson and Greenville counties in US state of South Carolina.

Particle density: of a particulate solid or powder, is the density of the particles that make up the powder or the weight per unit volume of the solid portion of soil.

Pedogenesis: which was first explored by a Russian geologist, is the science and study of the processes that lead to the formation of soil which are formed over time as a consequence of climatic, mineral and biological processes.

Pore spaces: The spaces within a rock/soils body that are unoccupied by solid material. Pore spaces include spaces between grains, fractures, vesicles, and voids formed by dissolution.

APPENDICES:

Appendix I: HORIZON DEPTH OF DIFFERENT GULLY PROFILES (Length of section in meters)

S/ No	GULLY PROFILES	LITERATURE CLASSIFICATION OF ERODED AREA (m)	EROSION STATUS (m)	TOP SOIL (m)	SUB SOIL (m)	UNDERLYING ROCKS/STONES (m)	TOTAL DEPTH OF MEASURED SECTION (m)
1	Agu-Awka	Moderately gullied	Moderately gullied	0.96	13.63	3.96	18.55
2	Agulu	Most Severely gullied	Most Severely gullied	0.87	29.93	2.90	33.70
3	Nanka	Most Severely gullied	Most Severely gullied	0.40	11.90	47.77	60.07
4	Ekwulobia	Most Severely gullied	Most Severely gullied	0.94	23.80	13.97	38.71
5	Ogidi	Severely gullied	Severely gullied	0.20	10.48	12.53	23.21
6	Nkpor	Most Severely gullied	Moderately gullied	0.25	9.25	N.A.	9.5
7	Agu-Awka (Burrow Pit	Moderately gullied	Severely gullied	2	9	13.50	24.5

N/B: Nkpor site; the erosion has not reached the underlying rocks and stone layer.
Concrete/Stone erosion control method has been deployed at the site too.

Appendix II: RELATIVE SIZE OF SOIL PARTICLES

a. Percentage sand under different horizons in the studied gully profile

S/ No	GULLY PROFILES	TOP SOIL (%)	SUB SOIL (%)	UNDERLYING ROCKS AND STONES (%)
1	Agu-Awka	80.51	74.23	74.91
2	Agulu	84.01	70.99	79.46
3	Nanka	69.31	72.01	99.6
4	Ekwulobia	69.91	75.11	81.92
5	Ogidi	97.7	93.4	99.5
6	Nkpor	95.0	93.2	N. A
7	Agu-Awka(Burrow pit)	72.90	66.79	66.67
8	Odekpe (Control)	78.16	N.A	N.A
9	Igbariam (Control)	76.98	N.A	N.A
10	Alor (Control)	81.99	N.A	N.A

b. Percentage silt under different horizons in the studied gully profiles

S/No	GULLY PROFILES	TOP SOIL (%)	SUB SOIL (%)	UNDERLYING ROCKS AND STONES (%)
1	Agu-Awka	13.3	9.0	18.96
2	Agulu	5.56	5.56	5.68
3	Nanka	6.42	4.5	0.05
4	Ekwulobia	19.1	6.78	17.29
5	Ogidi	0.10	0.11	0.17
6	Nkpor	0.09	0.16	N. A
7	Agu-Awka(Burrow pit)	8.5	7.2	9.0
8	Odekpe (Control)	2.8	N.A	N.A
9	Igbariam (Control)	12.14	N.A	N.A
10	Alor (Control)	15.13	N.A	N.A

c. Percentage clay under different horizons in the studied gully profiles

S/No	GULLY PROFILES	TOP SOIL (%)	SUB SOIL (%)	UNDERLYING ROCKS AND STONES (%)
1	Agu-Awka	6.19	24.33	6.13
2	Agulu	10.43	23.36	14.86
3	Nanka	24.27	23.49	0.35
4	Ekwulobia	10.99	18.11	0.79
5	Ogidi	2.2	6.49	0.33
6	Nkpor	4.91	6.64	N. A
7	Agu-Awka(Burrow pit)	18.6	26.01	24.33
8	Odekpe (Control)	19.04	N.A	N.A
9	Igbariam (Control)	10.88	N.A	N.A
10	Alor (Control)	2.71	N.A	N.A

Appendix III: SOIL SEDIMENTATION

TIME INTERVALS

S/N	SOIL SAMPLE	TOP SOIL			SUB SOIL			UNDERLYING ROCKS AND STONES		
		5s	10s	20s	5s	10s	20s	5s	10s	20s
1	Agu-Awka	0.092	0.112	0.2	0.87	0.93	0.98	0.49	0.52	0.6
2	Agulu	0.22	0.31	0.42	1.32	1.42	1.52	0.032	0.053	0.06
3	Nanka	0.061	0.066	0.078	0.32	0.42	0.5	0.14	0.22	0.32
4	Ekwulobia	0.072	0.082	0.09	0.063	0.072	0.081	0.077	0.081	0.092
5	Ogidi-Onitsha	2.79	2.83	2.9	0.22	0.68	0.78	0.078	0.083	0.09
6	Nkpor-Onitsha	0.89	0.92	0.18	1.22	1.28	1.32	N.A	N.A	N.A
7	Agu-Awka(Burrow pit)	0.179	0.011	0.089	1.28	1.49	1.52	0.18	0.125	0.28
8	Odekpe (Control)	2.16	0.92	2.82	N.A	N.A	N.A	N.A	N.A	N.A
9	Igbariam (Control)	0.28	0.14	0.3	N.A	N.A	N.A	N.A	N.A	N.A
10	Alor (Control)	0.14	0.28	0.29	N.A	N.A	N.A	N.A	N.A	N.A

Values are cumulative, measured in seconds

Appendix IV: SOIL WATER

a. Natural moisture content (in %)

S/No	GULLY PROFILES	TOP SOIL (%)	SUB SOIL (%)	UNDERLYING ROCKS AND STONES (%)
1	Agu-Awka	7.84	3.72	6.99
2	Agulu	8.12	9.13	6.61
3	Nanka	9.34	10.27	5.73
4	Ekwulobia	7.10	11.87	7.35
5	Ogidi	13.30	9.49	5.85
6	Nkpor	6.03	6.26	N. A
7	Agu-Awka(Burrow pit)	6.31	7.97	8.08
8	Odekpe (Control)	8.03	N.A	N.A
9	Igbariam (Control)	6.50	N.A	N.A
10	Alor (Control)	3.83	N.A	N.A

Appendix V: CALIFORNIA BEARING RATIO (CBR) TEST (%)

S/No	GULLY PROFILES	TOP SOIL (%)	SUB SOIL (%)	UNDERLYING ROCK AND STONES (%)
1	Agu-Awka	73	62	19
2	Agulu	45	57	52
3	Nanka	30	39	37
4	Ekwulobia	47	39	24
5	Ogidi	32	34	33
6	Nkpor	12	72	N.A
7	Agu-Awka(Burrow pit)	46	37	4
8	Odekpe (Control)	51	N.A	N.A
9	Igbariam (Control)	44	N.A	N.A
10	Alor (Control)	48	N.A	N.A

Appendix VI: SOIL DENSITY (G/CM^3)

a. Pore density (g/cm^3)

S/No	GULLY PROFILES	TOP SOIL (g/cm^3)	SUB SOIL (g/cm^3)
1	Agu-Awka	1.30	1.13
2	Agulu	1.35	1.20
3	Nanka	0.99	1.16
4	Ekwulobia	1.18	1.07
5	Ogidi	1.09	1.22
6	Nkpor	1.16	1.16
7	Agu-Awka(Burrow pit)	1.28	1.35
8	Odekpe (Control)	0.85	N.A
9	Igbariam (Control)	1.11	N.A
10	Alor (Control)	1.14	N.A

b. Bulk density (g/cm^3)

S/No	GULLY PROFILES	TOP SOIL (g/cm^3)	SUB SOIL (g/cm^3)	UNDERLYING ROCKS AND STONES (g/cm^3)
1	Agu-Awka	1.25	1.09	1.11
2	Agulu	1.06	1.32	1.04
3	Nanka	1.11	1.19	1.19
4	Ekwulobia	1.06	1.16	1.22
5	Ogidi	1.28	1.19	1.14
6	Nkpor	1.28	1.06	N.A
7	Agu-Awka(Burrow pit)	1.22	0.94	1.06
8	Odekpe (Control)	0.96	N.A	N.A
9	Igbariam (Control)	1.04	N.A	N.A
10	Alor (Control)	1.16	N.A	N.A

Appendix VII: SOIL POROSITY (%)

S/No	GULLY PROFILES	TOP SOIL	SUB SOIL
1	Agu-Awka	0.17	0.21
2	Agulu	0.18	0.16
3	Nanka	0.16	0.14
4	Ekwulobia	0.15	0.18
5	Ogidi	0.22	0.18
6	Nkpor	0.13	0.14
7	Agu-Awka(Burrow pit)	0.13	0.12
8	Odekpe (Control)	0.14	N.A
9	Igbariam (Control)	0.20	N.A
10	Alor (Control)	0.19	N.A

Porosity = 1 - (BD/PD) x 100, where BD is the bulk density and PD is the pore density.

Appendix VIII: SOIL COMPACTION

S/No	GULLY PROFILES	TOP SOIL MDD (kg/m³) OMC (%)	SUB SOIL MDD (kg/m³) OMC (%)	UNDERLYING ROCKS AND STONES MDD (kg/m³) OMC (%)
1	Agu-Awka	1859.42 11.70	2023.55 5.70	1932.61 13.06
2	Agulu	2004.07 9.30	1890.66 13.08	1944.52 11.85
3	Nanka	1843.76 13.19	1905.68 13.03	1788.88 14.99
4	Ekwulobia	1902.13 12.13	1763.14 15.19	1907.71 13.07
5	Ogidi	1681.57 18.81	1751.90 10.74	1776.12 8.70
6	Nkpor	1757.95 11.50	1946.50 11.63	N.A
7	Agu-Awka(Burrow pit)	1948.64 11.82	1744.12 9.62	1691.2 11.2
8	Odekpe (Control)	1645.47 19.36	N.A	N.A
9	Igbariam (Control)	1869.57 12.16	N.A	N.A
10	Alor (Control)	1862.43 11.50	N.A	N.A

N/B: The MDD were converted to g/cm³ for the plot.

Appendix IX: SOIL PERCOLATION (percolation time in seconds)

S/No	GULLY PROFILES	TOP SOIL (s)	SUB SOIL (s)	UNDERLYING ROCKS AND STONES (s)
1	Agu-Awka	36.33	381	294
2	Agulu	207.33	322.33	60.33
3	Nanka	111	708.67	118
4	Ekwulobia	1068	143.67	239.67
5	Ogidi	726	180	25.33
6	Nkpor	726	340.67	N.A
7	Agu-Awka(Burrow pit)	392.67	98	16
8	Odekpe (Control)	1880	N.A	N.A
9	Igbariam (Control)	206	N.A	N.A
10	Alor (Control)	203	N.A	N.A

Values of Average (of 3 percolations) time taken for 1litre of water to drain into the soil.

Appendix X: SOIL TEMPERATURE (^{0}C)

S/N	SOIL SAMPLE	TOP SOIL									
		AREA UNDER SHADE					AREA UNDER SUN				
		AGL		BGL			AGL		BGL		
1	Agu-Awka	36	34	36	34	32	36	34	34	32	30
2	Agulu	32	34	36	34	32	34	30	30	28	27
3	Nanka	30	28	26	26	24	32	26	24	24	22
4	Ekwulobia	34	32	32	32	30	38	40	34	34	32
5	Ogidi-Onitsha	30	30	28	28	29	33	38	32	30	28
6	Nkpor-Onitsha	30	30	28	28	30	31	32	32	30	30
7	Agu-Awka(Burrow pit)	32	33	32	32	32	34	38	34	33	32
8	Odekpe (Control)	34	34	30	28	28	36	38	32	30	30
9	Igbariam (Control)	34	32	30	30	28	36	36	36	32	30
10	Alor (Control)	34	31	29	28	27	36	34	30	30	30

LEGEND: AGL= Above Ground level; BGL= Below Ground Level

Appendix XI: pH VALUES

S/No	GULLY PROFILES	TOP SOIL	SUB SOIL	UNDERLYING ROCKS AND STONES
1	Agu-Awka	6.48	6.56	6.63
2	Agulu	6.72	6.43	6.52
3	Nanka	5.87	7.13	7.22
4	Ekwulobia	6.78	6.38	5.93
5	Ogidi	6.48	6.39	5.98
6	Nkpor	5.94	5.88	N.A
7	Agu-Awka(Burrow pit)	6.22	6.54	6.72
8	Odekpe (Control)	7.03	N.A	N.A
9	Igbariam (Control)	6.48	N.A	N.A
10	Alor (Control)	6.83	N.A	N.A

Appendix XII: SOIL RESISTIVITY (cm/µs)

S/No	GULLY PROFILES	TOP SOIL (cm/µs)	SUB SOIL (cm/µs)	UNDERLYING ROCKS AND STONES (cm/µs)
1	Agu-Awka	0.0006527	0.00030	0.0167
2	Agulu	0.0357	0.0357	0.0385
3	Nanka	0.0133	0.033	0.0023
4	Ekwulobia	0.0074	0.0087	0.037
5	Ogidi	0.0052	0.05	0.019
6	Nkpor	0.056	0.04	N.A
7	Agu-Awka(Burrow pit)	0.0375	0.568	0.0732
8	Odekpe (Control)	0.137	N.A	N.A
9	Igbariam (Control)	0.0568	N.A	N.A
10	Alor (Control)	0.0075	N.A	N.A

Appendix XIII: SOIL ORGANIC MATTER or HUMUS CONTENT (% Concentration)

S/No	GULLY PROFILES	TOP SOIL (% Conc.)	SUB SOIL (% Conc.)	UNDERLYING ROCKS AND STONES (%Conc.)
1	Agu-Awka	2.25	1.83	1.23
2	Agulu	2.30	1.64	2.03
3	Nanka	1.16	1.67	2.17
4	Ekwulobia	1.30	1.23	1.88
5	Ogidi	2.08	1.41	1.43
6	Nkpor	1.32	1.97	N.A
7	Agu-Awka(Burrow pit)	1.96	2.75	1.15
8	Odekpe (Control)	1.16	N.A	N.A
9	Igbariam (Control)	1.79	N.A	N.A
10	Alor (Control)	1.85	N.A	N.A

Appendix XIV: PERCENTAGE LOSS ON IGNITION (%)

S/No	GULLY PROFILES	TOP SOIL (%)	SUB SOIL (%)	UNDERLYING ROCK AND STONES (%)
1	Agu-Awka	39	34.5	49.5
2	Agulu	42	25	22.5
3	Nanka	58.5	42.5	24
4	Ekwulobia	47	46	38
5	Ogidi	50.5	28	28
6	Nkpor	17	40	N.A
7	Agu-Awka(Burrow pit)	1	3	5
8	Odekpe (Control)	15	N.A	N.A
9	Igbariam (Control)	5	N.A	N.A
10	Alor (Control)	15	N.A	N.A

Appendix XV: SOIL CATION EXCHANGE CAPACITY (cmol$_c$/kg)

S/No	GULLY PROFILES	TOP SOIL (cmol$_c$/kg)	SUB SOIL (cmol$_c$/kg)
1	Agu-Awka	0.20	0.44
2	Agulu	2.08	0.34
3	Nanka	2.08	0.29
4	Ekwulobia	1.15	0.31
5	Ogidi	2.11	0.42
6	Nkpor	21.26	0.29
7	Agu-Awka(Burrow pit)	0.29	0.20
8	Odekpe (Control)	0.24	N.A
9	Igbariam (Control)	0.25	N.A
10	Alor (Control)	0.39	N.A

Appendix XVI: BASE SATURATION (%)

S/No	GULLY PROFILES	TOP SOIL (%)	SUB SOIL (%)
1	Agu-Awka	106.79	102.09
2	Agulu	100.12	102.19
3	Nanka	100.27	103.38
4	Ekwulobia	103.94	100.86
5	Ogidi	100.06	101.68
6	Nkpor	100.13	101.68
7	Agu-Awka(Burrow pit)	110.37	101.74
8	Odekpe (Control)	102.20	N.A
9	Igbariam (Control)	101.47	N.A
10	Alor (Control)	100.32	N.A

Appendix XVII: SOIL RHEOLOGY (pa.s) Pascal/sec (Spindle 1, RPM = 60, Temp = 30^0C)

S/No	GULLY PROFILES	TOP SOIL (pa.s)	SUB SOIL (pa.s)	UNDERLYING ROCKS AND STONES (pa.s)
1	Agu-Awka	0.081	0.079	0.085
2	Agulu	0.090	0.085	0.087
3	Nanka	0.078	0.091	0.085
4	Ekwulobia	0.088	0.091	0.077
5	Ogidi	0.096	0.079	0.072
6	Nkpor	0.083	0.081	N.A
7	Agu-Awka(Burrow pit)	0.080	0.079	0.079
8	Odekpe (Control)	0.079	N.A	N.A
9	Igbariam (Control)	0.083	N.A	N.A
10	Alor (Control)	0.067	N.A	N.A

APPENDIX XVIII: CONCENTRATIONS OF EXCHANGABLE CATIONS (in ppm)

a. Sodium (in ppm)

S/No	GULLY PROFILES	TOP SOIL	SUB SOIL
1	Agu-Awka	31.462	92.158
2	Agulu	475.654	76.077
3	Nanka	475.654	66.136
4	Ekwulobia	263.192	70.038
5	Ogidi	475.654	94.423
6	Nkpor	475.654	63.846
7	Agu-Awka(Burrow pit)	44.731	38.596
8	Odekpe (Control)	24.962	N.A
9	Igbariam (Control)	35.750	N.A
10	Alor (Control)	47.39	N.A

b. Calcium (in ppm)

S/No	GULLY PROFILES	TOP SOIL	SUB SOIL	UNDERLYING ROCKS AND STONES
1	Agu-Awka	2.716	1.822	0.897
2	Agulu	0.495	1.471	0.248
3	Nanka	1.125	1.992	2.522
4	Ekwulobia	9.1	0.525	1.532
5	Ogidi	0.249	0.975	0.642
6	Nkpor	0.568	0.969	N.A
7	Agu-Awka(Burrow pit)	6.013	0.711	1.376
8	Odekpe (Control)	1.045	N.A	N.A
9	Igbariam (Control)	0.725	N.A	N.A
10	Alor (Control)	1.484	N.A	N.A

c. Magnesium (in ppm)

S/No	GULLY PROFILES	TOP SOIL	SUB SOIL	UNDERLYING ROCKS AND STONES
1	Agu-Awka	5.04	3.86	0.2
2	Agulu	0.16	0.13	0.13
3	Nanka	0	0	6.97
4	Ekwulobia	0.07	0.05	0.02
5	Ogidi	2.26	0.72	3.48
6	Nkpor	4.79	0.04	N.A
7	Agu-Awka(Burrow pit)	10.39	3.46	3.43
8	Odekpe (Control)	9.48	N.A	N.A
9	Igbariam (Control)	8.6	N.A	N.A
10	Alor (Control)	8.1	N.A	N.A

d. Potassium (in ppm)

S/No	GULLY PROFILES	TOP SOIL	SUB SOIL	UNDERLYING ROCKS AND STONES
1	Agu-Awka	8.298	1.073	2.546
2	Agulu	2.281	1.743	2.578
3	Nanka	6.423	2.885	2.977
4	Ekwulobia	3.735	0.727	3.033
5	Ogidi	9.449	1.373	2.426
6	Nkpor	7.049	3.998	N.A
7	Agu-Awka(Burrow pit)	3.374	2.978	2.059
8	Odekpe (Control)	19.678	N.A	N.A
9	Igbariam (Control)	7.896	N.A	N.A
10	Alor (Control)	1.108	N.A	N.A

Appendix XIX: CONCENTRATIONS OF TRACE ELEMENTS (in ppm)

a. Zinc (in ppm)

S/No	GULLY PROFILES	TOP SOIL	SUB SOIL	UNDERLYING ROCKS AND STONES
1	Agu-Awka	163.1	117.41	67
2	Agulu	102.94	159.59	53.6
3	Nanka	117.11	173.3	148.02
4	Ekwulobia	102.79	58.48	78.88
5	Ogidi	107.21	136.6	141.78
6	Nkpor	38.83	45.84	N.A
7	Agu-Awka(Burrow pit)	44.01	75.84	102.49
8	Odekpe (Control)	7.01	N.A	N.A
9	Igbariam (Control)	16.9	N.A	N.A
10	Alor (Control)	86.63	N.A	N.A

b. Copper (in ppm)

S/No	GULLY PROFILES	TOP SOIL	SUB SOIL	UNDERLYING ROCKS AND STONES
1	Agu-Awka	5.33	24.67	4.67
2	Agulu	2.67	11.33	16
3	Nanka	3.33	3.33	5.33
4	Ekwulobia	3.33	9.33	2.67
5	Ogidi	9.33	5.33	5.33
6	Nkpor	4	5.33	N.A
7	Agu-Awka(Burrow pit)	31.33	3.33	4
8	Odekpe (Control)	16	N.A	N.A
9	Igbariam (Control)	25.33	N.A	N.A
10	Alor (Control)	20	N.A	N.A

c. Manganese (in ppm)

S/No	GULLY PROFILES	TOP SOIL	SUB SOIL	UNDERLYING ROCKS AND STONES
1	Agu-Awka	8	0	0
2	Agulu	0	0	0
3	Nanka	2	0	4
4	Ekwulobia	0	2	4
5	Ogidi	0	6	0
6	Nkpor	8	2	N.A
7	Agu-Awka(Burrow pit)	14	0	0
8	Odekpe (Control)	0	N.A	N.A
9	Igbariam (Control)	32	N.A	N.A
10	Alor (Control)	0	N.A	N.A

d. Cobalt (in ppm)

S/No	GULLY PROFILES	TOP SOIL	SUB SOIL	UNDERLYING ROCKS AND STONES
1	Agu-Awka	0.198	0.215	0.185
2	Agulu	0.188	0.197	0.153
3	Nanka	0.213	0.149	0.138
4	Ekwulobia	0.162	0.123	0.096
5	Ogidi	0	0.108	0.114
6	Nkpor	0	0.048	N.A
7	Agu-Awka(Burrow pit)	0.136	0.225	0.146
8	Odekpe (Control)	0.120	N.A	N.A
9	Igbariam (Control)	0.250	N.A	N.A
10	Alor (Control)	0.197	N.A	N.A

Appendix XX: CONCENTRATIONS OF HEAVY METALS (in ppm)

a. Cadmium (in ppm)

S/No	GULLY PROFILES	TOP SOIL	SUB SOIL	UNDERLYING ROCKS AND STONES
1	Agu-Awka	0	0	0
2	Agulu	0	0	0
3	Nanka	0	0.007	0
4	Ekwulobia	0	0	0
5	Ogidi	0	0	0
6	Nkpor	0.004	0.006	N.A
7	Agu-Awka(Burrow pit)	0	0	0.005
8	Odekpe (Control)	0.004	N.A	N.A
9	Igbariam (Control)	0.033	N.A	N.A
10	Alor (Control)	0.006	N.A	N.A

b. Nickel (in ppm)

S/No	GULLY PROFILES	TOP SOIL	SUB SOIL	UNDERLYING ROCKS AND STONES
1	Agu-Awka	0.034	0.02	0.109
2	Agulu	0.05	0.029	0.725
3	Nanka	0.268	0.42	0
4	Ekwulobia	0.316	0.484	0
5	Ogidi	0	0.001	0
6	Nkpor	0.004	0.901	N.A
7	Agu-Awka(Burrow pit)	0.06	0.62	0.06
8	Odekpe (Control)	0.594	N.A	N.A
9	Igbariam (Control)	0.63	N.A	N.A
10	Alor (Control)	0.089	N.A	N.A

c. Chromium (in ppm)

S/No	GULLY PROFILES	TOP SOIL	SUB SOIL	UNDERLYING ROCKS AND STONES
1	Agu-Awka	116	104	108
2	Agulu	72	88	84
3	Nanka	108	124	96
4	Ekwulobia	68	72	64
5	Ogidi	92	96	80
6	Nkpor	72	96	N.A
7	Agu-Awka(Burrow pit)	100	100	136
8	Odekpe (Control)	96	N.A	N.A
9	Igbariam (Control)	92	N.A	N.A
10	Alor (Control)	96	N.A	N.A

d. Lead (in ppm)

S/No	GULLY PROFILES	TOP SOIL	SUB SOIL	UNDERLYING ROCKS AND STONES
1	Agu-Awka	0.2	0.05	0.09
2	Agulu	0.2	0.05	0.14
3	Nanka	1.2	0.05	0.04
4	Ekwulobia	0.11	0.27	0.5
5	Ogidi	0.08	0.22	0.08
6	Nkpor	0.13	0.24	N.A
7	Agu-Awka(Burrow pit)	0.11	5.5	0.35
8	Odekpe (Control)	0.18	N.A	N.A
9	Igbariam (Control)	5.27	N.A	N.A
10	Alor (Control)	13.22	N.A	N.A

Appendix XXI: CONCENTRATIONS OF OTHER METALS (in ppm)

a. Silver (in ppm)

S/No	GULLY PROFILES	TOP SOIL	SUB SOIL	UNDERLYING ROCKS AND STONES
1	Agu-Awka	0.711	0.886	1.612
2	Agulu	0.699	0.551	1.567
3	Nanka	0.922	0.716	0.649
4	Ekwulobia	0.662	1.231	0
5	Ogidi	0.858	0.703	0.564
6	Nkpor	1.854	2.094	N.A
7	Agu-Awka(Burrow pit)	0	1.319	1.327
8	Odekpe (Control)	13.70	N.A	N.A
9	Igbariam (Control)	5.444	N.A	N.A
10	Alor (Control)	1.108	N.A	N.A

b. Iron (in ppm)

S/No	GULLY PROFILES	TOP SOIL	SUB SOIL	UNDERLYING ROCKS AND STONES
1	Agu-Awka	2.16	5.14	14.04
2	Agulu	17.79	15.45	15.05
3	Nanka	13.92	11.35	5.68
4	Ekwulobia	5.5	9.59	8.11
5	Ogidi	5.54	17.03	15
6	Nkpor	16.44	13.33	N.A
7	Agu-Awka(Burrow pit)	9.23	0.81	1.85
8	Odekpe (Control)	14.77	N.A	N.A
9	Igbariam (Control)	1.13	N.A	N.A
10	Alor (Control)	8.38	N.A	N.A

c. Aluminium (in ppm)

S/No	GULLY PROFILES	TOP SOIL	SUB SOIL	UNDERLYING ROCKS AND STONES
1	Agu-Awka	4.90	0	0.37
2	Agulu	7.66	9.61	26.21
3	Nanka	13.12	6.47	21.26
4	Ekwulobia	3.20	7.11	11.80
5	Ogidi	21.01	28.24	6.81
6	Nkpor	13.31	8.89	N.A
7	Agu-Awka(Burrow pit)	11.47	2.66	4.66
8	Odekpe (Control)	0	N.A	N.A
9	Igbariam (Control)	4.87	N.A	N.A
10	Alor (Control)	0	N.A	N.A

Appendix XXII: CONCENTRATIONS OF METALLOID (in ppm)

a. Silicon (in ppm)

S/No	GULLY PROFILES	TOP SOIL	SUB SOIL	UNDERLYING ROCKS AND STONES
1	Agu-Awka	7.14	9.82	5.11
2	Agulu	9.31	5.45	6.28
3	Nanka	8.19	4.2	3.22
4	Ekwulobia	7.14	8.32	9.41
5	Ogidi	5.81	6.32	7.31
6	Nkpor	6.8	8.31	N.A
7	Agu-Awka(Burrow pit)	5.81	6.32	7.31
8	Odekpe (Control)	4.2	N.A	N.A
9	Igbariam (Control)	3.22	N.A	N.A
10	Alor (Control)	8.19	N.A	N.A