INVESTIGATION OF THE CHEMICAL STABILIZATION OF SOME SOILS OF GULLY EROSION-PRONE AREAS OF ANAMBRA STATE

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CERTIFICATION PAGE

I, **Okoye Okechukwu Nnaemeka N.** hereby certify that I am responsible for the work submitted in this thesis and that this is an original work which has not been submitted to this university or any other institution for the award of a degree or a diploma.

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Signature of Candidate Date

APPROVAL PAGE

DEDICATION

I dedicate this work to the Lord Jesus Christ, the Fountain of Living Waters. I also dedicate it to all postgraduate students who have been finding it quite difficult to sponsor themselves through their programmes, yet persisted, by the help of God to do so.

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successful completion of this research. God, may Your Name be highly exalted in Jesus Name. Amen.

ABSTRACT

Soil erosion is the removal/movement of soil particles from one area to another; and one method of preventing these soil particles from eroding is by chemical stabilization (which involves altering the properties of the soil particles by adding cement, lime or any other cementing material). The aim of this study is to investigate the chemical stabilization of some soils of gully erosion-prone areas of Anambra State. Seven soil samples were collected from seven different locations of Anambra State. Two of the soil samples were non-erosion prone, while five were erosion prone. Physico-chemical analyses of these soil samples were conducted using different experimental techniques. The elemental components of the soil samples were analysed using AAS (Atomic Absorption Spectrophotometer). Results obtained from the non-erosive soils were used as control, and compare with the results from the erosive soils. From the results, the values of the cations (ppm), anions (ppm) and percentage clay were relatively higher in non-erosive soils than the erosive soils. For the percentage sulphur, percentage organic carbon and organic matter, pH in water and chloride, percentage moisture content and porosity (g/mL) had values which varied interchangeably. For percentage sand, the erosive soils have higher percentage sand than in the non-erosive soils. The 10g and 15g of the five erosive soils were each stabilized with 2mL of the following chemicals: $AlCl_3$, $CaCl_2$, $MgCl_2$, $CaCO_3$ and $Ca(OH)_2$. After that, a pocket penetrometer was used to test for the Unconfined Compressive Strength (UCS). The results for the use of $AlCl_3$ salt solution on 10g and 15g of Nanka, Oko, Oba, Nnewi and Oraukwu erosive soils are: 5.00, 5.00, 5.00, 4.00, 4.60kg/cm^2 and 5.00, 5.00, 5.00, 5.00, 5.00kg/cm^2, respectively. The results for the use of $MgCl_2$ salt solution on 10g and 15g of Nanka, Oko, Oba, Nnewi and Oraukwu erosive soils are: 5.00, 2.60, 3.80, 2.50, 5.00kg/cm^2 and 2.24, 5.00, 5.00, 3.30, 5.00kg/cm^2, respectively. The results for the use of $CaCl_2$ on 10g and 15g of Nanka, Oko, Oba, Nnewi and Oraukwu erosive soils are: 5.00, 3.00, 5.00, 5.00, 4.40kg/cm^2 and 5.00, 5.00, 5.00, 5.00, 5.00kg/cm^2, respectively. The results for the use of $Ca(OH)_2$ on 10g and 15g of Nanka, Oko, Oba, Nnewi and Oraukwu erosive soils are: 1.55, 1.65, 1.30, 1.26, 0.80kg/cm^2 and 0.60, 0.60, 2.52, 1.10, 0.15kg/cm^2, respectively. The results for the use of $CaCO_3$ on 10g and 15g of Nanka, Oko, Oba, Nnewi and Oraukwu erosive soils are: 1.10, 1.74, 1.70, 1.24, 1.45kg/cm^2 and 1.14, 2.26, 3.65, 0.90, 3.74kg/cm^2, respectively. Statistical analysis, such as: Kruskal Wallis Test, Mean Test and Wilcoxon Signed Rank Test were used to analyse the data. From the overall results, the increase in the rate of stabilization of the following salts as it relates to the use of different soil-sample masses are as follows: $AlCl_3 > CaCl_2 > MgCl_2 > CaCO_3 > Ca(OH)_2$. This then means that the menace of soil erosion in Anambra State can be curbed by the use of these chemical solutions, which when administered in their right proportions, will go a long way in solving the problem of gully erosion in the State.

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CHAPTER ONE

INTRODUCTION

1.1 Background to the Study

One of the most important natural resources for humans is soil. It is a limited, strategic resource of huge social, economic and environmental significance [Telles *et al.*, 2013]. Soils play an essential role for mankind because they provide the fundamental ecosystem services required for human life primarily for the production of food by providing the environment for plant growth [Okorafor *et al.*, 2017].

Soil is a key component of the earth system that controls the bio-geo-chemical and hydrological cycles and also offers to the human societies many resources, goods and services [Adugna*et al.*, 2015]. Soil is a dynamic, natural body that occurs on the earth's surface which supports the growth of plants. Soils are formed by the decomposition of rock and organic matter over many years [Lad and Samant, 2015].

Soils are fundamental to life on earth. They are central to sustainable development and the future we want. Soils have critical relevance to global issues such as food and water security and climate regulation, and they are increasingly recognized as major contributors to a wide range of ecosystem services [Montanarella *et al.*, 2016].Soils provide the pathways through which water and nutrients move to the roots of plants, they are the matrix for nutrient transformations and environment for micro-organisms and fauna [Okorafor *et al*, 2017].

Soil is a vital component of the earth system fundamental for many aspects of science. The damage caused to soils by soil erosion is therefore of considerable concern [Ola *et al*, 2015]. According to Konz *et al* (2010), "Soil erosion is a major environmental problem in many parts of the world".

Erosion is one of the surface processes that sculpture the earth's landscape and constitutes one of the global environmental problems [Abdulfatai *et al*., 2014]. Erosion alters the soil chemical, physical and biological properties, reducing soil fertility and, as a direct result, soil productivity, which has caused concern among researchers in various fields about the losses and costs incurred [Telles *et al*., 2011].

The impacts of erosion are enormous; they include the lowering of soil production capacity hence, the main cause of low crop yield, a situation that requires higher input to bring the land back to shape. Others include sediment yield in streams and reservoirs, reduction of water quality status and the deposition of toxic materials on farmland [Egbai *et al*., 2012].

The Nigerian environment is degraded through the menace of soil erosion in several parts of the country [Mallam *et al*., 2016]. Yusuf *et al.* (2016) made the following statement concerning erosion in Nigeria: "Erosion is a serious problem in the tropical countries like Nigeria due to heavy rainfall with high intensity which is common in tropics. The problem of erosion is a dual problem because the land from where soil is removed and the place where soil particle is deposited are destroyed. Many arable lands have been destroyed as a result of washing away of the top soil to another place. Some places such as farm land, urban areas and roads (highways) have been destroyed especially in the southern parts (South-east, South-south and South-west) of Nigeria. Erosion causes loss of the top soil and reduces the fertility of the agricultural soil".

Soil erosion, world over, is becoming a serious problem because of considerable economic damage it causes to the society at large. In India, the annual average loss of nutrients from land due to soil erosion has been estimated as 5.4-8.4 million tonnes (Mt) and the loss of production due to non-development of ravines has been estimated to be 3 Mt per annum [Pandea *et al.*, 2013].

As quantities of soil particles are carried away on daily basis unnoticeably, soil quality depreciates significantly. The soil that erosion carries off now totals 22 billion tons a year worldwide. In Europe, 12% of soil is threatened by water erosion alone. Similarly, 95 million and 500 million of land are badly affected by soil erosion in North America and Africa respectively [Abegunde *et al.*, 2006]. It is estimated that erosion of agricultural soils in the United States is responsible for loss of an average of 30 tons per hectare per year, about eight times greater than the rate of soil formation in a human lifetime [Ghabbour *et al.*, 2017].

Economic losses from soil erosion in South Asia is said to have currently accumulated to 6.9 billion dollars[Abegunde *et al.*, 2006]. Chinafaces one of the most serious soil erosion problems in the world. The latest remote – sensing survey of the area shows that the country has some 3.56 million square kilometres of soil erosion areas [Abegunde *et al.*, 2006]. This accounts for about 38% of China's total territory. If only the economic cost of soil erosion in different parts of the globe were easily calculable, planners and politicians would think twice before allowing activities and projects that damage the land. This is because, soil making processes are notoriously slow, requiring from 200 to 1000 years to form 2.5 centimetres of topsoil under normal agricultural condition. In South-Asia, 140 million hectares, or 43% of the region's total agricultural land, suffered from one form of degradation or more; soil erosion, impacting many areas than other forms of degradation. In South Africa, annual soil loss is estimated at 300-400 million tonnes. Study revealed that not less than 43% of the country's population were confined to 13% of the land. This has resulted into pressure on and over-utilization of the land, exposing it to soil erosion and causing poverty to the people. It requires R1000 million each year to replace soil nutrients carried out to the sea by run-offs annually in the area [Abegunde *et al*, 2006]. The soil loss rate by water ranges from 16 to over 300 mg ha^{-1} yr^{-1} in Ethiopia, mainly depending on the degree of slope gradient, intensity and type of land cover and nature of rainfall intensities [Adugna *et al.*, 2015].

The subject of soil erosion and its associated menace have become a matter of concern in Nigeria today. It has undoubtedly become known as a potential environmental hazard to almost every community in Nigeria. This menace affects soil properties and the potential of soil resource in many communities all over the Federation are being destroyed [Ubuoh *et al.*, 2013]. According to Eyankware *et al.* (2015), soil erosion is a well-known environmental problem in South-eastern Nigeria. It is the removal of soil particles from surface of the earth, transportation and deposition of the particles by the action of wind, heat, and water. Soil erosion encompasses all activities by water in all forms (rain, flood, ice, sea) resulting in soil erosion. Socio-economic problems caused by soil erosion include removal of nutrients from soil, leading to low farm produce and destruction of farms. It also results in collapse of buildings. Soil erosion by water is a continuing, long-term problem related to South-eastern part of Nigeria forming a threat to infrastructure and agricultural production.

The soil in the South Eastern part of Nigeria constitutes sandy stones and loose surface. This makes such areas to be vulnerable to attacks by floods; and in some areas the steep slopes reinforce the rapid flow of rain water to wash away the soil including the vegetation and other nutrients [Egede, 2013]. Akinnagbe and

Umukoro (2011) stated that, "Sheet erosion is nation-wide while gully erosion is most severe and dense in certain southern states of Anambra, Imo, Abia, Enugu, Ondo, Delta and Akwa-Ibom".

Gully erosion in Anambra State, South Eastern part of Nigeria has continued to pose a challenge to geoscientist and other environmental scientists [Eyankware *et al.*, 2015]. The menace has taken its toll on the socioeconomic wellbeing of the people living in the study area, such that lands used for agricultural and industrial purposes, ancestral homes, crops and livestock production, and other infrastructure are lost to the hazard at an alarming rate. Soils of south eastern Nigeria have high erodibility and are classed as structurally unstable. Therefore gully erosion forms a major type of soil degradation in the area [Eyankware *et al.*, 2015].

Anambra is famous with its Agulu-Nanka-Oko- Ekwulobia gullies. Gullies of about 120m depth and 2km width have been recorded in this area. In Anambra State, erosion is a peculiar environmental problem. Almost all communities in the State are affected by one form of erosion or the other [Obi and Okekeogbu, 2017]. According to recent media reports, over 70 percent of the land of the State is ravaged by or threatened by erosion at various levels. Available statistics indicate the presence of about 500 gully erosions spread across the rural communities of the area. Notable areas include: Aguata/Orumba L.G.A's with about 78 gullies, Nnewi 60, Njikoka/Aniocha 50 gullies, Idemili 46, Ihiala 40, Awka 30, Onitsha 22, Anambra/Oyi 16 gullies [Obi and Okekeogbu, 2017]. Okoye *et al.*(2014) made the following points: "Houses with the entire families living in them have often been swallowed by landslides in Nanka, Agulu,Nnewi, Ekwulumili, Obosi etc. Sometimes major landslides carry away many houses, trees, roads, all standing as they were, into loose flood plains or wide deep gully bottoms. Poorly constructed roads that become major flood channels later were wantonly contracted out and built. Ancient and recent natural flood/stream/river channels are often blocked with buildings without leaving enough safety flood flow measures. Sensitive drainage areas, wetlands and flood channels are encroached upon by hungry land developers. Unapproved and unplanned buildings spring up in Anambra State within and across these environmentally sensitive areas and later block them. Excavations of red earth, laterite and sands are carried out anywhere and anyhow, often without proper planning, or permission from the relevant government authorities. The harmful deforestation and devegetation activities have resulted in the continued loss of the rainforest belt, and the consequent savannizationof parts of Anambra State. These devastating events have kept the citizens of the State in a state of continuous concern, fear and dismay all the year-round. Land, lives, infrastructure, and property are regularly lost yearly. The citizens are now so threatened and desperate for their life existence and sustenance".

1.2 Statement of the Problem

In Anambra State, there are many areas that have stable soils, which are suitable for engineering works, construction, agricultural practices and other anthropogenic activities. Unfortunately, there are several parts of the State that have unstable soils which are gully erosion prone. Hence, such areas have very big gully erosion sites of varying magnitudes. Several, if not all of such gullies, have destroyed many properties and have even taken human lives. Typical of such areas are Nanka, Oko, Ekwulobia, Ekwulunmili, Nnewi, Abagana, Ebenebe, Obosi and many other places. For example, Egboka and Okpoko (1984) stated that the development of the gullies has caused extensive damage to the environment, and has driven many people away from their homes and farmlands. According to Obiadi *et al.* (2012), gully erosion in Anambra State, South-Eastern Nigeria has continued to pose challenges to geoscientists and other environmental scientists. The menace has taken its toll on the socioeconomic wellbeing of the people living in the affected areas and the country at large, such that lands used for aesthetic, agricultural and industrial purposes, ancestral homes, crops, livestock and other infrastructure are everyday lost to the hazard at alarming rate. Field studies showed that the environmental hazard has remained active over the years, defying control measures put in place by government, communities and individuals.

Several scholars have employed several methods for preventing or minimizing this menace. For example, Egboka and Orji (2016) proffered some solutions like avoiding human induced soil/gully erosion initiation, public awareness, planting of vegetation on flood plains to be encouraged, laws guiding construction and building codes that should be enacted by governments and relevant agencies; construction of special road infrastructure must be emplaced on solid engineering structures for soil and gully erosion control as well as regular maintenance of roads and drainages. Also, a research carried out by Ezezika and Adetona (2011) on Resolving the gully erosion problem in Southeastern Nigeria: Innovation through public awareness and community-based approaches, came to a conclusion that community-based, low-technology land management practices and public awareness programs through workshops could halt the development of many gullies in the South-eastern region of Nigeria.

Despite several solutions already proffered by these scholars to curb this menace, there has been, so far, little or no remedy.

In response to this problem, the study then proposes to investigate the physico-chemical characteristics of the soils of these gully erosion-prone areas, and hence come up with chemicals suitable for stabilizing them.

1.3 Aim and Objectives of the Study

The aim of this research is to chemically stabilize some soils gully erosion-prone areas of Anambra State, with a view to ascertaining suitable chemicals for stabilizingthose erosion sites.

To achieve the above aim, the following objectives will be pursued:

1. To determine the cation and anion compositions of the soil samples of the gully erosion and non-gully erosion prone soils of the area.
2. To determine the sulphur content, organic matter and organic carbon in the erosion and non-gully erosion prone soil samples.
3. To determine the porosity of the soil samples.
4. To prepare salt solutions for efficient and effective stabilization of the erosive soil samples.
5. To determine the extent of stabilization of the erosive soils by using 16-T171 model penetrometer.

1.4 Scope of Study

The study is concerned with finding out the physico-chemical constituents in the erosion prone and non-erosion prone areas in Anambra State. Also the research will use the following towns as study sites: Nanka, Nnewi, Oko, Oba, Oraukwu, Awka and Umunya. Then using standard analytical techniques the study is concerned with finding out the physical and chemical compositions of these sites.

1.5 Limitation of Study

A study of this type ought to consider two seasons of the year differently, but in this study, they were handled alike. In other words, the seasonal variations that affected the soil composition of the different soil samples, were not separately considered.

1.6 Significance of Study

- This research will help to solve the environmental menace caused by gully erosion in several communities in Anambra State, albeit in Nigeria.
- The most suitable salt(s) of these elements that are used for gully erosion-sites stabilization will be identified.
- It will provide a short term and long term solution to gully erosion prone areas in the State.

1.7.0 Study Area

In this study, the sites used are Nanka Erosion Site, Oko Erosion Site, Oraukwu Erosion Site, Nnewi Erosion Site, Oba Erosion Site, Umunya Non-Erosion Site (an Excavation Site) and Awka Non-Erosion Site (an Excavation Site), which are all located within Anambra State.

1.7.1 Brief History of Anambra State

Anambra possesses a history that stretches back to the 9th century AD, as revealed by archaeological excavations at Igbo-Ukwu and Ezira; Great works of art in iron, bronze, copper, and pottery works belonging to the ancient Kingdom of Nri, revealed a sophisticated divine Kingship administrative system which held sway in the area of Anambra from c. 948 AD to 1911 [http://www.anambrastate.gov.ng/history, Date Assessed, 04/03.2018].

Old Anambra State was created in 1976 from part of East Central State, and its capital was Enugu. A further re-organisation in 1991 divided Anambra into two states, Anambra and Enugu. The capital of Anambra is Awka [http://www.anambrastate.gov.ng/history, Date Assessed, 04/03.2018].

1.7.2. Geology of the Study Area

The geological setting in the study area is that of layered sequences in which a predominantly sandstone formation is underlain by a predominantly shale formation, the Imo Shale. The Imo Shale (Palaeocene – Lower Eocene) is a transgressive sequence of dark grey shale and outcrops on the plane of the Mamu River (Figure 1). No active gullies are found in this formation. The Ameki Formation (Middle – Upper Eocene) is a regressive sequence composed of sandstone units with intercalations of claystone, shale and limestone. The sandstone is expressed as a NW – SE trending cuesta with a north-east facing scarp slope. Active gullies of enormous magnitude are found in this unit. The general strike of the rock unit is approximately N – S with a gentle westward dip of less than 50. The soils of the study area are derived from the underlying Ameki Formation [Obiadi *et al.*, 2011].

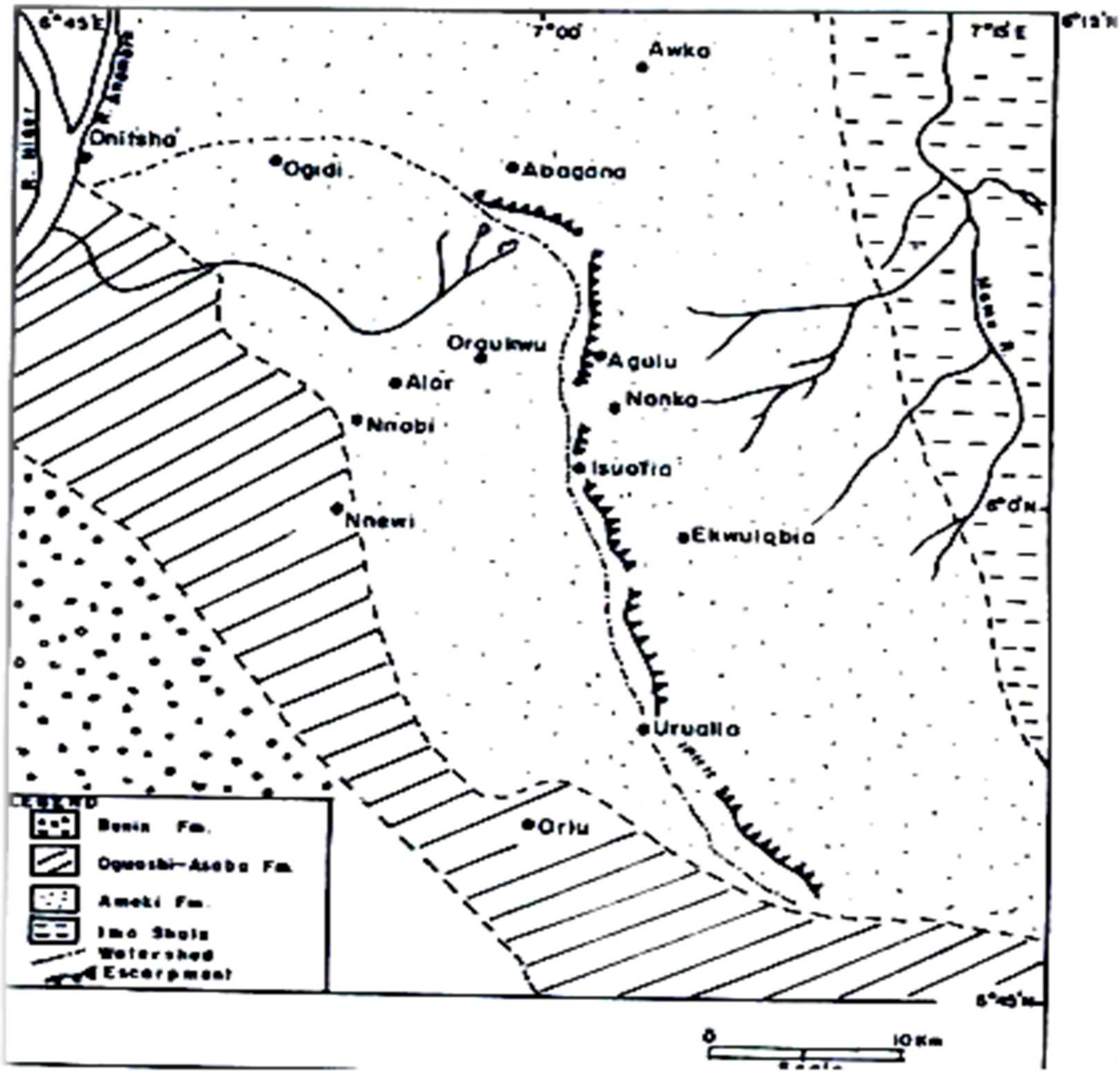

Fig. 1: Physiography and general geology of study area [Obiadi*et al.*, 2011]

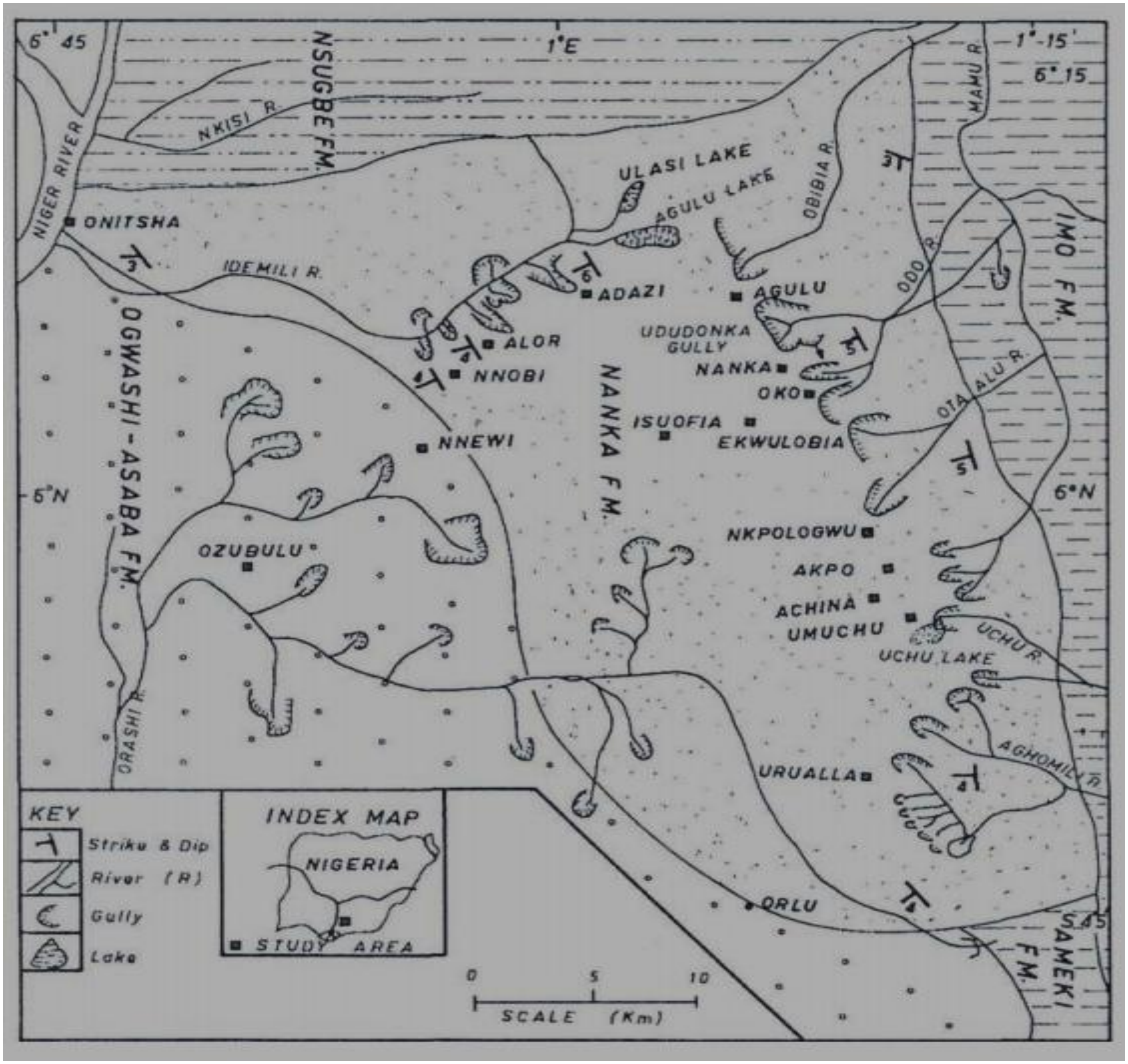

Fig. 2: Geologic map of study area showing areas where gully erosion is common [Obiadi *et al.*, 2011

CHAPTER TWO

LITERATURE REVIEW

The review of the following literature will be discussed under three main headings, namely:

- **Causes of soil erosion**
- **Effects of soil erosion**
- **Control measures for soil erosion**

2.1 Causes of Soil Erosion

There are basically two phenomena that cause erosion of soil: natural and anthropogenic causes. Different researches carried out by different scholars will be reviewed under the **natural** and **anthropogenic** causes of soil erosion.

2.2 Natural Causes

2.2.1. Climate

In the study carried out by Dregne (1987) on Soil erosion: Causes and Effects, he stated that water and wind are the two main mechanisms by which soil is eroded and transported. Of the two, water has proven experimentally to be the most important in causing soil erosion with long-lasting results. Controlling water erosion, within overall integrated desertification control plans, is thus a top priority if land productivity is to be maintained.

Obasi (2013) investigated the Vulnerability of Soil Erosion in Okitipupa Area of Ondo State, Southwest Nigeria: A Climatic Problem. Rainfall and temperature data of Ondo State were used for Okitipupa area since the latter is under the same climatic coverage. These data were grouped into decades for purposes of trend analyses. The results suggest that in the last three and half decades (1971-1980, 1981- 1990, 1991-2000, and 2001- 2007) the rainfall has been on the increase, an indication to show a change in the climate. The unusual increase in the trend of rainfall over time is attributable to the cause of flooding and erosion in Okitipupa area. He recommended that Dry season farming is suggested for those areas with high percentage of fine- medium grained sand. He also recommended that Government should discourage the construction of civil infrastructures along the coastal terrain of Okitipupa area.

A study on Soil erosion risk associated with climate change at Mantaro River Basin, Peruvian Andes was carried out by Correa *et al.*(2016). The objective of the study was to analyze the soil erosion risk, associated with A1B climate change scenario over the twenty-first century, for the Mantaro River basin (MRB), Peruvian Andes. The temporal analyses revealed maintenance of current soil erosion risk along the twenty-first century in almost all the MRB, whose current risk is either “very severe” or “extremely severe”. At the sub-basin level, for those located in the center and northern MRB, progressive increases were observed in the average erosion rate by the end of this century, increasing the soil erosion risk. In sub-basins under greater influence of the Andes, this risk was classified as “moderate” and remained this way throughout the century, despite the increase in rainfall erosive potential simulated for these. In annual terms, there was a significant trend of decreasing rainfall erosivity and increasing the concentration of rainfall simulated based on A1B climate change scenario. Because the A1B scenario affects rainfall erosivity mainly during the rainy season, this causes a risk to the environmental sustainability and future agricultural activities.

Sachs and Sarah (2017) investigated the combined effect of rain temperature and antecedent soil moisture on runoff and erosion on Loess. The experiments were applied to soil with two pre-prepared moisture conditions: hygroscopic and field capacity. For each condition, three rainfall temperatures were applied: 2 (cold), 20 (mid-temperature), and 35 °C (hot). The effect of antecedent soil moisture on soil erosion was found to be depended on rainfall temperature. For the cold rainfall, the sediment yield of the dry soil was 5.2 times greater than that of the pre-wetted soil, whereas for the mid-temperature and for the hot rainfall it was 1.5 and 1.2, respectively. For the pre-wetted soil, the sediment yield in the mid-temperature rainfall was 3 times greater than in the cold one. In the light of the predicted changes in global climate characteristics, an increase in rainfall temperature might lead to enhanced soil loss in Loess and perhaps elsewhere.

A study was conducted by Segura *et al.*(2014), on the potential impacts of climate change on soil erosion vulnerability across the conterminous United States. In this study they first evaluated the changes of R (rainfall runoff erosivity) from 1970 to 2090 across the United States under nine climate conditions predicted by three general circulation models for three emissions scenarios (A2, A1B, and B1) from the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Then, they identified watersheds that are most vulnerable to future climate change in terms of soil erosion potential. They developed a novel approach to evaluate future trends of R magnitude and variance by incorporating both the rate of change with time as well as the level of agreement between climatic projections. Their results showed that mean decadal R values would increase with time according to all nine climatic projections considered between 1970 and 2090. However, these trends varied widely spatially. In general, catchments in the North-eastern and North-western United States were characterized by strong increasing trends in R, while the trends in the Midwestern and South-western United States were either weak or inconsistent among the nine climatic projections considered. The North-eastern and North-western United States would likely experience a significant increase in annual variability of R (i.e., increase in extreme events). Conversely the variability of R was unlikely to change in large areas of the Midwest. At the watershed scale (8-digit Hydrologic Unit Code), the mean vulnerability to erosion scores varied between –0.12 and 0.35 with a mean of 0.04. The five hydrologic regions with the highest mean vulnerability to erosion were 5, 6, 2, 1, and 17, with values varying between 0.06 and 0.09. These regions occupied large areas of Ohio, Maryland, Indiana, Vermont, and Illinois, with mean erosion vulnerability score statewide above 0.08.

Another study was undertaken by Klik and Eitzinger (2010) on the Impact of Climate change on soil erosion and the efficiency of soil conservation practices in Austria. The goal of that study was to assess the impact of selected soil protection measures on soil erosion and retention of rainwater in a 1·14 km^2 watershed used for agriculture in the north-east of Austria. Watershed conditions under conventional tillage (CT), no-till (NT) and under grassland use were simulated using the Water Erosion Prediction Project (WEPP) soil erosion model. The period 1961–90 was used as a reference and results were compared to future Intergovernmental Panel on Climate Change (IPCC) scenarios A1B and A2 (2040–60). The simulations for the NT and grassland options suggested runoff would decrease by 38 and 75%, respectively, under the current climatic conditions. The simulation results suggest that, under future climate scenarios, the effectiveness of the selected soil conservation measures with respect to runoff will be similar, or decreased by 16–53%. The actual average net soil losses in the watershed varied from 2·57 t/ha/yr for conventional soil management systems to 0.01 t/ha/yr (ton/hectare/year) for grassland. This corresponds to a maximum average annual loss of about 0·2 mm, which is considered to be the average annual soil formation rate and therefore an acceptable soil loss. The current soil/land use does not exceed this limit, with most of the erosion occurring during spring time. Under future climate scenarios, the simulations suggested that CT would either decrease soil erosion by up to 55% or increase it by up to 56%. Under these conditions, the acceptable limits will partly be exceeded. The simulations of NT suggested this would reduce annual soil loss rates (compared to CT) to 0·2 and 1·4 t/ha, i.e. about the same or slightly higher than for NT under actual conditions. The simulation of conversion to grassland suggested soil erosion was almost completely prevented.

Giang *et al.* (2017) undertook to study the Spatial and Temporal Responses of Soil Erosion to Climate Change Impacts in a Transnational Watershed in Southeast Asia. Their study focused on the impact of climate change on spatial and temporal patterns of soil erosion in the Laos–Vietnam transnational Upper Ca River Watershed. The Soil and Water Assessment Tool (SWAT) coupled with downscaled global climate models (GCMs) was employed for simulation. Soil erosion in the watershed was mostly found as "hill-slope erosion", which occurred seriously in the upstream area where topography is dominated by numerous steep hills with sparse vegetation cover. However, under the impact of climate change, they found out that it was very likely that soil erosion rate in the downstream area will increase at a higher rate than in its upstream area due to a greater increase in precipitation. The results of their study provide useful information for decision makers to plan where and when soil conservation practice should be focused.

A study was carried out by O'Neal *et al.*(2005) on Climate change impacts on soil erosion in Midwest United States with changes in crop management. In this study, changes in management were assigned based on previous studies of crop yield, optimal planting date, and most profitable rotations under climate change in the Midwestern United States. Those studies predicted future shifts from maize and wheat to soybeans based on price and yield advantages to soybeans. In the results of their simulations, for 10 of 11 regions of the study area runoff increased from + 10% to + 310%, and soil loss increased from + 33% to + 274%, in 2040–2059 relative to 1990–1999. Soil loss changes were more variable compared to studies that did not take into account changes in management. Increased precipitation and decreasing cover from temperature-stressed maize were important factors in the results. The soil erosion model appeared to underestimate the impact of change in crop type, particularly to soybeans, meaning that erosion increases could be even higher than simulated. This research shows that future crop management changes due to climate and economics can affect the magnitude of erosional impacts beyond that which would be predicted from direct climate change.

2.2.2. Topography and Slope

Sun *et al.*(2014) in their study on Assessing the effects of land use and topography on soil erosion on the Loess Plateau in China, used The Revised Universal Soil Loss Equation (RUSLE), which was used in conjunction with geographic information system (GIS) mapping to determine the influence of land use and topography on soil erosion on the Loess Plateau during the period 2000 to 2010. The average soil erosion on the Loess Plateau was 15.2 t ha^{-1} yr^{-1} in 2000–2010. Most of the Loess Plateau fell within the minimal and low erosion categories during 2000 to 2010. Forest, shrub and dense grassland provided the best protection from erosion, but the decadal trend of reduced soil erosion was greater for the lower vegetation cover of woodland and moderate and sparse grassland. Midslopes and valleys were the major topographical contributors to soil erosion. With slope gradient increased, soil erosion significantly increased under the same land use type, however, significant differences in soil erosion responding to slope gradients differed from land uses. The results indicate that the vegetation restoration as part of the Grain-to-Green Program on the Loess Plateau has been effective.

Şensoy and Kara (2014) did a research to determine the effects of slope shapes on runoff and soil erosion. A field experiment was conducted from September 2007 to September 2009 on hillside field plots located in the northern part of the city of Bartin in North-western Turkey. The experiment focused on complex topography including uniform, concave, and convex slopes. Runoff and soil loss were greater in uniform plots than in concave and convex plots. The greatest amount of runoff was measured between September 2007 and August 2008 (Period1: P1), with 211.53 mm from uniform plot1 and during September 2008 and August 2009 (Period2: P2) with 430.06 mm from uniform plot3. The lowest runoff quantities with 157.44 and 371.63 mm from concave plot3 and concave plot1, respectively, were measured at P1 and P2. The highest soil loss was recorded at 2.97 kg m^{-2} and 6.16 kg m^{-2} during P1 and P2 from uniform plot2 and uniform plot3, respectively, and soil loss was lowest from concave plot3 and concave plot1, with a total of 0.23 kg m^{-2} and 0.67 kg m^{-2}, respectively. The distribution of eroded soil was separated into >2 mm (coarse) and ≤2 mm (fine) size classes, and suspended quantity in runoff was also determined. Results indicated that the majority of soil lost from the uniform plots is composed of fine particles rather than coarse and suspended material. On the other hand, both concave and convex slopes demonstrated larger variability in the size distribution of eroded particles from individual plots.

Agyarko *et al.*(2012) did a study Soil Erosion around Foundations of Houses in Four Communities in Ghana. Thirty houses were selected from each of the four communities for the study. Measurements of slope and the depth of exposed foundation of houses were done with the help of a string and a tape measure. Data were also obtained through questionnaire and interview of house owners. The

Pearson's correlation coefficient was used to measure some relationships among data. The extent of building foundation exposed by soil erosion was found to be positively correlated with the age of building and the slope of the land.

Zhang *et al.*(2015) researched on the Effects of Land Use and Slope Gradient on Soil Erosion in a Red Soil Hilly Watershed of Southern China. The study was undertaken to develop an appropriate plan of land use under suitable slope gradient to control soil erosion from a red soil hilly watershed of southern China by using the GeoWEPP (Geo-spatial Interface for the Water Erosion Prediction Project) model. The model was calibrated and validated using monitoring data of the outlet from 2010 to 2012, in which the 2010 and 2012 annual total runoff and sediment yield data were used for calibration, and the 2011 monthly runoff and sediment yield data for validation. The performance of the model in validation period were good with a high coefficient of determination values of 0.98 and 0.93 and Nash-Sutcliffe simulations of 0.96 and 0.91 while low root mean square error values of 6.91 mm and 0.35 t respectively for runoff and sediment yield. Subsequently, the model was used to simulate four typical land use (forest, farm, orchard, and fallow land) in the study area to evaluate their impacts on soil erosion production. The results showed that the runoff decreased by 44.7% and 61.1% for forest and orchard land compared to the current land use, as well as the sediment yield decreased by 43.7% and 68.6%. While the runoff and sediment yield increased by 52.2% and 42.6% for farm land, and 48.8% and 29.6% for fallow land. As the same time, soil erosion increased with increasing of the slope gradient of the quadratic regression equation for all land use. The critical slope gradient of 15° for returning the farmland to forest or others is suitable in the red soil region but is not accurate. The result of the study provides good scientific evidence for developing an appropriate plan of land use in the watershed and other similar areas.

Rieke-Zapp and Nearing (2005) did a study on Slope Shape Effects on Erosion: A Laboratory Study. In this study, artificial rainfall was applied for 90 minutes to a silt loam soil in a 4 by 4 box. Five slope shapes were formed: uniform, concave-linear, convex-linear, nose slope, and head slope. Digital elevations models (DEMs) of the surface were measured using photogrammetry after 0, 10, 20, 40, 60 and 90 minutes. Slope shape had a significant impact on rill patterns, sediment yield, and runoff production. The uniform, nose, and convex-linear slopes yielded more sediment than the concave-linear and head slopes, where sediment deposited on toe slopes. Soil topography led to flow convergence and divergence, resulting in a non-uniform distribution of rill spacing and efficiency. The degree of rill incision was related to slope steepness and length, and rill success was related to the contribution area of the rill. Drainage density approached a similar value foe all networks during the experiments. Development of the drainage system was similar to the development of optimum channel networks, in that during the evolution of the rill network energy expenditure was reduced. This indicated that energy expenditure was a quantifiable measure of network development and self-organization.

Defersha *et al.*(2011) conducted a study on the effect of slope steepness and antecedent moisture content on interrill erosion, runoff and sediment size distribution in the highlands of Ethiopia. Rainfall intensity, slope and antecedent moisture contents were varied in the experiment. The soil types ranged from clay to sandy clay to loam (Alemaya Black soil, Regosols and Cambisols). Rainfall was applied for six sequential 15- min periods with rainfall intensities varying between 55 and 120 mm h^{-1}. The three slopes tested were 9, 25, and 45%. Results show that as slope increased from 9 to 25%, splash erosion and sediment yield increased. An increase in slope from 25 to 45% generally decreases in splash erosion. Sediment yield for one soil increased and one soil decreased with slope and for the third soil the trend was different between the two initial moisture contents. Sediment yield was correlated (r = 0.66) with runoff amounts but not with splash erosion. Interrill erosion models that were based on the flowing water and rainfall intensity fitted the data better than when based on rainfall intensity solely.

A research was done by Fang *et al.*(2014) on Effects of rainfall and slope on runoff, soil erosion and rill development: an experimental study using two Loess soils. In the paper, rainfall simulation experiments were conducted in two neighbouring plots (scale: 1 m by 5 m) with four varying slopes (17.6%, 26.8%, 36.4% and 46.6%) and two rainfall intensities (90 and 120 mm h^{-1}) using two loess soils. Data on rill development were extracted from the digital elevation models by means of photogrammetry. The effects of rainfall intensity and slope gradient on runoff, soil loss and rill development were different for the two soils. The runoff and soil loss from the Anthrosol surface were generally higher than those from the Calcaric Cambisol surface. Higher rainfall intensity produced less runoff and more sediment for almost each treatment. With increasing slope gradient, the values of cumulative runoff and soil loss peaked, except for the treatments with 90 mm h^{-1} rainfall on the slopes with Anthrosol. With rainfall duration, runoff discharge decreased for Anthrosol and increased for Calcaric Cambisol for almost all the treatments. For both soils, sediment concentration was very high at the onset of rainfall and decreased quickly. Almost all the sediment concentrations increased on the 17.6% and 26.8% slopes and peaked on the 36.4% and 46.6% slopes. Sediment concentrations were higher on the Anthrosol slopes than on the Calcaric Cambisol slopes. At 90 mm h^{-1} rainfall intensity, increasingly denser rills appeared on the Anthrosol slope as the slope gradient increased, while only steep slopes (36.4% and 46.6%) developed rills for the Calcaric Cambisol soil. The contributions of rill erosion ranged from 36% to 62% of the cumulative soil losses for Anthrosol, while the maximum contribution of rill erosion to the cumulative soil loss was only 37.9% for Calcaric Cambisol.

A paper was presented by Lal (1998) Effects of slope length, slope gradient, tillage methods and cropping systems on runoff and soil erosion on a tropical Alfisol: preliminary results. Field runoff plots of variable slope lengths and 4 m width were established on a tropical Alfisol of about 7 to 9% slope at the International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria. There were six slope lengths varying from 10 to 60 m with 10 m increment. An additional plot of 25 m length was established to study the soil erodibility factor K. There were two tillage methods e.g. ploughed and no-till system of seedbed preparation. Corn (Zea mays) was sown in the first season and cowpea (Vigna unguiculata) in the second season. Runoff and erosion were significantly influenced by tillage methods and slope length. For ploughed plots, slope length had a negligible effect on runoff per unit area. In contrast, however, erosion from ploughed plots increased as a power function of slope length and slope length parameters. In no-till treatments, both runoff and soil erosion decreased linearly or inversely with increase in slope length. This differential response due to tillage methods may be attributed to the variable effects of slope length, crop residue mulch, and tillage methods on time of concentration and runoff velocity.

2.3. Anthropogenic Causes

2.3.1. Famers' Perception and Orientation

Pravat *et al.* (2015) undertook a study on Farmers' Perceptions of Soil Erosion and Management Strategies in South Bengal in India, to understand the complex inter-relationships between perception of farmers' knowledge and soil water conservation (SWC). Data was obtained from a survey of 540 farm households and informal discussions selected by stratified random sampling from upper, middle and lower catchment at Paschim Medinipur, Bankura and Purulia districts respectively. The analysis reveals that farmer age, farming experience, farm training, education and numbers of economically active household members are positively responsible to soil erosion and SWC in the study area. They recommended that consequently, potential knowledge of farmers is to be harnessed effectively to mitigate the problem through perception of benefits from conservation of natural resources.

Meshesha and Tripathi (2016) also studied on the Farmer's Perception on Soil Erosion and Land Degradation Problems and Management Practices in the Beressa Watershed of Ethiopia. From 92 randomly selected households using survey, formal and informal discussion with farmers and field observation were employed to generate the data. The result indicated that farmers were acknowledged that the prevalence of soil erosion and land degradation in their watershed (93.5%) was affecting their livelihoods. However, mostly they noticed erosion and degradation when it forms gullies. They identified many prominent causes for natural resource degradation such as improper conservation practice, traditional farming practice, continuous cultivation without fallow periods, deforestation and over population. To tackle the ongoing problems, many ranges of conservation technologies were used by farmers. Following the intervention and rehabilitation practice, the rate of erosion and degradation overtime moderately reduced (58.7%). Though the practice was not demand driven and site specific management practice. Finally, this study concluded important points which needs immediate consideration for community based watershed management practice effort not only for the study area but also for the country at large are: Identifying and integrating technical as well as efficiency of indigenous and site specific and demand driven technology help to cope erosion and degradation hazard –hence increase short and long term benefit obtained from the practice.

Amsalu and de Graaff (2006), did a study on Farmers' views of soil erosion problems and their conservation knowledge at Beressa watershed, central highlands of Ethiopia. Data were obtained from a survey of 147 farm households managing 713 fields during the 2002/2003 cropping season. In-depth interviews and group discussions were also held with the farmers to obtain additional information. The results show that 72% of the farmers reported erosion problems, and they recognized that conservation was necessary. However, they considered erosion to be severe mostly when visible signs – rills and gullies – appeared on their fields. The majority of the farmers believe that erosion could be halted, and they use a range of practices for erosion control and fertility improvement. These include contour plowing (83%), drainage ditches (82%), and stone terraces/bunds (73%). Nevertheless, despite decades of conservation intervention in the area, it appears that most farmers have developed negative attitudes towards externally recommended measures. The research concludes that under the conditions present in the Ethiopian central highlands, soil and water conservation interventions should consider farmers' conservation knowledge and practices to improve acceptance and adoption of the recommendations.

Another study was conducted by Belay (2014) in Dejen district, in Northwestern Ethiopia to assess perception of farmers on soil erosion and conservation practices. In this study, both primary and secondary data collection techniques were used. These includes interviews, focus group discussions, field observations, and questionnaires were the source of this research. The sampling technique employed in this study were stratified, purposive and simple random were applied to select sample kebele and representative households heads. A sample of 250 heads of households were used to gain insight into soil erosion perceived by farmers and conservation practices in the study area. The finding of the study shows that almost all farmers of the study area had good perception on the causes, indicators and problems of soil erosion. The main causes of soil erosion perceived by farmers in the study area were high intensity of rainfall, continuous cultivation, topography and inappropriate soil conservation practices.

In a study conducted by Zerssa *et al.* (2017) on Assessment of farmers' perception towards soil and water conservation in Obi Koji Peasant Association, Woliso District, South West Shewa Ethiopia, a total of 36 (20 male and 16 female) household samples from three zones of Obi Koji, West Ethiopia were selected proportionally to the population size, respectively. Data was collected in the form of interview, questioner and field observations and secondary data from documented files. Direct household survey and formal interview method were used to take sampling. The study was focused on the determinant factors which affect the decision of farmers to adopt soil and water conservation practices in their local conditions. Majority of the farmers have awareness about the introduced soil and water conservation (SWC) and few of them implement it. The rest uses cultural practices such as diversion ditch and water ways. Nonetheless, the sustainability of the implemented structures was unlikely. The study concluded that many of those problems were related to lack of real participation of farmers in planning of conservation effort.

Eze and Osahon (2016) did a study on Farmers' Perception of Soil Erosion Control Measures: Implications for Sustainable Development in Agriculture and Environment in South East, Nigeria. Purposive, multistage and random sampling techniques were employed in selecting a sample size of two hundred and forty (240) respondents. Structured interview schedule was used for data collection, while percentages, mean ratings and factor analysis techniques were employed for analysis. The findings show that majority (64.6%) of farmers were within the ages of 40-59, while majority (67.9%) had either FSLC or WASCE/SSCE/GCE/OL qualifications. The farmers reported that the major soil erosion control measures used were strip cropping (M = 4.8) and making of ridges against slopes (M = 4.7). The study reported that poor group affinity, inadequate institutional support and inadequate technical knowhow were constraints to soil erosion control in southeast, Nigeria. The study highlighted implications for sustainable development in agriculture and environment on organizational overhaul in extension, participatory extension policy on farmers groups and institutional re-orientation and synergy between Universities, Agricultural Development Programme (ADP), Ministry of Agriculture (MOA) and Local Government Councils. In conclusion, success in soil erosion control and sustainable development in agriculture and environment in southeast Nigeria, depends on the extent issues raised and implications highlighted can be addressed. The study recommends improved funding support to extension, participatory extension training and contacts with farmers' groups and groups' resources management. Key words: Farmers, erosion control, sustainable

Werner *et al.*(2017) conducted a research on Farm level implementation of soil conservation measures: farmers' beliefs and intentions. The objective of that paper was to investigate the influence of farmers' subjective beliefs on their intention to apply and actual implementation of cover cropping, with the region of Brandenburg (Germany) as a case. An additional objective was to investigate how these insights could contribute to increase farm level implementation of soil conservation measures. Theory of planned behaviour provides an approach to understand human behaviour by analysing farmers' subjective beliefs. Their results, based on a survey of 96 farmers, show that attitudes (ATTs) and perceived difficulty significantly explain variations in intention to apply cover cropping, with ATTs being generally very positive. They discussed that, in that case, the most effective way to increase on-farm implementation was to decrease the farmers' perception of difficulty. This can be achieved by providing information to farmers on how to overcome barriers to implementation of conservation measures. In-depth insights into belief structures reveal what kind of information is most useful in the case of cover cropping.

2.3.2. Tillage System

Bertol *et al.*(2005), carried out a study on Soil tillage, water erosion, and calcium, magnesium and organic carbon losses. This study was carried out on an Inceptisol, representative of the Santa Catarina highlands, southern Brazil, between November 1999 and October 2001, under natural rainfall. The soil tillage treatments (no replications) were: no-tillage (NT), minimum soil tillage with chiselling + disking (MT), and conventional soil tillage with ploughing + two diskings (CT). The crop cycles sequence was, soybean (*Glycine max*), oats (*Avena sativa*), beans (*Phaseolus vulgaris*) and vetch (*Vicia sativa*). Conventional soil tillage treatment with ploughing + two disking in the absence of crops (BS) was also studied.

Calcium and magnesium concentrations were determined in both water and sediments of the surface runoff, while organic carbon was measured only in sediments. Calcium and magnesium concentrations were greater in sediments than in surface runoff, while total losses of these elements were greater in surface runoff than in sediments. The greatest calcium and magnesium concentrations in surface runoff were obtained under CT, while in sediments the greatest concentration occurred under MT. Organic carbon concentration in sediments did not differ under the different soil tillage systems, and the greatest total loss was under CT system.

A research was carried out by Packer and Hamilton (1993) on Soil physical and chemical changes due to tillage and their implications for erosion and productivity. A seven-year tillage trial was conducted in central New South Wales, Australia to measure the effect and extent of conservation tillage practices on soil physical and chemical properties. Three tillage treatments, traditional tillage (TT), reduced tillage (RT) and direct drilling (DD) were imposed on hardsetting red-brown earths at Cowra and Grenfell. A fourth treatment, direct drilling without grazing (NT) was imposed at Cowra only. At Cowra there was a significant trend of reduced total runoff in the DD and NT treatments but not in the RT treatment. Runoff significantly increased in the TT treatment. At Grenfell, runoff decreased in all treatments but only significantly in the DD and RT treatments. Similar trends in total sediment loss were measured at both sites. Associated physical measurements of saturated hydraulic conductivity, sorptivity and bulk density confirmed that the changes in runoff were due to the creation of macroporosity greater than 0.75 mm diameter. The relationship between macroporosity, organic carbon and aggregate stability was discussed. Conclusions were that in these soil types runoff and sediment loss were affected more by destruction of macroporosity due to cultivation than changes in organic carbon from residue retention. To achieve these soil improvements using conservation tillage a continuous cropping period of four years was necessary to obtain significant and consistent trends. Soil chemical data showed that total nitrogen increased with conservation tillage practices. Available phosphorus changes due to tillage were not observed because of more than adequate fertiliser applied. Soil pH decreased significantly in the DD and NT treatments at Cowra only. The implications of these chemical changes were discussed.

Another research was conducted by Yao *et al.* (2004) on the Influence of Tillage Practices on Yield, Water Conservation and Soil Loss: Results of Field Experiments in the Eastern Loess Plateau (Henan Province, China). In order to examine the effect of alternative tillage practices on crop yield, water conservation and soil loss, a field study was conducted over a period of 4 years. On field plots near Luoyang (Henan province, China) the following tillage practices were applied: reduced tillage, no-tillage, subsoiling and conventional tillage. Rainfall simulation experiments were done to examine the effect of tillage on runoff and soil losses. Negligible runoff amounts were observed on the no-tillage plot. Subsoiling reduced runoff and soil losses by more than 50, respectively more than 90 % compared to conventional tillage. Although soil losses under reduced tillage decreased by half compared to conventional tillage, the differences in runoff amounts were small. For every year of the field trial period, subsoiling was found to give the highest yields. On average, an increase of 11% was observed compared to conventional tillage. The average yield from the no-tillage plots was slightly higher than under conventional tillage, while a slightly lower yield was found under reduced tillage. Because yield is an important criterion in promoting alternative tillage practices towards farmers, subsoiling can be regarded as a promising measure to improve soil and water conservation in the Eastern Loess Plateau of China.

Dickey *et al.*(1983) did a study on Effects of Tillage on Soil Erosion in a Wheat-Fallow Rotation in the study erosion from alternative tillage systems in winter wheat-fallow rotations was measured using a rainfall simulator. The Nebraska study, conducted at the High Plains Agricultural Laboratory, showed that during the fallow period between harvest and tillage, soil erosion was not affected by the tillage systems studied. However, erosion following tillage was different for the systems evaluated and mouldboard ploughing with the slope had the largest amount. The no-till system reduced erosion by about 95% during this period. Although contour plowing was effective in reducing erosion when compared to ploughing with the slope, no differences were measured between with the slope and contour tillage for the no-till or stubble-mulch treatments.

In a review written by Van Oost *et al.* (2006) on Tillage erosion: a review of controlling factors and implications for soil quality, they presented a summary of available data describing tillage erosion. This provided insights in the controlling factors determining soil redistribution rates and patterns by tillage for various implements used in both mechanized and non-mechanized agriculture. Variations in tillage depth and tillage direction caused the largest variations in soil redistribution rates, although other factors, such as tillage speed and implement characteristics, also played an important role. In general, decreasing tillage depth and ploughing along the contour lines substantially reduced tillage erosion rates and can be considered as effective soil conservation strategies. Implement erosivities reported in literature, characterized by the tillage transport coefficient, were very consistent and range in the order of 400–800 kg $m^{-1}yr^{-1}$ and 70–260 kg $m^{-1}yr^{-1}$ for mechanized and nonmechanized agriculture, respectively. Comparison of tillage erosion rates with water erosion rates using a global data set indicated that tillage erosion rates were at least in the same order of magnitude or higher than water erosion rates, in almost all cases. Finally, they discussed how tillage erosion increases the spatial variability of soil properties and affected soil nutrient cycling. Considering the widespread use of tillage practices, the high redistribution rates associated with the process and its direct effect on soil properties, it was clear that tillage erosion should be considered in soil landscape studies.

Mhazo *et al.*(2016) conducted a literature survey on Tillage impact on soil erosion by water: Discrepancies due to climate and soil characteristics. A global literature review was conducted to quantify the impact of NT (No-tillage) on water runoff, sediment concentration and soil losses. The objective was to identify the underlying causes of the variability in the performance of NT across different environments. Data from 282 paired NT and CT (conventional tillage) runoff plots from 41 research studies worldwide were analysed using meta-analysis and principal component analysis (PCA). Sediment concentration and soil losses were 56 and 60% lower under NT than CT, respectively. These tended to be greater under CT than NT on long plots (90% for sediment concentration and 94% for soil losses) and steepest slopes (79 and 77%, respectively). Greater differences in sediment concentration and soil losses between NT and CT were observed in low clay soils and under temperate climates. While on average there were no differences on runoff coefficient, NT decreased runoff coefficient by about 40% compared to CT in mulched soils, under cool climate (<10 °C), and for experiments done >5 years. Overall, the results indicated that NT has greater potential to reduce runoff and soil losses in temperate regions where soils of peri-glacial influence are relatively young, moderately weathered and fragile compared to the heavily weathered clayey tropical soils that are well aggregated and less erodible. The results of this study were expected to inform scientists, practitioners and policy makers on the links between land management and soil functioning processes. Policy makers and development implementers will be able to make informed choices of land management techniques for effective NT implementation, for instance by having more mulch input under warm climates.

2.3.3. Deforestation

In the research by Zeraatpishe *et al.*(2013) that discussed The Effect of Deforestation on Soil Erosion, Sediment and Some Water Quality Indicates, seven hydrological stations were selected in deforestation lands in Iran. The field survey showed that different types of soil erosion features such as shallow gullies and sheet erosion were observed in deforested lands in comparison to forest lands. Also, results showed that there is a significant relation between deforestation and the amount of runoff, sediment, TDS (total dissolved solids) and EC (electrical conductivity).

Another study was conducted by Gholami (2013) on the influence of deforestation on runoff generation and soil erosion (Case study: Kasilian Watershed) in north of Iran. This research was done using a runoff-rainfall model, sediment-erosion model, Geographical Information System and remote sensing to determine the hydrologic effects of deforestation on Kasilian watershed (north of Iran). A runoff-rainfall model was presented using GIS (HEC-GeoHMS extension) and hydrologic model (HEC-HMS). The SCS method was used for presenting the hydrologic model. It is to be noted that the optimized model is evaluated by other six events of floods. Then, the optimized model was validated. Erosion potential method model was applied in GIS environment to simulate soil erosion and sediment rate. According to the obtained results, the runoff and sediment generation potential have been increased in the Kasilian watershed due to deforestation during the last forty years.

Sahani and Behera (2001) conducted a study on Impact of deforestation on soil physicochemical characteristics, microbial biomass and microbial activity of tropical soil. The study dealt with the assessment of the impact of deforestation on tropical soil through a comparative analysis of physicochemical and microbiological parameters of natural forest and a deforested barren site. With significant decline in clay, texturally the soil of the deforested barren site was observed to be different from that of natural forest. Bulk density and porosity data revealed structural deterioration of deforested barren soil. The soil hydrological regime was also adversely affected by the deforestation. Levels of soil organic carbon, total nitrogen, microbial biomass C, N and microfungal biomass also exhibited significant decline in deforested site. Analysis of microbial respiratory quotient (q CO_2) was also observed to be impaired in the deforested site.

Villarino *et al.* (2017)conducted a study on Deforestation impacts on soil organic carbon stocks in the Semiarid Chaco Region, Argentina. Soil organic C was determined up to 100 cm depth and physically fractionated into mineral associated organic carbon (MAOC) and particulate organic C (POC). Models describing vertical distribution of SOC were fitted. Total SOC, POC and MAOC stocks decreased markedly with increasing cropping age. Particulate organic C was the most sensitive fraction to cultivation. After 10 yr of cropping SOC loss was around 30%, with greater POC loss (near 60%) and smaller MAOC loss (near 15%), at 0–30 cm depth. Similar relative SOC losses were observed in deeper soil layers (30–60 and 60–100 cm). Deforestation and subsequent cropping also modified SOC vertical distribution. Soil organic C loss was negatively associated with the proportion of maize in the rotation and total crop biomass inputs, but positively associated with the proportion of soybean in the rotation. Without effective land use polices, deforestation and agricultural expansion could lead to rapid soil degradation and reductions in the provision of important ecosystem services.

2.4. Effects of soil erosion

2.4.1 Effect on Agriculture: Livestock farming and Crop production

Ighodaro *et al.*(2013) conducted a study to investigate the impact of soil erosion on the agricultural potential and performance of Sheshegu community farmers in the Eastern Cape of South Africa. Structured interview schedule was used to collect data from 50 respondents using simple random sampling. Respondents affirmed that erosion contributed to poor health of livestocks due to lack of pasture grass to feed on, loss of grazing land and poor bush regrowth. It was recommended that awareness on the negative effect of human causes of erosion should be created while simple technologies on soil erosion control should be pushed to the farmers. Finally, edict on bush burning should be enforced to check indiscriminate bush burning.

Another study was conducted by Yisehak *et al.*(2013) on Impact of soil erosion associated factors on available feed resources for free-ranging cattle at three altitude regions: Measurements and Perceptions. The research location was in three altitude regions of southwest Ethiopia, where a total of 342 farmers were interviewed. In addition, the ecological condition of rangelands was assessed. Severe soil erosion, ranked as the primary restriction to free-ranging livestock, occurred predominantly in the lower altitude region (LAR) ($P < 0.05$). More farmers in LAR witnessed an inadequacy of palatable plant biomass, grazable pasture as well as increased gully formation and expansion, which are strong indicators of soil erosion ($P < 0.001$). In addition to a decrease in grass cover and productivity of cattle, botanical composition, species richness and grazing capacity of herbaceous plants, less fodder trees and shrubs were observed ($P < 0.05$). There was a corresponding increase in the percentage of bare ground and soil erosion status along the degradation gradients ($P < 0.05$). The reported shift in botanical composition, and especially encroachment of invading plant species, could be attributed to soil erosion ($P < 0.001$). The results suggested that erosion was associated with reduced availability of feed resources and is related to altitude variation.

Verity and Anderson (1990) undertook a study which examined the cumulative effect of erosion on soil properties that were important to productivity, and estimates the effect of erosion on grain yields. Experiments were located in Central Saskatchewan on Dark Brown soils of the Weyburn Association. The relationship between yields and relative distance down eroded hillslopes was described best by a third-order polynominal equation. Grain yields were lowest on the upper slopes and increased steadily through mid-slopes to maximum values that were often double the upper slope yield on the lower or foot slope, then decreased again in the more level parts of the fields away from the slope.

A study on the Crop production and economic loss due to wind erosion in hot arid ecosystem of India was done by Santra *et al.*(2017). In this study, an attempt was made to quantify the indirect impact of wind erosion process on crop production loss and associated economic loss in hot arid ecosystem of India. It was observed that soil loss due to wind erosion varied from minimum 1.3 tonne per hectare (t ha^{-1}) to maximum 83.3 t ha^{-1} as per the severity. Yield loss due to wind erosion was found maximum for groundnut (*Arachis hypogea*) (5–331 kg ha^{-1} yr^{-1}), and minimum for moth bean (*Vignaaconitifolia*) (1–93 kg ha^{-1} yr^{-1}). For pearl millet (*Pennisetumglaucum*), which covers a major portion of arable lands in western Rajasthan, the yield loss was found to be 3–195 kg ha^{-1} yr^{-1}. Economic loss was found higher for groundnut and clusterbean (*Cyamopsistetragonoloba*) than rest crops, which were about 191–12465 ha^{-1} depending on the severity of wind erosion. For mustard (*Brassica* spp.) and wheat (*Triticum* spp.) the economic loss was about 47–3181 ha^{-1}, whereas for pearl millet the economic loss was lowest (36–2294 ha^{-1}). Since only indirect impact of wind erosion in terms of reduction in soil fertility was considered in this calculation, there was need of future research work for assessing the direct damage on crops by wind erosion process, addition of which may lead to higher magnitude of losses.

A research was also conducted by Gao *et al.*(2015) on the Effects of soil erosion on soybean yield as estimated by simulating gradually eroded soil profiles. The research location was on the black soil region of North-eastern China. To assess yield response to soil erosion, a new method for gradually simulating eroded soil profiles was developed for experimentation with potted soybeans in which the top 20 cm layer simulated the cultivated layer, which was mixed with soils below due to annual soil loss and a ploughing depth of 20 cm. The experimental results of five treatments, including "no erosion" and soil losses of the top 20 cm, 40 cm, 50 cm, and 70 cm, showed reduction rates of 5.06%, 5.97%, and 1.77% per 10 cm of soil loss on average for the biomass, yield, and harvest index, respectively. The response curve for soil erosion was concave, with a faster erosion rate at the top layer of 40 cm and a slower erosion rate for the lower layers. The declining yield rates were 9.44% and 1.51% per 10 cm of soil loss for the top and lower layers, and 7.6% and 2.48%, respectively, for declining rates of biomass. The yields were more sensitive to soil erosion than the biomass, whereas the harvest index was not as sensitive.

A study was done by Pimentel (2006) on Soil Erosion: A Food and Environmental Threat. In it he stated that humans obtain more than 99.7% of their food (calories) from land and less than 0.3% from oceans and other aquatic ecosystems. He said that each year about 10 million ha are lost due to soil erosion, thus reducing the cropland available for food production. Also he said that the loss of cropland is a serious problem because the World Health Organisation reported that more than 3.7 billion people are malnourished in the world. He pointed out that overall soil is being lost from land areas 10 to 40 times faster than the rate of soil renewal imperilling future human food security and environmental quality.

Bakker *et al.*(2007) conducted a research on The Effect of Soil Erosion on Europe's Crop Yield in which they quantified the relationship between crop yields and soil water available to plants, the most important yield-determining factor affected by erosion, at the European scale. Using information on the spatial distribution of erosion rates they calculated the potential threat of erosion-induced productivity losses. They showed that future reductions in productivity in Europe as a whole were relatively small and do not pose a substantial threat to crop production within the coming century. However, within Europe there was considerable variability, and although productivity in northern Europe was not likely to be significantly reduced by soil erosion, for the southern countries the threat of erosion-induced productivity declines was stronger.

2.4.3. Effect on Surrounding Water Bodies

Lenat (1984) investigated the Agriculture and stream water quality: A biological evaluation of erosion control practices. In this study, benthic macroinvertebrates were sampled in three different geographic areas of North Carolina, comparing control watersheds with well-managed and poorly managed watersheds. Agricultural streams were characterized by lower taxa richness (especially for intolerant groups) and low stability. These effects were most evident at the poorly managed sites. Sedimentation was the apparent major problem, but some changes at agricultural sites implied water quality problems. The groups most intolerant of agricultural runoff were Ephemeroptera, Plecoptera and Trichoptera. Tolerant species were usually filter-feeders or algal grazers, suggesting a modification of the food web by addition of particulate organic matter and nutrients. This study clearly indicated that agricultural runoff can severely impact stream biota. However, this impact can be greatly mitigated by currently recommended erosion control practices.

A study was carried out by Sthiannopkao *et al.*(2006) on the Effects of soil erosion on water quality and water uses in the Upper Phong watershed. Suspended solids carry down attached nutrients and agricultural chemicals causing water pollution in the downstream. There were four different types of land use in this simulation, namely forestlands, flatland and highland sugarcane plantation areas, and paddy fields. The highest mean annual amount of soil erosion was from paddy fields (585,700 tons/year), followed by highland (73,800 tons/year) and flatland (63,950 tons/year) sugarcane plantation areas and forestlands (41,800 tons/year), respectively. However, as most paddy fields were located in a low land and are wet type cultivations, the soil erosion occurred has less impact on river water quality and its production compared to the soil erosion from the steeper slopes of highland plantation areas. Under the resource-based agriculture, the sugarcane production was mainly increased by expanding the plantation areas leading to a significant loss of topsoil and a considerable reduction of agricultural production. Soil erosion contributes to an increase in the average annual suspended solids concentration by 72 mg/l.

Johannsen and Armitage (2010), wrote an article on Agricultural Practice and the Effects of Agricultural Land-Use on Water Quality. In their work, the effects of agricultural land-use on water quality were considered in relation to excessive nutrients, application of agrochemicals, sediment input and contamination by heavy metals.

In a research conducted by McBroom *et al.*(2012) on Soil Erosion and Surface Water Quality Impacts of Natural Gas Development in East Texas, USA,a 1.4 ha natural gas well pad was constructed in an intermittent stream channel at the Alto Experimental Watersheds in East Texas, USA (F1), while another 1.1 ha well pad was offset about 15 m from a nearby intermittent stream (F2). V-notch weirs were constructed downstream of these well pads and stream sedimentation and water quality were measured. For the 2009 water year, about 11.76 cm, or almost 222% more runoff resulted from F1 than F2. Sediment yield was significantly greater at F1, with 13,972 kg ha^{-1} yr^{-1} *versus* 714 kg $ha^{-1}yr^{-1}$ at F2 on a per unit area disturbance basis for the 2009 water year. These losses were greater than was observed following forest clear-cutting with best management practices (111–224 kg ha^{-1}). Significantly greater nitrogen and phosphorus losses were measured at F1 than F2. While oil and gas development can degrade surface water quality, appropriate conservation practices like retaining streamside buffers can mitigate these impacts.

Issaka and Ashraf (2017) reviewed on the Impact of soil erosion and degradation on water quality. In the review they focused principally on the erosion factors and how to prevent and/or mitigate them. The application of soil erosion models such as the universal soil loss equation, its modification and others were also studied. The results established by various researchers showed a relationship between impact of soil erosion and degradation on water quality indicating the source of pollutant as anthropogenic and industrial activities. These are the sources of particles and deleterious material that contribute to the surface water deterioration including the East Lake. The review revealed that erosion causes both on-site and off-site effects on land and also on water bodies, thereby affecting its quality.

2.5. Control Measures for soil erosion

2.5.1. Land-Use Method, Reforms and Policies

Satriawan *et al.*(2015) did a study on the Effectiveness of Soil Conservation to Erosion Control on Several Land Use Types. The experiment was treated with three conservation practices and the conventional treatment as control in a completely randomised block design. The results showed for the areca land use, that soil conservation with ridges + maize, produced the lowest erosion (1.68 t/ha). For cocoa land use, the ridges + groundnut treatment produced the lowest erosion

(8.2 t/ha). For oil palm land use, the cover crop of Mucunabracteata had lowest erosion yield (12.2 t/ha).

Hacisalihoglu (2007) conducted a study on the Determination of soil erosion in a steep hill slope with different land-use types: A case study in Mertesdorf (Ruwertal/Germany). In that paper, in a steep hill slope of the village Mertesdorf (Ruwertal/Germany), Algemeine boden abtrags gleichung (ABAG) have been applied to determine and compare the soil erosion amounts between the different land use types such as vine growing, forest lands, grasslands, shrubs and new forestations. The results showed that the soil erosion amounts differed in a high ratio between the land use types. Soil erosion amounts in the vine growing areas were the highest (6.47 t/ha/year), then comes with 1.19 t/ha/year the over grazed grasslands and the lowest erosion amounts have been determined, as expected, in the forest lands (0.66 t/ha/year).

A research was done by Zare *et al.*(2017) on simulating the impacts of future land use changes on soil erosion in the Kasilian watershed, Iran. In the study, Revised Universal Loss Equation and Markov Cellular Automata were employed. Data from 1981 to 2011 were used as a baseline to estimate changes that might occur in 2030. The results reveal that the mean erosion potential would increase 45% from the estimated 104.52 $t\ ha^{-1}\ year^{-1}$ in the baseline period. Moreover, the results indicated that land use change from forest area to settlements would be the most significant factor in erosion induced by land-use change, showing the highest correlation among erosional factors. Projecting land use change and its effect on soil erosion indicated that conversion may be unsustainable if change occurs on land that is not suited to the use. The method predicted soil erosion under different scenarios and provided policymakers a basis for altering programs related to land use optimization and urban growth. Those results indicated the necessity of appropriate policies and regulations particularly for limiting land use changes and urban sprawl in areas of unfavourable soil erosion risk factors.

Dagnew *et al.*(2017) conducted a study on the Effects of land use on catchment runoff and soil loss in the sub-humid Ethiopian highlands. They selected two small catchments: cultivated land and grassland dominated catchments within the 95 ha Debre Mawi catchment. Hydrometric and sediment concentration data were collected for five years (i.e., 2010–2014). Significant ($p < 0.05$) differences in daily, monthly and annual runoff, as well as suspended sediment concentrations were observed between cultivated land and grassland dominated catchments. The greater runoff, suspended sediment concentration and yield in the cultivated catchment could be attributed to repeated tillage and low soil organic matter. Repeated tillage in the cultivated land lead to soil disturbance and the low organic matter lead to aggregate instability, both of which consequently increase the detachment of soil particles and transport by generated runoff. Their results supported the idea that land management practices that involve lower soil disturbance and increase ground cover on degraded highland areas such as the Ethiopian highlands could help reduce runoff and soil loss.

2.5.2. Use of Mulch and Biochar

Babcock and McLaughlin (2013) conducted a study on the Erosion control effectiveness of straw, hydromulch, and polyacrylamide in a rainfall simulator. This study was an evaluation of straw, with or without polyacrylamide (PAM), and wood fiber hydromulch, with or without PAM, for reducing erosion and improving runoff water quality. From the results they got, they arrived at the following conclusions: Applying PAM with straw provided benefits in reducing turbidity, but the dry application could exacerbate erosion if heavy rain occurs soon after application. The best results were usually obtained with hydromulch plus PAM, but adding PAM to a less expensive straw ground cover produced similar or better results than the hydromulch application without PAM.

Montenegro *et al.*(2013) undertook a study on the Impact of mulching on soil and water dynamics under intermittent simulated rainfall. This study aimed to investigate in the laboratory the effect of distinct mulch densities on runoff and sediment transport, by using multiple step intermittent rainfall events. Laboratory experiments were conducted using a soil flume and rainfall simulator with three soil cover treatments: 1) bare soil; 2) low mulch cover, 2 t/ha density; and 3) high mulch cover, 4 t/ha density. Experiments comprised a sequence of five different rainfall events in an intermittent way, i.e., three uniform patterns with increasing rainfall intensities, one advanced pattern and one delayed pattern. The laboratory experiments described in this work clearly showed that mulching strongly affected infiltration, soil moisture, surface runoff and erosion. Intermittency and characteristics of sequential rainfall events also influenced these processes. Experimental results showed that mulch covers of 2 t/ha and 4 t/ha caused reductions of, respectively, 21% and 51% in the runoff peak. High mulch cover rates resulted in a significant increase in soil moisture. Additionally, soil temperature was more optimally regulated under a mulch cover density of 4 t/ha.

Donjadee and Tingsanchali (2016), conducted a research on Soil and water conservation on steep slopes by mulching using rice straw and vetiver grass clippings. This research investigated the performance of mulching using rice straw mulch (RC) and vetiver grass clippings as mulch (VGM) in reducing soil loss and runoff during the early stages of cultivation on an agricultural area. The effects of the rainfall intensity and mulch rate in conserving runoff and trapping sediment were determined by field experiments on land with a steep 30% slope. Three rainfall intensities of 35 mm/h, 65 mm/h and 95 mm/h were applied using an artificial rainfall simulator. The effects of five mulch rates (1.0, 1.5, 2.5, 5.0 and 7.5 t/ha) with conventional tillage were compared with un-mulched treatment. Both VGM and RC showed good potential for reducing runoff and soil loss. For a given rainfall intensity of 65 mm/h and a mulch rate of 1.5 t/ha, RC reduced runoff and soil loss less than VGM. For higher mulch rates, RC performed better than VGM. For example, at the 5.0 t/ha mulch rate, RC reduced runoff and soil loss by about 47.5% and 62.9%, respectively, compared to VGM with a corresponding reduction of 42.4% and 53.7%, respectively. It was recommended that application of 5.0 t/ha of RC or 7.5 t/ha of VGM is the most suitable for soil and water conservation.

Zeng-Yei *et al.*(2014) studied the Impacts of Biochar on Physical Properties and Erosion Potential of a Mudstone Slopeland Soil. Rice hull biocharpyrolized at 400°C was incorporated into the soil at rates of 2.5%, 5%, and 10% (w/w) and was incubated for 168 days in that study. The results indicated that biochar application reduced the Bd (Bulk density) by 12% to 25% and the PR (Soil penetration resistance) by 57% to 92% after incubation, compared with the control. Besides, porosity and aggregate size increased by 16% to 22% and by 0.59 to 0.94 mm, respectively. The results presented that available water contents significantly increased in the amended soils by 18% to 89% because of the obvious increase of micropores. The water conductivity of the biochar-amended soils was only found in 10% biochar treatment, which might result from significant increase of macropores and reduction of soil strength (Bd and PR). During a simulated rainfall event, soil loss contents significantly decreased by 35% to 90% in the biochar-amended soils. In conclusion, biochar application could availably raise soil quality and physical properties for tilth increasing in the degraded mudstone soil.

A study was also conducted by Jien and Wang (2013), on the Effects of biochar on soil properties and erosion potential in a highly weathered soil. The study evaluated the influences of biochar made from the waste wood of white lead trees (*Leucaenaleucocephala (Lam.) de Wit*) on the physicochemical and biological properties of long-term cultivated, acidic Ultisol. This study used three application rates (0%, 2.5%, and 5% (wt/wt)) of the biochar with an incubation time of 105 days (d) for all cases. Soils were collected at 21 d, 42 d, 63 d, 84 d and 105 d during the incubation period to evaluate changes in soil properties over time. A simulated rainfall event (80 mm h^{-1}) was performed to estimate soil loss for all treatments at the end of the incubation time. Among other results, it was found that incorporating biochar into the soil significantly reduced soil loss by 50% and 64% at 2.5% and 5% application rates, respectively, compared with the control. Also a 5% application rate of biochar was considered as suitable for highly weathered soil because this application rate efficiently improves soil physicochemical properties and reduces soil loss.

2.5.3. Use of Vegetation covers/hedges

Angima*et al.*(2000) did a study on Use of Tree/Grass Hedges for Soil Erosion Control in the Central Kenyan Highlands. Three erosion control methods of using a tree hedge, a grass hedge, and a combination of the two were used on an alfisol in central Kenya. Soil loss, biomass yield, and profile survey of the runoff plots were measured during two cropping seasons. Average cumulative soil loss from plots with hedges of tree, combination, grass, and non-hedged control were 5.6, 7.4, 11.2 and 10.9 Mg ha^{-1}, respectively. Dry matter yields were 2.98, 9.24, and 11.90 Mg $ha^{-1}yr^{-1}$for tree, combination, and grass hedge, respectively. Topographic survey of the plots showed a near uniform terrace formation and decrease in slope of about 0.2% for all hedges, but an increase in slope for the control plots by the same magnitude. Small-scale farmers in the highlands of Central Kenya who practiced a mixed farming system could use this soil conservation technology as a step towards sustainable farming practices.

Hou *et al.*(2016); in their study on the effect of plant diversity on soil erosion for different vegetation patterns, which was carried out in the Three-River-Source region, located in the hinterlands of the Qinghai–Tibet Plateau, China: by examining 99 plots within the study area, and analysing the soil ^{137}Cs inventory within the plots. They found that with a greater number of plants distributed within an aggregation pattern, there was greater interception of the soil particles by the vegetation patch.

Lenka *et al.*(2017) conducted a research on Weed strip management for minimizing soil erosion and enhancing productivity in the sloping lands of north-eastern India. In the research, a field experiment was conducted during the monsoon period of 2008 and 2009, in runoff plots on a land slope of 40% to test the hypothesis that weed cover, if properly managed, minimized soil erosion and improved soil productivity. The treatments implemented in duplicates were: maize (*Zea mays*) under shifting cultivation (T_1), maize on contour lines (T_2), groundnut (*Arachis hypogea*) on upper and maize on lower half of treatment plot, with both on contour lines (T_3), groundnut on contour lines (T_4) and maize on contour lines with natural vegetation as buffer strips (T_5). This study indicated that cover management involving selective weed retention could reduce soil erosion, favourably modify land slope and promote soil productivity.

A study was done by Noelle *et al.*(2017) on Slash Application Reduces Soil Erosion in Steep-Sloped Piñon-Juniper Woodlands. On a steep (30% ± 5%) slope that had been encroached by piñon and juniper trees, they evaluated the effectiveness of slash in reducing runoff and erosion using a portable rainfall simulator (100-yr return period events). Although total runoff did not differ across slash levels, there was marginal evidence of a difference associated with vegetation cover. Sediment yield for plots with low vegetation cover (< 13% cover) was 3.4 times greater than those with high cover, while plots with slash present (≥ 30% cover) experienced 5.4 times less sediment yield than plots without slash. These results extend findings from moderate to steep slopes, highlighting the potential efficacy of slash application for reducing erosion in steep-sloped rangelands.

2.5.4. Use of Plant Roots

Ali (2010) did a research on the Use of vegetation for slope protection: Root Mechanical Properties of Some Tropical Plants.In the study, both pull-out and tensile strength of some tropical plants, namely Leucaena leucocephala, Acacia mangium and Melastoma malabathricum were investigated on different stem sizes. Plots of pull-out capacity against displacement in L. leucocephala exhibited the presence of two peak values. Closer examination concluded that the first peak indicated the failure of the lateral roots and the second peak was achieved when the tap roots failed. As for the tensile strength tests, results showed that the tensile strength decreases with increasing root diameter. The results also indicated that there was no correlation observed between the tensile strength, root length and root moisture content. Amongst the species, the highest root tensile strength was observed in L. leucocephala, followed by A. mangium and M. malabathricum. Thus, the study suggested that of the plants conserved, L. leucocephala is the best choice for slope stabilization work as it exhibits outstanding root mechanical properties.

Ghestem *et al.*(2011) wrote an article on The Influence of Plant Root Systems on Subsurface Flow: Implications for Slope Stability. In the article they stated thus: "Although research has explained how plant roots mechanically stabilize soils, in this article we explore how root systems create networks of preferential flow and thus influence water pressures in soils to trigger landslides. Root systems may alter subsurface flow: Hydrological mechanisms that promote lower pore-water pressures in soils are beneficial to slope stability, whereas those increasing pore pressure are adverse. Preferential flow of water occurs in the following types of root channels: (a) channels formed by dead or decaying roots, (b) channels formed by decayed roots that are newly occupied by living roots, and (c) channels formed around live roots. The architectural analysis of root systems improves our understanding of how roots grow initially, develop, die, and interconnect. Conceptual examples and case studies are presented to illustrate how root architecture and serse traits (e.g., diameter, length, orientation, topology, sinuosity, decay rate) affect the creation of root channels and thus affect preferential flow."

A study was thus conducted by Mwango *et al.* (2014) on Root Properties of Plants Used for Soil Erosion Control in the Usambara Mountains, Tanzania. It was carried out in the Western Usambara Mountains, Tanzania to investigate rooting characteristics of Guatemala grass (Tripsacum andersonii), Napier grass (Pennisetum purpureum) and Tithonia shrub (Tithonia diversifolia), also referred to as wild sunflower, and to evaluate their potential for erosion control. For each plant species, mean root diameter (D), root density (RD), root length density

(RLD) and root area ratio (RAR) were assessed for six plants in each species and relative soil detachment rate (RSD) predicted. Mean RD values in the 0 - 0.4 m soil depth for Majulai village and Migambo village respectively were 50.9 and 58.6 kg/m3 for Guatemala grass, 30.4 and 31.3 kg/m^3 for Napier grass and 22.1 and 23.0 kg/m^3 for Tithonia shrub. RLD values were 35.9 and 45.0 km/m^3 for Guatemala grass, 31.3 and 150.0 km/m^3 for Napier grass and 10.5 and 6.4 km/m^3 for Tithonia shrub. Predicted RSD values were 4.43×10^{-12} and 1.20×10^{-14} for Guatemala grass, 6.10×10^{-5} and 2.74×10^{-4} for Napier grass and 4.43×10^{-3} and 2.24×10^{-4} for Tithonia shrub in the 0 - 0.4 m soil depth. The results indicated that Guatemala grass has a higher potential to reduce soil erosion rates by concentrated flow as compared to Napier grass or Tithonia shrub in the 0 - 0.4 m soil depth. These findings have implications on the selection and use of appropriate plants for soil erosion control.

A research was undertaken by Saifuddin and Normaniza (2016) on Rooting Characteristics of Some Tropical Plants for Slope Protection. The study was aimed at investigating root architectural and mechanical properties of seven tropical plants. Based on root growth pattern, it was observed that Leucaena leucocephala and Pterocar pusindicus had taproots and their lateral roots grew horizontally and profusely. Therefore, the root systems of L. leucocephala and P. indicus were categorised as VH-type and the trees were recommended for planting in the middle of the slope. Peltophorum pterocarpum and Acacia mangium exhibited R- and H-types root systems respectively and were also recommended for planting in the middle of the slope. Melastoma malabathricum, Dillenia suffruticosa and Lantana camara possessed shallow roots. Their root systems were more similar to the M-type and these plants were suggested for planting at the top or toe of the slope. Leaf area index and root biomass of the species were positively correlated (r^2 =

0.90). Tensile strength decreased with increasing root diameter, implying that lower root diameter contributed to the higher tensile strength. Different plants have different types of root architecture and tensile strength. These rooting characteristics can be used as important factors in selecting potential plants for slope stability.

Li *et al*. (2017) undertook a research on the Relative contribution of root physical enlacing and biochemistrical exudates to soil erosion resistance in the Loess soil. This study selected *Purple alfalfa* root- and designed root-penetrated Loess soil as study object, and subjected to flow scouring. The results showed that roots could significantly ameliorate soil properties, especially for soil enzymes.

A study was also carried out by Vannoppen*et al*.(2017) with the prime objective of assessing the erosion-reducing potential of both fibrous and tap roots in sandy soils. Furthermore, they investigated potential effects of root diameter, soil texture and dry soil bulk density on the erosion-reducing potential of plant roots. Flume experiments conducted on sandy soils (the study) were compared with those on sandy loam and silt loam soils (using the same experimental set up). Results showed that plant roots were very efficient in reducing concentrated flow erosion rates in sandy soils compared to root-free bare soils. Furthermore, their results confirmed that fibrous roots were more effective compared to (thick) tap roots.

Another study on the effect of Bahiagrass roots on soil erosion resistance of Aquults in subtropical China was undertaken by Ye *et al*.(2017). The study evaluated the effects of root distribution characteristics on soil shear resistance and soil detachment rates, correlations among root mechanical properties, root chemical composition and root parameters, and whether the Wu-Waldron model could accurately estimate soil reinforcement by roots. Bahiagrass

(*Paspalumnotatum*) was planted in planter boxes by overlapping four rectangle frames (0.4 × 0.1 × 0.1 m). A series of laboratory tests of direct shear strength and soil detachment were conducted on two soils that were derived from granite and shale with different soil depths and sowing densities. The results indicated that soil aggregate stability was positively correlated with root characteristics. This study demonstrated that the root area ratio was a more suitable root characteristic parameter that contributes to soil reinforcement.

2.5.5. Use of Soil Stabilizers

According to Afrin (2017), who did a Review on Different Types of Soil Stabilization Techniques, defined Soil stabilization as the process of improving the shear strength parameters of soil and thus increasing the bearing capacity of soil. It is required when the soil available for construction is not suitable to carry structural load. She also said that Soil Stabilization is the alteration of soils to enhance their physical properties. Stabilization can increase the shear strength of a soil and/or control the shrink-swell properties of a soil, thus improving the load bearing capacity of a sub-grade to support pavements and foundations.

Liu *et al.*(2011) conducted a Research on the stabilization treatment of clay slope topsoil by organic polymer soil stabilizer. The stabilizer, known as STW, was introduced in the study. In order to understand the effect of STW on the stabilization of clayey soil, laboratory tests on the unconfined compressive strength, shear strength, water stability and erosion resistance of untreated and treated soil specimens were performed. The results indicated that STW soil stabilizer can significantly increase the unconfined compression strength, shear strength, water stability and erosion resistance of clayey soil. Based on the scanning electron microscopy (SEM) analysis of the stabilized soil, the stabilization mechanisms of STW soil stabilizer in the clayey soil were discussed. Finally, a field test of the stabilization treatment of clay slope topsoil with STW was carried out, and the results indicated that the STW soil stabilizer on the stabilization treatment of clay slope topsoil was effective for improving the erosion resistance of slope topsoil, reducing the soil loss and protecting the vegetation growth. Therefore, this technique is worth popularizing for the topsoil protection of clay slope.

A research was investigated by Zhao *et al.*(2014) on the Effects of Chemical Stabilizers on an Expansive Clay. The work investigated the effects of chemical agents on an expansive soil from Texas through a laboratory injection method. The agents used in this study included lime, potassium based agents, and a group of ionic agents. Swelling tests, chemical tests, and soil suction tests were used to evaluate the stabilizing effects of those chemical agents. The testing results indicated that potassium based stabilizer, was an effective stabilizing agent to control the swelling potential of the expansive clay. It can also be injected in the field to build a moisture barrier. The chemical tests on the injected Texas clay showed that the stabilizing mechanism of the ionic agents was possibly through the cations' exchange and the increase of the cations' concentrations in the soil pore water.

Chen *et al.*(2016) researched on the Effects of polyacrylamide on soil erosion and nutrient losses from substrate material in steep rocky slope stabilization projects. In this paper, twenty-seven simulated rainfall events were carried out in a greenhouse, in which the substrate material was artificial soil; nine types of anionic polyacrylamide (PAM) were studied, which consisted of three molecular weight (6, 12, and 18 $Mg\ mol^{-1}$) and three charge densities (10, 20, and 30%) formulations in a 3 by 3 factorial design. The results showed that: Polyacrylamide treatments increased water-stable aggregates content by 32.3% to 59.1%, total porosity by 11.3% to 49.0%, final infiltrative rate by 41.3% to 72.5%, and reduced soil erosion by 18.9% to 39.8% compared with the control group. The results of this study indicated that polyacrylamide application in the steep rocky slope stabilization projects could significantly reduce nutrient losses and soil erosion of substrate material.

Treatment of dispersive clay soil by ZELIAC (a new additive; and a non-hazardous composite material produced using naturally existing low-cost ingredients such as zeolite, activated carbon, and calcium carbonate) was investigated by Vakili *et al.* (2017), for treating a Malaysian dispersive clay soil. An appreciable decrease in dispersivity was achieved due to treatment with 8% of the ZELIAC. The curing time was found to be significant that after 28 days, the initially dispersive samples became non-dispersive. Furthermore, due to the treatment, the samples had increased unconfined compressive strength (UCS), permeability, and optimum moisture content; and decreased fines content, plasticity index, maximum dry density, and compressibility index. The UCS increased nearly 7.3 times for sample treated with 8% ZELIAC and cured for 90 days. The X-ray fluorescence (XRF) results showed a cementitious structure with calcium content 10.8 times more in the treated sample than in the untreated one, reflecting the constructive cation exchange reaction taking place during the curing process. The sodium ion was noticeably replaced by calcium ion which resulted in a decreased thickness of the diffused double layer and the subsequent reduction in the dispersivity of the sample. These results were also reflected by the lower peak intensity as measured by the X-ray diffraction test (XRD) for the treated sample, as compared to the higher peak intensity for the un-treated sample. Finally, the SEM images indicated that the flocculated structures of the treated dispersive clay were surrounded by the

ZELIAC particles. Thus, the ZELIAC was proven to be effective in improving the studied Malaysian dispersive clay.

Mirzababaei *et al.* (2017) carried out a study on Polymers for Stabilization of Soft Clay Soils. In this study, the influence of two chemical additives, (i.e., poly(vinyl alcohol), PVA and 1,2,3,4 Butane Tetra Carboxylic Acid, BTCA on the engineering properties of an expansive clay soil was investigated. The effect of polymers on the unconfined compressive strength of soil samples prepared at maximum dry unit weight (i.e., 16.2 kN/m^3 and 17% water content) and a lower dry unit weight (i.e. 10.8 kN/m^3 and 48% water content) was evaluated. PVA and BTCA added at dosages of 0.1% to 1.5% and 0.1% to 0.5% respectively to both compacted soil samples and cured for 1 and 14 days. The results of unconfined compression tests on clay soil samples stabilized with different PVA and BTCA contents cured for 1 and 14 days indicated that such hydrophilic polymers improved the compression strength of both dense and soft clay soils significantly and their strength even increases with curing time. However, the efficiency of the additives is highly dependent on the unit weight of the soil.

In a research undertaken by Eires*et al.*(2017) on Enhancing water resistance of earthen buildings with quicklime and oil, the main aim of the research was to improve the resistance of compressed soil against rainwater action. For this purpose, ancient and contemporary knowledge was analysed. Different mixtures of stabilized soil were studied in order to test the effects of quicklime, oils and a mineral additive. The main results obtained in that research showed that quicklime led to increased performance in compressive strength and significantly reduced erosion in the accelerated erosion test of rain simulation. This study provided a contribution to the scientific knowledge required to achieve increased durability for new earthen buildings, as well as for conservation of existing earthen construction heritage, preserving the sustainability of the construction.

From the literature review, the following gaps were observed:

1. Several studies on the components of erosion soils have been done. For example, a research was carried out by Ojiako (2008) on the Solutions to Gully Erosion Menace in Anambra State: Chemists' Contribution from Soil Profile Studies. The aim was to ascertain the difference in the soils' compositions of highly erosive areas (HEA), intermediately erosive areas (IEA) and non-erosive areas (NEA). Nevertheless, the research did not treat the soil samples of these HEA, IEA and NEA, individually, but as composites. As a result, specific soil composition of each of these soils remained unascertained. For this reason, this research therefore seeks to find out the individual compositions of some selected erosion and non-erosion prone areas under some specified geological formations which have a history of possessing soil structures that are highly erosive.

2. None of the works reviewed tried to proffer chemical solution to the gully erosion in South-Eastern Nigeria through soil stabilization. Most of them, if not all, only considered the use of plants/vegetation, engineering methods, attitudinal change and policy enactment for soil stabilization. But it is clear that the chemical constituents of soil affects its erodibility and erosivity. Hence, this study proffers solution to gully erosion in Anambra State through critically looking at the soil chemical constituents.

3. Again, none of the studies tried to determine the ratios of their chemicals usable to stabilize the gully-erosion prone soils. But this study, in addition to determining the usable chemicals, further established the accurate proportions of the stabilizing

chemicals. As a results of the following literature gaps, the present research then seeks to fill these gaps.

CHAPTER THREE

MATERIALS AND METHODS

This chapter will focus on the different methods of analysing the soil components. It will also state the steps/chemicals used in stabilizing the erosive soil samples, and how the Unconfined Compressive Strength (UCS) of the stabilized soil samples were determined, using a Pocket Penetrometer.

3.1 SAMPLE COLLECTION AND PREPARATION

3.2. MATERIALS

3.2.1. Materials employed for the collection of the soil samples were:

Shovel, Polymeric (Plastic) bags, Labelling/Masking Tape.

3.2.2. Soil samples

Seven soil samples, five from the Erosion Prone Areas (EPAs) of Nanka, Oko, Oraukwu, Nnewi and Oba; and two from non-erosion prone areas (NEPAs) of Umunya and Awka were used throughout the analysis.

Soils from Nanka, Oko, Oba, Nnewi and Oraukwu were represented with EPA 1, EPA 2, EPA 3, EPA 4 and EPA 5; while the soil samples from Awka and Umunya were represented by NEPA 1 and NEPA 2 respectively.

3.3.3 Method of soil samples collection

Soil samples were collected from seven areas in the State which falls under the Ameki Geological Formation[Obiadi *et al.*, 2011]. The soil samples were collected (with shovel and plastic bags) >10 feet below the soil surface. This was done in order to get to the parent soils. After the soil samples were collected, they were put inseparate plastic bags, tied and properly labelled with a paper tape. They were then taken to the lab for analysis.

3.2.4. Instruments for analysis

The following instruments were employed in the analysis of these soil samples:

Varian AA240 Atomic Absorption Spectrophotometer (AAS), UV/Visible spectrophotometer, 16-T0171 pocket penetrometer, crucible, electric muffle furnace, beakers, filter paper, 250ml Erlenmeyer flask, porcelain dish

3.2.4. Reagents and chemicals for analysis

The following are the different laboratory solvents/reagents used throughout the analysis:

Distilled water, strontium nitrate solution, phenolphthalein indicator, calcium chloride, solution, sodium carbonate, sodium nitrate, hydrochloric acid, barium sulphate, barium chloride, sodium hexametaphosphate, nitric acid, sulphuric acid, ammonium persulphate, perchloric acid, potassium chromate, iron (II) sulphate, aluminium chloride, calcium hydroxide, magnesium chloride.

3.3.0. METHODS FOR ANALYSIS

3.3.1. Determination of pH in $CaCl_2$

10g of the air dried and sieved soil sample were weighed out; which was then placed into a glass container and 10mL of 0.01M $CaCl_2$ solution was added. It was mixed thoroughly and left standing for 1 hour. It was then siphoned and the pH was ascertained from the pH meter.

3.3.2 Percentage Sulphur Determination.

Fusion: 1.0g of finely powdered soil was mixed with 5.0g of $NaCO_3$ and 5g of $NaNO_3$, in a crucible. The mixture was preheated at 400^0C for 30mins in an electric muffle furnace, and then fused at 950^0C after the fusion, the crucible was allowed to cool and was placed on its side in a 200mL beaker. Enough deionized water barely to cover the content of the crucible was added and the beaker was heated at a temperature just below boiling on a hot plate, until the melt was thoroughly disintegrated. The crucible was then removed and washed with deionized water. At this point $20cm^3$ of 6M HCl was added to neutralize the $NaCO_3$ and to make the solution slightly acidic. This was filtered into a $100cm^3$ volumetric flask and the volume made up to the mark with deionized water.

Precipitation of $BaSO_4$: The solution was brought to boiling and $10cm^3$ of 10% $BaCl_2$ was slowly added to precipitate the sulphate. The solution was allowed to cool and was filtered. The residue was washed with deionized water.

Ignition of $BaS0_4$

The ashless filter paper was ignited at low temperature (40^0C) and the precipitate weighed. The percentage sulphur in the precipitate was calculated from the expression below:

$$\%\,Sulphur = \frac{BaSO4(g)\ \times 13.17}{wt\ of\ sample\ in\ gram}$$

3.3.3. Determination of % Silt, Clay, Sand (Particle size analysis).

- 30g of the soil sample was weighed into a 250mL beaker
- A beaker was filled with distilled water to 200mL mark.
- The soil was washed for four times with distilled water.

- 25% sodium hexametaphosphate solution was prepared.
- 20ml of the solution and 200mL of distilled water was added to the washed sand, and then allowed to stand for 16hrs (i.e. overnight).
- The soil sample was transferred into 0.1μm (micrometer) sieve. During sieving, the sample that was left on the sieve was the sand while the sample that passed through the sieve was the silt. The sample was then dried to a constant weight [AOAC, 1984]

$$\%\text{Sand} = \frac{\text{Residue wt.} \ \times \ 100}{\text{sample wt.}}$$

$$\%\ \text{Silt} = \frac{\text{Residue wt.} \ \times 100}{\text{sample wt.}}$$

% Clay = 100 – (% Silt + % Sand).

3.3.4. Cations Determination

Heavy metal analysis was conducted using Varian AA240 Atomic Absorption Spectrophotometer according to the method of APHA 1995 (American Public Health Association) [APHA, 1995].

Dry Digestion

Two grams of the sample was weighed into a crucible and put into a muffle furnace for ashing at a temperature of 450^0C for 2hours. The sample was removed from the furnace and allowed to cool. The dry ash was emptied into a 250mL beaker and 20mL of 20% H_2SO_4 was added, heated in a water bath for 20mins, filtered and made up to 50mL with distilled water and stored in a sample bottle for AAS macro and micro nutrient analysis [Adrian, 1973].

Preparation of Reference Solution:

A series of standard metal solutions in the optimum concentration range was prepared, the reference solutions were prepared daily by diluting the single stock element solutions with deionised water containing 1.5mL concentrated nitric acid/litre. A calibration blank was prepared using all the reagents except for the metal stock solutions.

Calibration curve for each metal was prepared by plotting the absorbance of standards versus their concentrations

3.3.5. Bicarbonate determination

Burette (50mL) was rinsed several times with 0.02N HCl.

The burette was filled with the HCl solution. It was ensured that there was no air bubbles in the tip, and that the meniscus was readable at close to 0.00mL on the burette scale.

1. 10g of the soil was mixed with 100mL of water and filtered.

2. 100.0mL of the filtrate sample to be analysed was measured into a 250mL Erlenmeyer flask, and 3 drops of bromocresol, as an indicator was put into the filtrate.

3. The filtrate was titrated with 0.02N HCl solution until a bromocresol green (pH = 4.5) end point was reached.

Calculations of the alkalinity was expressed in terms of milligrams of calcium carbonate per litre.

Alkalinity = (mL HCl titrant) x (normality of HCl) X (50,000) / (mL of water sample) [AOAC, 1984].

3.3.6 Chloride determination

Method: Chloride was analysed according to APHA Standard Method [APHA, 1998].

Procedure

A 100ml of the clear 10% sample was pipetted into an Erlenmeyer flask. Then 1ml of 5% K_2CrO_4 indicator solution was added and titrated against with standard solution of 0.01N $AgNO_3$ to a permanent reddish brown colouration.

Calculation

Chloride conc. = Titre value (x) x 10 =10xmg/L

3.3.7. Phosphate determination

Procedure: Exactly 10g of the dry soil sample in 100ml was homogenized (properly mixed) and filtered into a conical flask. The same volume of distilled water (serving as control) was also pipetted into another conical flask as blank. 1ml of 18M H_2S0_4 and 0.89g of ammonium persulphate were added to both conical flasks and gently boiled for 1½ hours, keeping the volume at 25-50cm^3 with distilled water. It was then cooled [Schofield, 1995].

One drop of phenolpthalein indicator was added and after neutralized to a faint pink colour with the 2M Na0H solution. The pink colour was discharged by drop-wise addition of 2M HCl, and the solution made up to 100ml with distilled water. For the colorimetric analysis, 20ml of the sample was pipetted into test tubes, 10ml of the combined reagent (68ml of nitric acid, 8ml of perchloric acid and 2ml of sulphuric acid)added, shaken and left to stand for 10mins before reading the absorbance at 690nm on a spectrophotometer, using 20ml of distilled water plus 1ml of the reagent as reference.

$$\text{Conc. of sample} = \frac{\text{Abs of sample } \times \text{conc. of Std.}}{\text{Abs of Std.}}$$

3.3.8. Loss of Organic Matter determination

1-2g scoop of soil sample was placed into a 20-ml beaker. It was then dried for 2 hours at 105^0C. The weight was record to ± 0.001g. The furnace temperature was heated to 360^0C. The soil samples was put into the furnace and allowed to stay at 360^0C for 2 hours. The sample was then cooled to room temperature, and weighed to ± 0.001g, in a draft – free environment [Bremner, 1990].

Calculation

$$\text{Loss of Organic Matter} = \frac{(\text{wt. at } 105°\text{C}) - (\text{wt. at } 360°\text{C } \times 100)}{\text{wt. at } 105°\text{C}}$$

3.3.9. Determination of Total Organic Carbon

10g of the air – dried soil was ground to pass a 0.1mm sieve. It was weighed accurately into a conical flask. 10ml of 5% $K_2Cr_2O_7$ was added into the flask and swirled gently to disperse the soil in the solution. 20mL concentration of H_2SO_4 was added into the suspension. Immediately it was swirled until the soil and the reagent were properly mixed. A 200^0C thermometer was inserted and heat applied while swirling the flask and the content on a hot plate until the temperature reached 139^0C. It was set aside to cool slowly on an asbestos sheet in a fume cupboard. One blank (without soil) must be run in the same way to standardized $FeSO_4$ solution.

When cooled (20 – 30mins), it was diluted with 200mL deionised water, and titrated with the $FeSO_4$ solution, using the phenanthroline indicator to a greenish endpoint.

$$\text{TOC \%} = \frac{\text{TOC\%} = 0.03\text{g} \times \text{N} \times 10\text{ml} \left(1 - \frac{\text{T}}{\text{S}}\right) \times 100}{\text{ODW}}$$

Where N= normality of $K_2Cr_2O_7$, T= Vol. of $FeSO_4$ used in sample, S= Vol. of $FeSO_4$ used in blank, ODW= oven dried sample weight [Ball, 1994].

3.3.10. Nitrite Determination

Method: Nitrite is determined using PD303 UV Spectrophotometer [APHA, 1998].

Five gram of soil sample was weighed into 50mL of distilled water, and was filtered. 50mL of the filtrate was pipetted into a porcelain dish and evaporated to dryness on a hot plate. 2ml of phenol disulphuric acid was added to dissolve the residue by constantly stirring with a glass rod. Solution of concentrated 2M sodium hydroxide, and distilled water was added with stirring to make it alkaline.

This was filtered into a Nessler's tube and made up to 50mL with distilled water. The absorbance was read at 410nm using a spectrophotometer after the development of colour. The value of nitrate was calculated as follows.

$$\text{Concentration os sample} = \frac{\text{Abs of sample} \times \text{conc. of Std.}}{\text{Abs of Std.}}$$

3.4.0 Chemical Stabilization Procedures

3.4.1. Preparation of Soil Particles

The five soil samples from the EPAs were first sun-dried for more that 20hrs, to remove moisture from the soil particles. Then they were put into an oven for I hour to remove the remaining moisture content.

A flat bottomed round metallic pipes of about 25mm diameter and 60mm high each were fabricated.

Plate. 3.0a. Pocket Penetrometer **Plate. 3.0b. Fabricated Pipes**

3.4.2. Preparation of the stabilizing chemicals

The soil stabilization chemical solutions used in the analysis were namely: Calcium Hydroxide ($Ca(OH)_2$) Magnesium Chloride ($MgCl_2$) Aluminum Chloride ($AlCl_3$) and Calcium Chloride ($CaCl_2$). Their solutions were each prepared by putting 20g each of their solutes in 200mL of water.

3.4.3. Steps for the Stabilization Process

1. 10g each of the five soil samples were weighed into the fabricated pipes.
2. 2mL each of the solution of the chemicals were weighed into the fabricated pipes.
3. The soil samples were allowed to absorb the chemicals.

4. The soil/chemical mixture were placed on an electric heater for 7-10 minutes to allow for the evaporation of the water molecules, leaving behind the solute particles which help in binding the soil particles.
5. They were brought down.
6. The experiment was repeated using 15g each of the five soil samples.
7. The use of 10 and 15g of the soil samples for the four chemical solutions were repeated 2-3 times, and the best values were selected

3.4.4. Confirmation of Soil Particles Compaction Test Procedure Using a Penetrometer

Penetrometer measure the resistance offered by the soil to penetration. The resistance offered by the soil is in proportion to soil strength [Jaiswal, 2003].

The penetrometer was used as follows:

1. The tip of the penetrometer was placed on the soil surface, making a right angle with the soil surface
2. Then the handle of the penetrometer was slowly pushed to penetrate the soil with the needle tip of the penetrometer.
3. As pressure on the handle of the penetrometer is released, the handle reverts smoothly to its initial position leaving behind the plastic ring on the needle (i.e. steel rod) which is calibrated [Jaiswal, 2003].

The Readings for the Unconfined Compressive Strength (UCS) were recorded in kg/cm^2. The experiment was carried out for 10g and 15g each of all the five soil samples using the four chemical solutions.

The use of 10 and 15g of the soil samples for the four chemical solutions were repeated 2-3 times, and the best values were selected

3.5.0 Statistical Analysis

3.5.1 Paired Sample T-Test

The Paired Samples *t* -Test compares two means that are from the same individual, object, or related units. The two means typically represent two different times (e.g., pre-test and post-test with an intervention between the two time points) or two different but related conditions or units (e.g., left and right ears, twins). The purpose of the test is to determine whether there is statistical evidence that the mean difference between paired observations on a particular outcome is significantly different from zero. The Paired Samples *t* -Test is a parametric test.

The Paired Samples *t*-Test is commonly used to test the following:

- Statistical difference between two time points
- Statistical difference between two conditions
- Statistical difference between two measurements
- Statistical difference between a matched pair

The Paired Samples *t*-Test can only compare the means for two (and only two) related (paired) units on a continuous outcome that is normally distributed [https://libguides.library.kent.edu/SPSS/PairedSamplestTest, Date Assessed, 8\4\2018].

3.5.2 Kruskal Wallis Test

The Kruskal-Wallis H Test is a nonparametric procedure that can be used to compare more than two populations in a completely randomized design. All n = $n_1+n_2+\ldots+n_k$ measurements are jointly ranked (i.e.treat as one large sample).

The test statistic is:

$$H = \frac{12}{n(n+1)} \sum_{i=1}^{k} \frac{R_i^2}{n_i} - 3(n+1).$$

[http://www.srmuniv.ac.in/sites/default/files/downloads/kruskal_wallis_test.pdf Date Assessed, 8/4/2018].

It is an alternative non-parametric procedure for one-factor analysis that may be used when the assumptions of the F-test are not satisfied.

3.5.3 Mean

This is the most familiar measure of central tendency. The mean of a set of data is obtained by adding together all the values in the population or sample and dividing the result by the number of values added. It is denoted by μ (population mean) or $\bar{x}$ (sample mean) [Oyeka, 2009].

The general expression for the population mean of x is given concisely by:

$$\mu = \frac{\sum_{i=1}^{N} x_i}{N}$$

The symbol $\sum_{i=1}^{N} x_i$ instructs us to add all the observations on the variable x from the first observation x_1 for i = 1 to the last observation x_N, for i = N.

The sample mean is given as:

$$\bar{x} = \frac{\sum_{i=1}^{N} x_i}{n}$$

3.5.4 Wilcoxon Signed Rank Test

The Wilcoxon signed-rank test is a non-parametric statistical hypothesis test used to compare two related samples, matched samples, or repeated measurements on a single sample to assess whether their population mean ranks differ (i.e. it is a paired difference test). It can be used as an alternative to the paired Student's t-test, *t*-test for matched pairs, or the *t*-test for dependent samples when the population cannot be assumed to be normally distributed. A Wilcoxon signed-rank test is a nonparametric test that can be used to determine whether two dependent samples were selected from populations having the same distribution. [https://en.wikipedia.org/wiki/Wilcoxon_signed-rank_test, Date Assessed, 09/04/2018].

The test statistic is given as [Oyeka, 2009]:

$$z = \frac{U - \mu_r}{\sigma_r} = \frac{T - \frac{n(n+1)}{4}}{\sqrt{\frac{n(n+1)(2n+1)}{24}}}$$

CHAPTER FOUR

RESULTS AND DISCUSSION

This chapter is broken into two sections:

1. **The first section will discuss the following:**

- **Soil chemical components which include: Cations, Anions, pH, Total Organic Carbon and Organic Matter components**
- **Soil physical properties which include: Particulate matter (% sand, silt and clay), Moisture content and Porosity**

2. **The second section will discuss the:**

- **Findings from the chemical stabilization of the five erosion prone soils from Nanka, Oko, Oba, Nnewi and Oraukwu erosion sites with solutions of $AlCl_3$, $CaCO_3$, $MgCl_2$, $CaCl_2$ and $Ca(OH)_2$.**
- **The confirmation of the Unconfined Compressive Strength (UCS) of these five erosive soils using a 16-T 171 Pocket Penetrometer.**

It is therefore expected that at the end of this chapter, the above points would have been adequately dealt with.

In addition, statistical tools were employed for the comparative and relative analysis of the values between the:

- **Cations of Erosive and Non-erosive soils**
- **Chemically stabilized soil samples using different soil masses of Erosive soils of EPAs 1-5.**

CATIONS	***NEPA 1 (Awka)***	***NEPA 2 (Umunya)***	***EPA 1 (Nanka)***	***EPA 2 (Oko)***	***EPA 3 (Oba)***	***EPA 4 (Nnewi)***	***EPA 5 Oraukwu)***
Si	44.25	878	76.65	55.1	611	3874.2	1269.15
Cu	1.15	82.55	2.9	2.25	105.05	202.15	64.8
Fe	979.9	1093.35	824.7	978.75	1007.25	1074.2	1070.5
Ni	87.15	37.8	56.65	95.5	15.7	72.7	42.25
Pb	5.5	136.15	12.8	9.25	176.35	41	30.75
Cd	3.85	26.35	3.05	1.950	32.75	22.65	7.7
Mn	39.6	58.6	8.25	224.5	86.4	308.35	708.45
Zn	78.2	258.5	35.75	80.35	203.35	420.35	485.3
K	261.05	589	155.1	205.4	633.5	561.55	411.15
Ca	42.95	378.9	66.65	51.1	643.35	462.8	412.9
Mg	753.45	904.5	623.25	710.3	790.05	799.25	877.4
Na	460.3	276.8	294.85	362.6	123.7	1543.21	1618.61
Al	2532.55	183.45	0	1324.25	0	1041.05	1237.4

Table 4.1: Composite Cations ratio of the different soil samples in ppm

Table 4.1 analysed statistically the mean difference of the NEPAs and EPAs respectively. This was done in order to know whether among the NEPA 1and 2, any of them can be used as a control for analysis. Also the values of the EPAs were analysed to find out among the EPAs 1-5 whether any of them deviated from the one another, significantly.

The statistical tool employed was Kruskal-Wallis Test. The result of the test was as follows:

S/N	Null Hypothesis	Test	Sig.	Decision
1	The distribution of OBSERVATION 1 is the same across categories of NONE EROSION AREA	Independent-Samples Kruskal Wallis Test	.293	Retain the null hypothesis

Table 4.1a: Kruskal-Wallis Hypothesis Test for NEPA 1 and NEPA 2

Note: The significance level 0.05

The result in Table 4.1a showed that there was no significant difference between mean values of cations in NEPA 1 and NEPA 2, due to a p-value of 0.293.

This means that either of the non-erosive soils can be used to compare with the EPAs.

Table 4.1b: Kruskal-Wallis Hypothesis Test for EPAs 1-5

S/N	Null Hypothesis	Test	Sig.	Decision
1	The distribution of OBSERVATION 2 is the same across categories of EROSION AREA	Independent-Samples Kruskal Wallis Test	.035	Reject the null hypothesis

Note: The significance level 0.05

The result in Table 4.1b showed that there was a significant difference between mean values of cations in EPAs 1-5, due to a p-value of 0.035.

This means that the values of some of the EPAs cannot be used interchangeably with one another. This is possibly due to the influence of natural and anthropogenic factors on these erosion-prone areas.

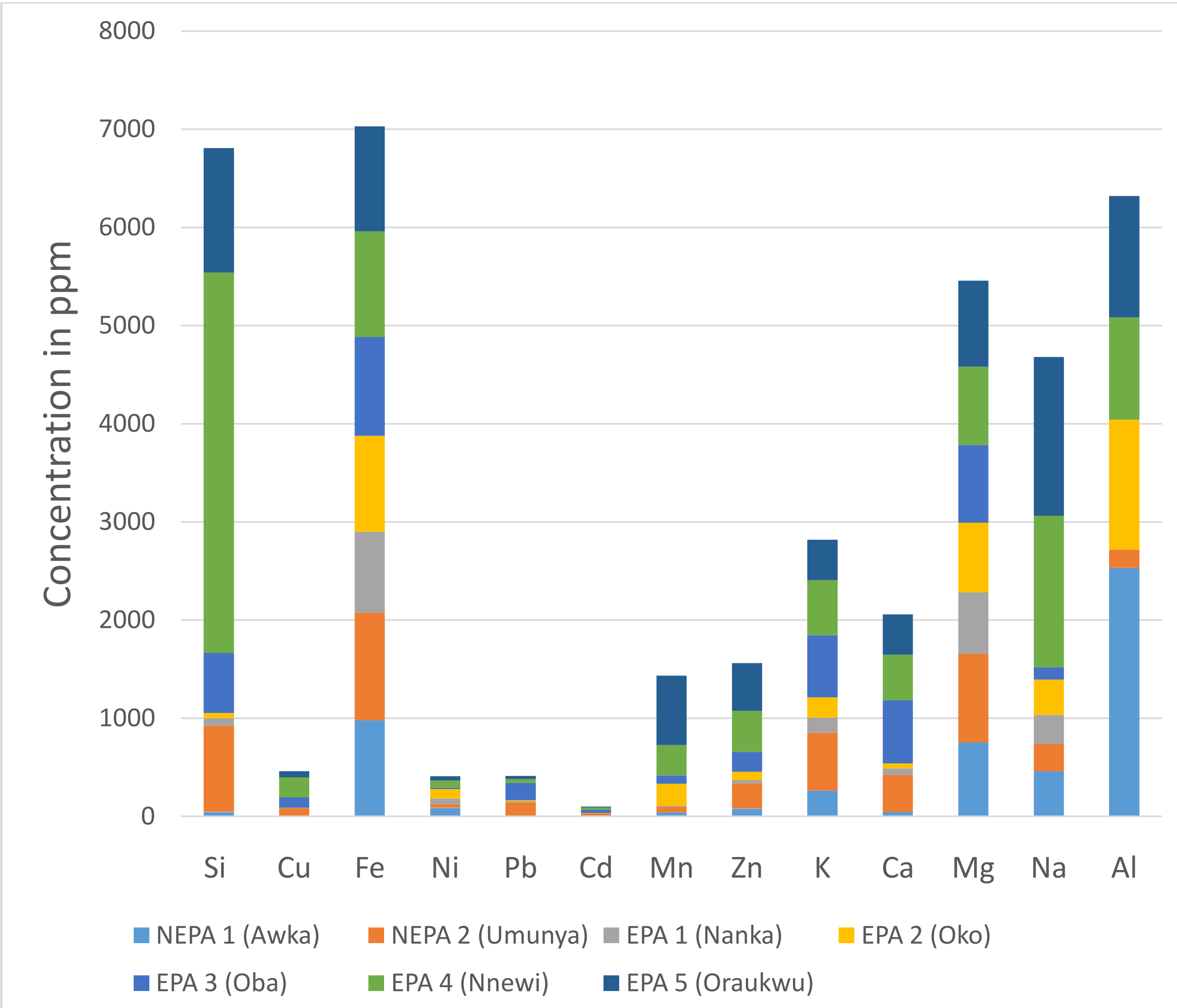

Fig. 4.1: Composite Concentration of Cations across the NEPAs and EPAs

Silicon (Si) in Awka and Umunya are 44.25 and 878ppm respectively, while those in Nanka, Oko, Oba, Nnewi and Oraukwu are as follows: 76.65, 55.1, 611, 3874.2 and 1269.15ppm respectively.

Now, the following soil samples were collected during the rainy season: NEPA 1 (Awka), EPA 1(Nanka) and EPA 2 (Oko), while those collected during the dry season were NEPA 2 (Umunya), EPA 3 (Oba), EPA 4 (Nnewi) and EPA 5 (Oraukwu). So the Si content in all the soils collected during the dry season generally have higher Si content than in those soils collected during the rainy season. As seen in the Table above; in EPA 4, its value is 3874.2, the highest value from other cations.

This was supported by the research carried out on the Evaluation of silica-supplying power of soils for growing rice, by Nayar *et al.* (1977). From their research it was discovered that the silica content of the dry-season crop was higher than that of the wet-season crop possibly because of more favourable climatic conditions prevailing during dry season which enhanced absorption.

Silicon or silicate material is a good soil binder as seen in the research carried out by Ojiakor (2008) where she found out that non-erosive soil has the greatest percentage of silicate material. However, even though Silicon is a good soil binder for erosive soils, yet due to seasonal variations of the silicon contents in the soils, its binding effect may not last on an erosive soil. Therefore it is not advisable that silicon salts be used as soil stabilizers.

The quantity of **copper (Cu)** in ppm found the soil samples of Awka and Umunya were 1.15 and 82.55ppm, respectively, while those in Nanka, Oko, Oba, Nnewi and Oraukwu were 2.9, 2.25, 105.05, 202.15 and 64.8ppm, respectively.

Cu is an essential element for various metabolic processes. Because it is required only in trace amounts, Cu becomes toxic at high concentrations. In non-tolerant plants, inhibition of root elongation and damage of root cell membranes are the immediate responses to high Cu levels [Sonmez *et al.*, 2006]. This literature could be a pointer to the contribution to the erosion properties of the EPAs 3, 4 and 5. This is because plant roots help to hold soil particles from dispersing, but the high copper content causes stunted growth to these roots, thereby inhibiting the root system of plants from effectively holding these soil particles together. Other factors may be responsible for the EPAs 1 and 2.

NEPA 2, though it contains a relatively high copper, yet other factors like high clay content still kept the soil particles aggregated. NEPA 1 has relatively low copper content, so plant roots are not affected by the copper adversely.

The quantity of **iron (Fe)** in ppm found in Awka and Umunya were 979.9 and 1093.35ppm respectively while those found in Nanka, Oko, Oba, Nnewi and Oraukwu were as follows: 824.7, 978.75, 1007.25, 1074.2, 1070.5ppm, respectively.

Fe is the second most abundant metallic element in the earth's crust and accounts for 5.6% of the lithosphere [Kumar *et al.*, 2015]. That forms the reason why Fe was very abundant in all these areas as a result of the general abundance of Fe in the earth crust. As a result even the EPAs, which should have a generally low percentage of Fe in them due to leaching of mineral constituents due to erosion, still have high concentrations of Fe. This shows that Fe salts can be used as stabilizing chemical.

Nevertheless, NEPA 2 (which is a non-erosive soil) still contains the highest concentration (1093.35ppm) of Fe. This is possibly due to the high CBR (California Bearing Ratio: value is used as an index of soil strength and bearing capacity. This value is broadly used and applied in design of the base and the sub-base material for pavement[https://sundoc.bibliothek.uni-halle.de/diss-online/06/06H107/t5.pdf,Date Assessed, 3/4/2018]contributed by the iron element.

This is supported by a research conducted by Kumar *et al.* (2015) on Soil Stabilization using Iron Powder. From their research it was observed (among other observations) that increase in the percentage of iron powder in soil is resulting in higher CBR values. Another possible reason for the relatively high Fe content in the NEPA 2 could be due to the binding capacity of the mineral constituents by the high clay content in the soil.

Another reason for the highest percentage of Fe in NEPA could be as a result of the averagely low pH in both water and chloride in the NEPA 2 soil. This is backed by a literature on Iron Basics, which states that "Iron toxicity is primarily pH related and occurs where the soil pH has dropped sufficiently to create an excess of available Iron" [https://www.spectrumanalytic.com/support/library/ff/Fe_Basics.htm, Date Assessed, 3/4/2018].

Also **Fe** toxicity can occur when Zinc is deficient [https://www.spectrumanalytic.com/support/library/ff/Fe_Basics.htm, Date Assessed, 3/4/2018]. From the results obtained, zinc component is relatively small in all the NEPA and EPA sites, thereby increasing the possible toxicity level of Fe in different soil samples.

From the overall findings, it will not be advisable to use salts of Fe for the stabilization of the erosive soils due to the toxicity impact of Fe contributed by low quantity of Zinc ion in those sites.

Zinc (Zn) concentration in NEPAs of Awka and Umunya are 78.2ppm and 258.5ppm, respectively, while those in EPAs of Nnaka, Oko, Oba, Nnewi and Oraukwu are35.75, 80.35, 203.35, 420.35 and 485.3ppm respectively; **lead (Pb)** concentrations for Awka and Umunya are5.5 and 136.15ppm respectively while for Nanka, Oko, Oba, Nnewi and Oraukwu are 12.8, 9.25, 176.35, 41 and 30.75ppm respectively; **cadmium (Cd)** concentration for Awka and Umunya are 3.85 and 26.35, respectively, while for Nanka, Oko, Oba, Nnewi and Oraukwu are: 3.05, 1.950, 32.75, 22.65 and 7.7ppm, respectively.

Zn, Pb, and Cd metals in NEPA 2, EPAs 3, 4 and 5 are higher than in those in the NEPA 1, EPA 1 and EPA 2. This is because heavy metals are higher in soil samples during the dry season than during the rainy (wet) season. This is supported by the research carried out by Osobamiro and Adewuyi (2015) on the Levels of Heavy Metals in the Soil: Effects of Season, Agronomic Practice and Soil Geology; in which they found out that the total levels of heavy metals (in mg/kg) found in the sampled soils were as follows: in the rainy season Mn (28.4 - 34.2), Fe (1599.7 - 2013.2), Pb (11.0 - 16.9), Zn (100.5 - 112.9) and Ni (11.3 - 13.8) and in the dry season Mn (32.1 - 40.1), Fe (1701.4 - 2455.5), Pb (13.0 - 18.7), Zn (105.7 - 110.4) and Ni (15.5 - 16.3). Also, Nwadinigwe *et al* (2014) in their research on Dry and Wet Seasons' Dynamics in Concentrations of Ni, V, Cd, Pb, Mn, Fe, Co And Zn In Soil Samples Within Farm Lands In Ibeno Coastal Area, Akwa Ibom State, Niger Delta, Nigeria, also stated that the amounts of the heavy metals in soil samples were higher in dry season than wet season.

The presence of these heavy metals negatively affect soil aggregation in that they cause stunted growth of plant roots (which generally aid in holding the soil particles from dispersion). As seen in the following literature which states that Excess Fe can result in Dark green foliage, stunted growth of tops and roots, dark brown to purple leaves on some plants (e.g. bronzing disease of rice) [https://www.spectrumanalytic.com/support/library/ff/Fe_Basics.htm, Date Assessed, 3/4/2018]

The values of **nickel (Ni)** in ppm for NEPAs 1 and 2 of Awka and Umunya were 87.15 and 37.8ppm respectively while those in Nanka, Oko, Oba, Nnewi and Oraukwu erosion prone soils were 56.65, 95.5, 15.7, 72.7 and 42.25ppm respectively.

Ni has relatively the same abundance in both the EPAs and NEPAs, as seen in Table 4.1. According to Iyaka (2011), Nickel's natural source to the environment include forest fires and vegetation, volcanic emissions and wind - blown dust, while, the anthropogenic activities result in atmospheric accumulation of nickel from combustion of coal, diesel oil and fuel oil, the incineration of waste and sludge as well as, from miscellaneous sources. Application of some phosphate fertilizers are also important sources of nickel into environment as pollutants.

All these are the possible contributors to why Ni was present, irrespective of whether the sites were erosion prone or non-erosion prone. As well, Ni does not directly contribute to either soil particles dispersion and/or coagulation.

The quantity of**manganese (Mn)** in ppm in EPAs of Awka and Umunya are 39.6 and 58.6ppm, respectively while those of the EPAs of Nnaka, Oko, Oba, Nnewi and Oraukwu are 8.25, 224.5, 86.4, 308.35 and 708.45ppm, respectively. As seen in the Zn component, **Mn** are relatively found more, comparatively, in the soils collected during the dry season than those in the rainy season, with the exception of EPA 2; which could be as a result of land topography, soil structure or climatic factors.

Calcium (Ca) has concentration of 42.95 and 378.9ppm in Awka and Umunya respectively, while it has 66.65, 51.1, 643.35, 462.8 and 412.9ppm in Nanka, Oko, Oba, Nnewi and Oraukwu, respectively.

Ca salts are important as soil binders as seen in Norambuena *et al.*(2014) which states that the application of calcium as an inorganic aggregate has important effects on soil aggregation. The flocculating power of Ca^{2+} generates bridges between the clays and the particles of organic matter.

EPAs 1 and 2 have low Ca content, which is the possible reason for why the soil particles are loose. For EPAs 3, 4 and 5; even though they have relatively high Ca contents, yet the soil particles are erosive. This is due to the presence Na (especially in EPAs 5 and 6, with Na contents as high as 1543.21 and 1628.61ppm respectively) which combines with K ions in the soil. These two ions aid in soil particles dispersion.

From literature, dispersion is defined as a process in which the individual particles are kept separate from one another. This is accomplished by potassium and sodium [http://civil.emu.edu.tr/courses/civl553/Lec12%20Flocculation%20[Compatibility %20Mode].pdf, Date Assessed, 16/11/17].

Magnesium (Mg) has the following values in ppm from Awka and Umunya: 753.45 and 904.5ppm; while the values for Nanka, Oko, Oba, Nnewi and Umunya are as follows: 623.25, 710.3, 790.05, 799.25 and 877.4ppm

NEPA 2 has **Mg** content of 904.5 (the highest among the other soil samples). So outside the high clay content present in the soil (which is the major reason for soil stabilization/aggregation), high Mg content could be another factor that can be said to contribute to the high aggregation of the NEPA soil samples. The above observation is supported by Taha *et al.*(2015) who carried out a study on Treatment of Soft Soil with Nano Magnesium Oxide. The results of the study indicated that the plasticity index exhibits significant reduction compared with untreated soil [https://www.researchgate.net/publication/277132155_Treatment_of_Soft_Soil_with_Nano_Magnesium_Oxide, Date Assessed, 13/11/17]. In the EPAs 1-5, irrespective of the relatively high content of Mg, yet they are erosion-prone. This is also as a result of the possible soil dispersive nature of the sodium and potassium contents in these areas, and also as a result of the low clay particle that are present in them.

The concentration of **sodium (Na)** in ppm in Awka and Umunya NEPAs are 460.3 and 276.8ppm respectively; while those in Nanka, Oko, Oba, Nnewi and Oraukwu EPAs are 294.85, 362.6, 123.7, 1543.21 and 1618.61ppm respectively.

The primary physical processes associated with high **sodium (Na)** concentrations are soil dispersion and clay platelet and aggregate swelling. The forces that bind clay particles together are disrupted when too many large sodium ions come between them. When this separation occurs, the clay particles expand, causing swelling and soil dispersion [http://waterquality.montana.edu/energy/cbm/background/soil-prop.html, Date Assessed, 17/12/17]. Thus, soil dispersion is the primary physical process associated with high sodium concentrations [Warrence *et al.*, 2002]. They are usually defined as containing an exchangeable sodium percentage greater than 15%. These soils tend to occur within arid to semiarid regions and are innately unstable, exhibiting poor physical and chemical properties, which impede water infiltration, water availability and ultimately plant growth [https://en.wikipedia.org/wiki/Sodic_soil, Date Assessed, 27/06/17].

This literature agreed with the results found in Table 4.1 because the EPAs 4 and 5 have increased Na content of 22.9% and 23.04% respectively; which are higher than 15% (the maximum amount of sodium that leads to soil dispersion according to Warrence *et al.* (2002). EPA 1 has sodium content of 14.13%, while EPAs 2 and

3 have 8.95% and 3.11% respectively. This is possible due to the land topography and soil structure of these areas.

For NEPAs 1 and 2, which have 8.76% and 6.76% sodium contents, respectively, it is obvious that the possible reason for the low sodium contents was what led to the relatively high soil stability in these areas.

The values of **potassium (K)** in ppm found in the NEPAs of Awka and Umunya are 261.05 and 589, while those found in the EPAs are as follows: 155.1, 205.4, 633.5, 561.55 and 411.15.

EPAs 3, 4 and 5 have relatively high **K** content, which act as soil dispersants. This is the possible reason for the dispersion of the soil particles in these area. EPA 1 and 2 have low K content, but due to other factors like low quantity of clay particles which aid in flocculation of soil particles, these are still erosive; unlike the NEPA 1 and 2, whose soil particles are not erosive due to relatively high clay content in the areas.

Aluminium (Al) concentration in ppm in NEPAs of Awka and Umunya are 2532.55 and 183.45ppm, respectively; while for the EPAs of Nanka, Oko, Oba, Nnewi and Oraukwu are 0, 1324.25, 0, 1041.05 and 1237.4ppm respectively.

From the Table 4.1, **Al** is highest in NEPA 1. This is possibly due to the presence of high clay content in the site which helps to bind the aluminum elements in the soil. This high aluminum content helps to stabilize the percentage organic matter (10.94%) as seen in the Fig. 4.6. This is supported by Scheel *et al.*(2008), which carried out an analysis on the Stabilization of dissolved organic matter by aluminum: a toxic effect or stabilization through precipitation? They found out that Organic matter degradation decreased significantly with Al addition. This organic matter also helps in stabilizing the NEPA 1.

EPA 1 and 2 have zero (0) **Al** content. This is possibly due to the loose nature of their soil particles, and as a result was leached by percolating rain.

Aluminium salts are the most widely used coagulants in Iran as well as many other countries in the drinking water industry [Zand and Hoveidi, 2015]. Due to the coagulating nature of Aluminum, it can be deduced, thus, that Al can be a good binding substance for soil particles.

Table 4.2: Composite Anions ratio in the EPAs and NEPAs in mg/kg

ANIONS	***NEPA 1 (Awka)***	***NEPA 2 (Umunya)***	***EPA 1 (Nanka)***	***EPA 2 (Oko)***	***EPA 3 (Oba)***	***EPA 4 (Nnewi)***	***EPA 5 (Oraukwu)***
Chloride (Cl^-)	10500	22200	10000	8000	21400	16000	14300
Phosphate (PO_4^{3-})	174	2377.58	174	174	1343.85	1175.19	1066.37
Nitrite (NO_2^-)	50.4	19.6	84	70	33.6	16.8	22.4
Bicarbonate (HCO_3^-)	500	3500	250	250	1750	2000	3000

The Table 4.2 was analysed statistically to find out the mean difference in the NEPAs and EPAs respectively. This was done in order to know whether, among the NEPA 1and 2, any of them can be used as a control for analysis. Also the values of the EPAs were analysed to find out among the EPAs 1-5 whether any of EPAs deviated from one another, significantly.

The statistical tool employed was Kruskal-Wallis Test. The result of the test was as follows:

Table 4.2a: Kruskal-Wallis Hypothesis Test for NEPA 1 and NEPA 2

S/N	**Null Hypothesis**	**Test**	**Sig.**	**Decision**
1	The distribution of OBSERVATION 1 is the same across categories of NONE EROSION AREA	Independent-Samples Kruskal Wallis Test	.564	Retain the null hypothesis

Note: The significance level is 0.05 and below

The result in Table 4.2a showed that there was no significant difference between mean values of cations in NEPA 1 and NEPA 2, due to a p-value of 0.564.

This means that either of the non-erosive soils can be used to compare with the EPAs.

Table 4.2b: Kruskal-Wallis Hypothesis Test for EPAs 1-5

S/N	**Null Hypothesis**	**Test**	**Sig.**	**Decision**
1	The distribution of OBSERVATION 2 is the same across categories of EROSION AREA	Independent-Samples Kruskal Wallis Test	.922	Retain the null hypothesis

Note: The significance level 0.05 and below

The result in Table 4.2b showed that there was no significant difference as well, between mean values of anions in EPAs 1-5, due to a p-value of 0.922.

This means that any of the values of the EPAs can be used interchangeably in comparison with the NEPAs.

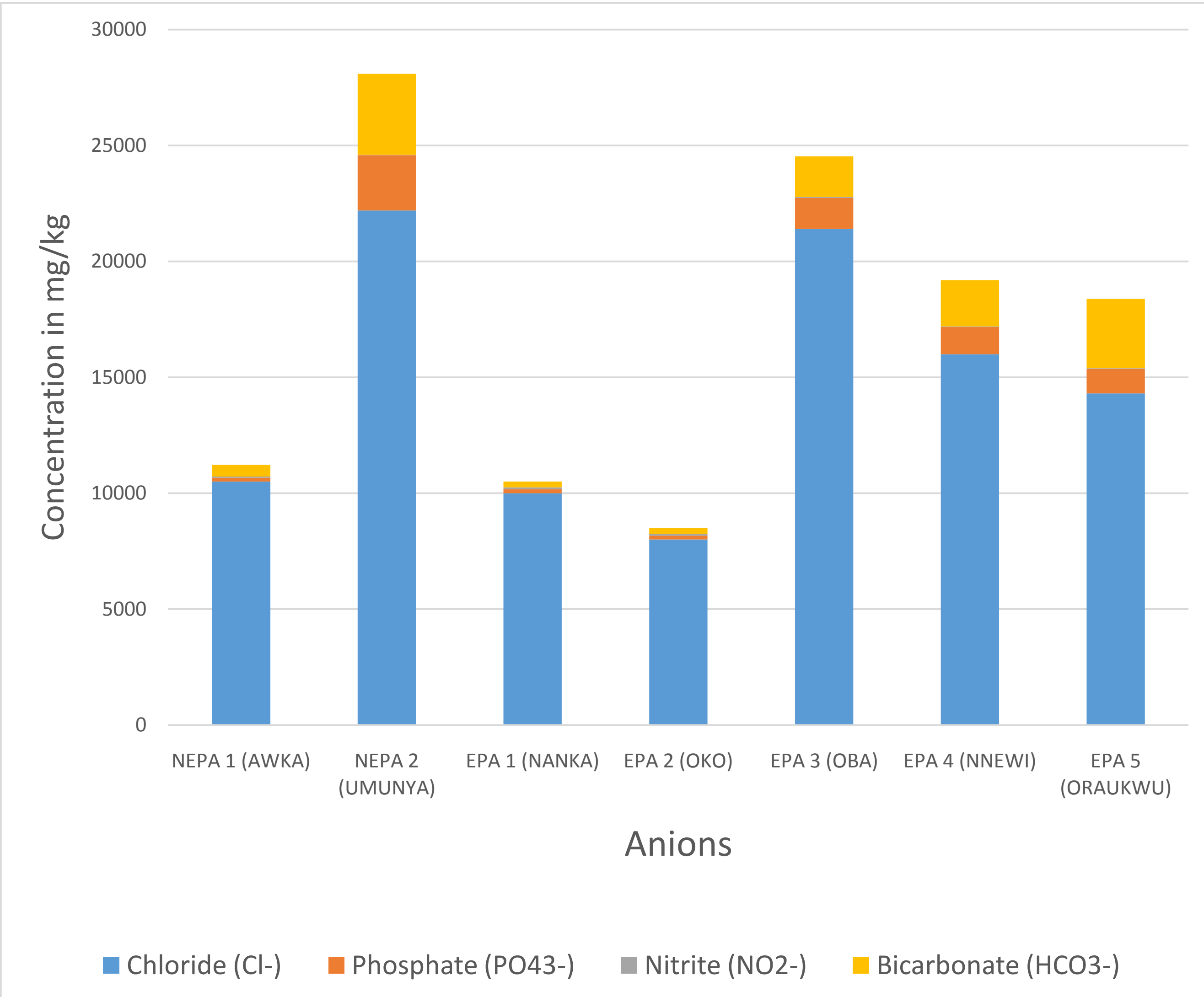

Fig. 4.2: Composite Concentration of Anions across the NEPAs and EPAs

The **Cl^-** in all the soil samples collected during the dry season increased more than the ones collected during the rainy season. This is supported by a research carried out by Al-Ahmadi (2014) on the effects of dry and wet seasons on some soil minerals and proteins in some plants; and found out that the minerals concentrations increased in the dry season because of high temperature and high evaporation that induce high level of air humidity, and lead to a decrease in protein contents as a result of salt and water stress. It is clear that NEPA 1 and 2 have more Cl^- content than EPA 1, 2 and EPA 3, 4, 5 respectively. The possible reason for this is the presence of the higher clay particle, present in the NEPA 1 and 2; and these clay particles help to bind minerals to the soil particles, thereby reducing the rate by which the soil minerals leach away from the soil.

From Table 4.2 the EPAs 3, 4, and 5 for the $\mathbf{PO_4^{3-}}$had the following values: 13.4385, 11.7519 and 10.6637mg/kg respectively. These increased values could be the possible reason why the soils are erosion prone. This agrees with Li *et al.*(2017) who conducted a research on Phosphate fertilizer enhancing soil erosion: effects and mechanisms in a variably charged soil, and then came to a conclusion that the application of phosphate decreased aggregate stability and stimulated soil erosion through increasing charge density of particle surface by a new non-classic induction adsorption of phosphate. However the increase of the $\mathbf{PO_4^{3-}}$ in the NEPA 2 (23.7758) could be due to the high clay particles and low pH value (high acidity: 3.67) in the soil sample. NEPA 1, EPAs 1 and 2 all have the phosphate values of 1.74. This relatively smaller value could be as a result of the low phosphate content (for NEPA1) and/or soil mineral constituents' run-off (for EPA 1 and 2).

Among the other anions $\mathbf{NO_2^-}$ concentration is comparatively minimal; which is in agreement with Van Cleemput and Samater (1995), who stated in their study that $\mathbf{NO_2^-}$ concentrations in soils are usually low (below 0.1mg NO_2^-–N kg^{-1}) and they rarely exceed 50mg NO_2^-–N kg^{-1} of soil. So that is the possible reason as to why quantity of the nitrite in all the soil samples were relatively low. Also no literature has mentioned whether it has a dispersive or flocculation impact on the soil particles.

HCO_3^-(bicarbonates) have the following values in the NEPAs 1 and 2, which are 500 and 3500ppm respectively, while the values for EPAs 1-5 are: 250, 250, 1750, 2000 and 3000ppm respectively.

The presence of high levels of **HCO_3^-** will precipitate with calcium when the soils dry. The result is an increase of sodium relative to the calcium. This will lead to the development of thin surface crusts where the sodium-dominated layer may be only 1/8' thick, but can impede water infiltration and increases runoff [http://www.soilsolutions.net/wp-content/uploads/2015/02/Understanding-Irrigation-Water-Analysis.pdf, Date Assessed, 18/12/17]. From the above literature, it is discovered that EPAs 3, 4 and 5 high erosivity is contributed by the presence of relatively high bicarbonates in the areas. Also bicarbonates have a physiological effect on roots reducing nutrient absorption [http://citrusagents.ifas.ufl.edu/events/GrowersInstitute2014/PDF/Understanding%20the%20Potential%20Problem%20with%20High%20Bicarbonates-%20Morgan.pdf, Date Assessed, 18/12/17].

However, for EPAs 1 and 2, though with low bicarbonates content, yet due to other factors like low clay content, soil structure etc. the areas are still erosion prone.

Table 4.3: Percentage of Sulphur in the Soil

Parameter	*NEPA 1 (Awka)*	*NEPA 2 (Umunya)*	*EPA 1 (Nanka)*	*EPA 2 (Oko)*	*EPA 3 (Oba)*	*EPA 4 (Nnewi)*	*EPA 5 (Oraukwu)*
% Sulphur	0.2905	26.03	0.1164	0.1039	10.96	11.853	19.755

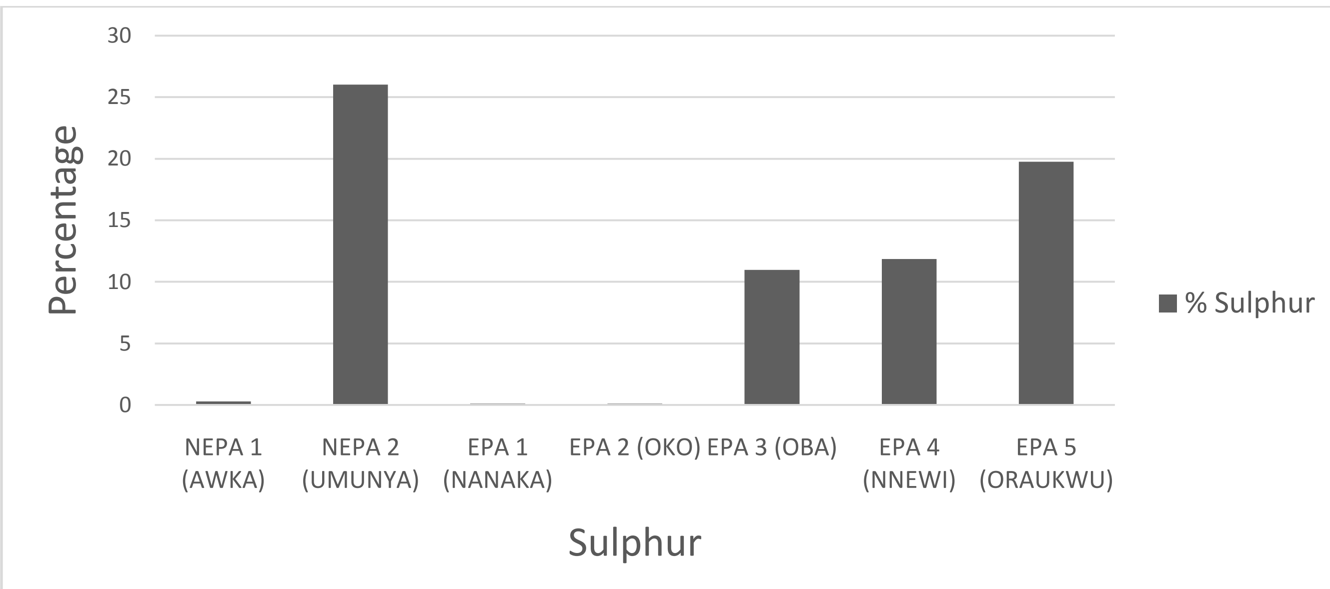

Fig 4.3: Percentage Sulphur composition in the EPAs and NEPAs

The values for the percentage of sulphur in the two NEPA soils are 0.2905 and 26.03% respectively while the values for the five EPAs of Nanka, Oko, Oba, Nnewi and Oraukwu are as follows: 0.1164, 0.1039, 10.96, 11.853 and 19.755%, respectively.

The values of sulphur from all these sites, clearly showed that Sulphur content was very small in the sites except in NEPA 2. From a research conducted by

Wainwright (1984) he cited that soils throughout the world are increasingly recognized as being S deficient, and deficiencies in the element are even appearing in soils in countries where such deficiencies were previously unknown. These deficiencies result mainly from the use of high analysis, low S-containing fertilizers, reduction in the use of elemental S as a fungicide, and increasing effectiveness in SO_2-pollution abatement programs. This could be the possible reason behind the low sulphur content in all these NEPAs and EPAs (for only one of the sites has up to 20% of sulphur).

Also from Isitekhale *et al* (2013), the results of earlier studies in Nigeria indicated that sulphur deficiency exists in some Nigeria soil. The deficiency of sulphur in the savanna soils of West Africa has been attributed to annual burning of grassland vegetation, low organic matter contact and the relatively insignificant accretion from precipitation.

Parameters	***NEPA 1 (Awka)***	***NEPA 2 (Umunya)***	***EPA 1 (Nanka)***	***EPA 2 (Oko)***	***EPA 3 (Oba)***	***EPA 4 (Nnewi)***	***EPA 5 (Oraukwu)***
% Sand	18.77	36.8	79.93	55.09	58.7	67.6	56.8
% Silt	42.73	12.4	12.327	18.397	34.7	25.3	29.7
% Clay	38.5	50.8	7.743	26.513	6.6	7.1	13.5

Table 4.4: Percentage of Clay, Silt and Sand in EPA and NEPA

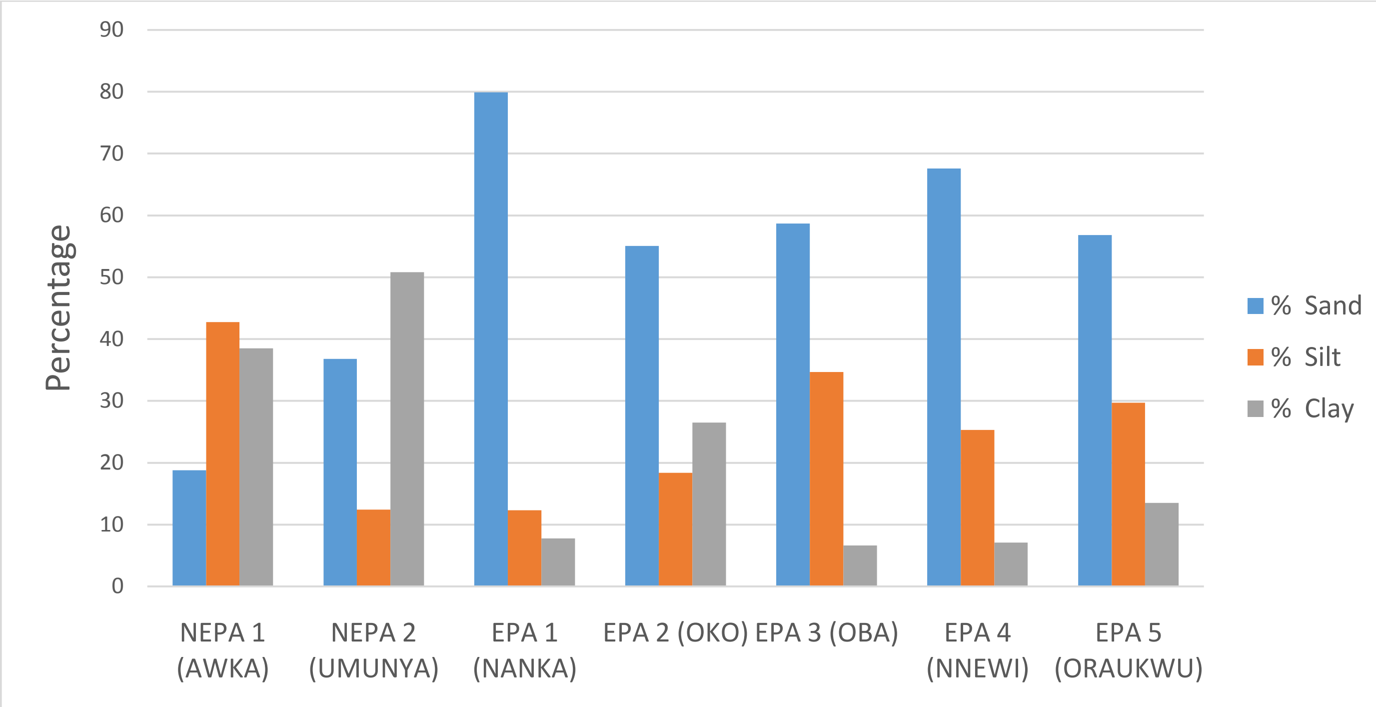

Fig 4.4: Percentage Clay, Silt and Sand compositions in the EPAs and NEPAs

According to Table 4.4, Fig. 4.4, it is clear that EPAs of Nanka, Oko, Oba, Nnewi and Oraukwu are indeed erosion prone. This is as a result of the high percentage of sand particles (which are very erosive), and relatively low percentage of clay particles (as low as 7.743, 6.6, 7.1 and 13.5 for EPA 1, 3, 4 and 5, respectively. This is supported by Manyiwa and Dikinya (2013) which stated that “moreover, soils with larger sand and silt proportions are more vulnerable to water erosion due to lack of stability of soil particles”.

The results are opposite for NEPAs. In these areas Sand particles are low, 18.77 and 36.8% for NEPA 1 and 2 respectively, while the level of their percentage clay are 38.5 and 50.8% for NEPA 1 and 2, respectively. These clay particles help to bind the soil particles together, and as a result inhibit/ reduce erosion process.

Table 4.5: pH in Water and Chloride

parameters	***NEPA 1 (Awka)***	***NEPA 2 (Umunya)***	***EPA 1 (Nanka)***	***EPA 2 (Oko)***	***EPA 3 (Oba)***	***EPA 4 (Nnewi)***	***EPA 5 (Oraukwu)***
pH in H_2O	5.15	4.49	5.40	5.41	4.48	5.43	6.07
pH in Cl^-	4.82	3.67	4.80	4.83	4.64	5.21	5.84

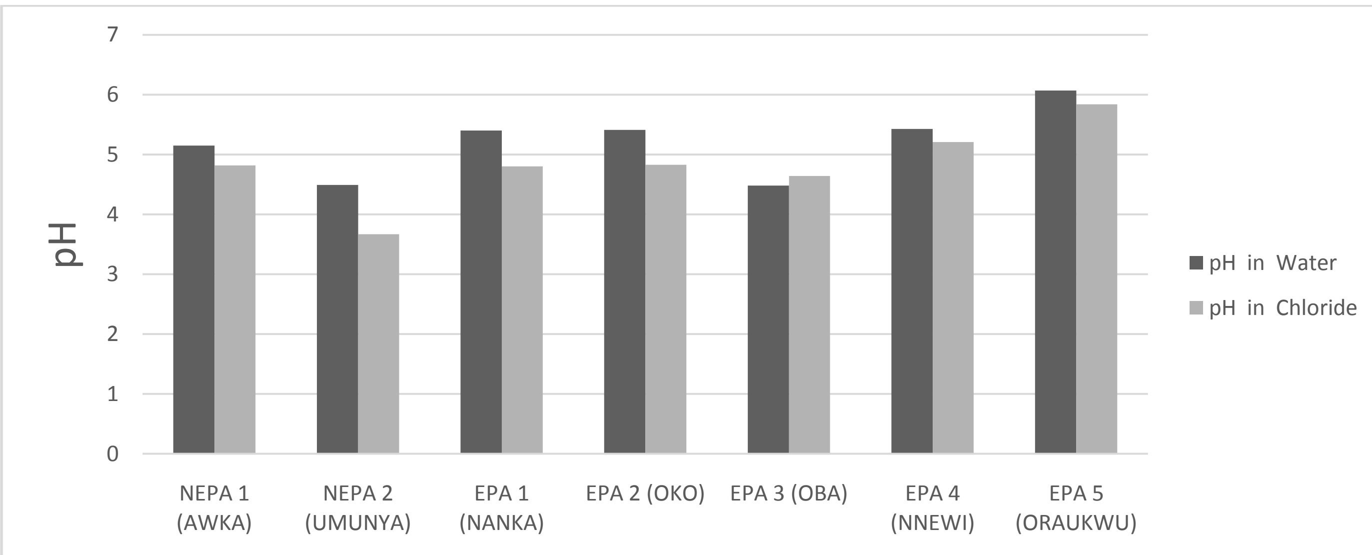

Fig 4.5: pH in Water and Chloride in the EPAs and NEPAs

Soil pH is a measure of the acidity or basicity of a soil. pH is defined as the negative logarithm (base 10) of the activity of hydronium ions (H^+ or, more precisely, $H_3O^+_{(aq)}$) in a solution. In soils, it is measured in a slurry of soil mixed with water (or a salt solution, such as 0.01 M $CaCl_2$), and normally falls between 3 and 10, with 7 being neutral. Acid soils have a pH below 7 and alkaline soils have a pH above 7. Ultra-acidic soils (pH < 3.5) and very strongly alkaline soils (pH > 9) are rare [https://en.wikipedia.org/wiki/Soil_pH, Date Assessed, 4/4/2018].

Using a dilute $CaCl_2$ solution will probably give more consistent results than using rainwater or diluted water. When the soil is diluted with water, most of the H^+ ions tend to remain attracted to the soil particles and are not released into the soil solution. The addition of small amounts of calcium chloride provides Ca^{2+} ions to replace some of the H^+ ions on the soil particles, forcing the hydrogen ions into the solution and making their concentration in the bulk solution closer to that found in the field. The pH measured in $CaCl_2$ is almost always lower than pH of the same soil measured in water due to the higher concentration of H^+ [http://www.bacto.com.au/measurement-of-ph-in-soil/, Date Assessed 26/06/17].

The explanation from the literature is clearly portrayed in the results above; the pH being more acidic in the Chloride than in water. This applies to soils in the NEPAs and soils in the EPAs.

Also according to the same literature, "Measurement of pH in soil is very common as it affects the relative availability of soil nutrients. If the pH is not within an acceptable range, growth will be curtailed and erosion potential is increased" [http://www.bacto.com.au/measurement-of-ph-in-soil/, Date Assessed, 26/06/17].

Form the results above, the pH of all the soil samples in water and calcium chloride were found to be acidic. And an acidic soil will hinder affects plant growth and nutrient availability.

Plant growth and most soil processes, including nutrient availability and microbial activity, are favoured by a soil pH range of 5.5 – 8.0. Acidic soil, particularly in the subsurface, will also restrict root access to water and nutrients [http://soilquality.org.au/factsheets/soil-acidity, Date Assessed, 4/4/18]. It specifically affects plant nutrient availability by controlling the chemical forms of the different nutrients and influencing the chemical reactions they undergo [https://en.wikipedia.org/wiki/Soil_pH, Date Assessed, 4/4/2018]. Therefore EPAs 1, 2, 4 and 5 will favour plant growth and other soil processes, while EPA 3 will not, due to pH value.

Parameters	*NEPA 1 (Awka)*	*NEPA 2 (Umunya)*	*EPA 1 (Nanka)*	*EPA 2 (Oko)*	*EPA 3 (Oba)*	*EPA 4 (Nnewi)*	*EPA 5 (Oraukwu)*
Total Organic Carbon (TOC) %	0.1091	0.1412	0.01092	0.0545	0.0513	0.0181	0.0354
Organic Matter (OM) %	10.94	1.90	10.44	39.97	1.45	1.05	1.95

Table 4.6: Percentage of Organic Carbon/Matter in EPAs and NEPAs

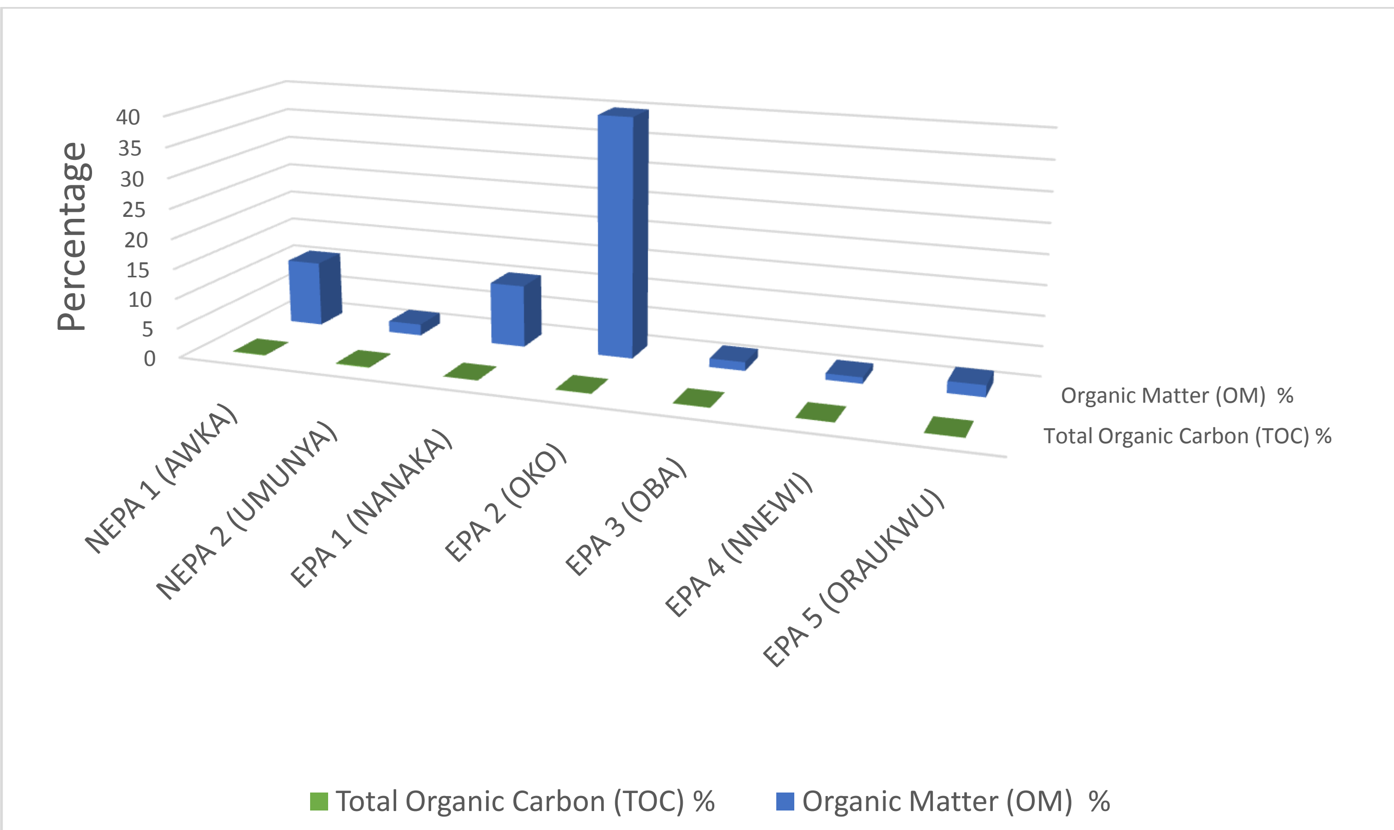

Fig 4.6: Percentage of TOC and OM composition in the EPAs and NEPAs

Organic Matter or Soil Organic Matter (SOM) includes all carbonaceous and silicified materials, earthworms, insects, fecal materials, plant debris larger than 2 mm, root bits and pieces, leaf matter that has been partially chewed by small insects or ants, fungal hyphae, glomalin (a complex polysaccharide given off fungal hyphae) and sticky secretions from roots, bacteria (i.e. actinomycetes) or earthworms [Petersen, 2015]. So from Table 4.6, Organic matter is very important in the functioning of soil systems for many reasons. Soil organic matter increases soil porosity, thereby increasing infiltration and water-holding capacity of the soil, providing more water availability for plants and less potentially erosive runoff and agro-chemical contamination [Jankauskas *et al*, 2007]. Therefore NEPA 2, which is a non-erosive prone area, has high organic matter compared to EPAs 3 and 4 (which were all collected during the same dry season (DS)). The same applies to NEPA 1 in comparison with EPA 1 (which were collected during the wet season (WS)). In support of the above explanation, Pimentel and Burgess (2013), stated that several studies have demonstrated that the soil removed by either water or wind erosion is 1.3 to 5 times richer in organic matter than the soil left behind.

According to particle size distribution, the EPA 5 contains more clay materials nearly twice the EPAs 3 and 4 (which were collected under the same climatic conditions). Also EPA 2 contains more than thrice the clay particles found in EPA 1 (also collected under the same climate factors). From Mtambanengwe *et al*(http://ciat-library.ciat.cgiar.org/articulos_ciat/AfNetCh19.pdf, Date Assessed, 24/06/17), “Clay particles are believed to protect some of the more easily decomposable organic compounds from rapid microbial breakdown through encrustation and entrapment”. Therefore this relatively high clay particles in EPA 2 and 5 will most likely hold the organic matter from being washed away by water or wind erosion.

Soil Organic Carbon (SOC), on the other hand, is a component of SOM. SOC is made up of four biological types or fractions in the soil: (a) Crop residues in the soil that are less than 2 mm in size, such as fine roots, bits and pieces of leaf, cob, shucks and stems, (b) Particulate sized plant debris between 0.053 mm and 2 mm that is partially decomposed, cellulosic and lignin fibers are less perceivable, (c) Humus fraction dominated by decomposed molecules glued to the soil minerals, generally smaller, and (d) Recalcitrant organic carbon that is stable—and silicified lignin or charcoal. There is also carbon in carbonates/silicates in soils of the western states [Petersen, 2015].

From the results obtained, the NEPAs 1and 2 contain a higher Total organic carbon than the five EPAs; 1, 2, 3, 4 and 5. This is because the organic carbon have been washed away by the agents of soil erosion in the latter than in the former. The above explanation can be drawn from Li *et al* (2016), who stated that SOC (soil organic carbon) loss is influenced by numerous factors, such as rainfall intensity, slope gradient, tillage, and soil type.

Parameters	***NEPA 1 (Awka)***	***NEPA 2 (Umunya)***	***EPA 1 (Nanka)***	***EPA 2 (Oko)***	***EPA 3 (Oba)***	***EPA 4 (Nnewi)***	***EPA 5 (Oraukwu)***
Porosity	0.3263	0.0965	0.3377	0.4358	0.1566	0.0540	0.0800

Table 4.7: Porosity in the EPA and NEPA in g/ml

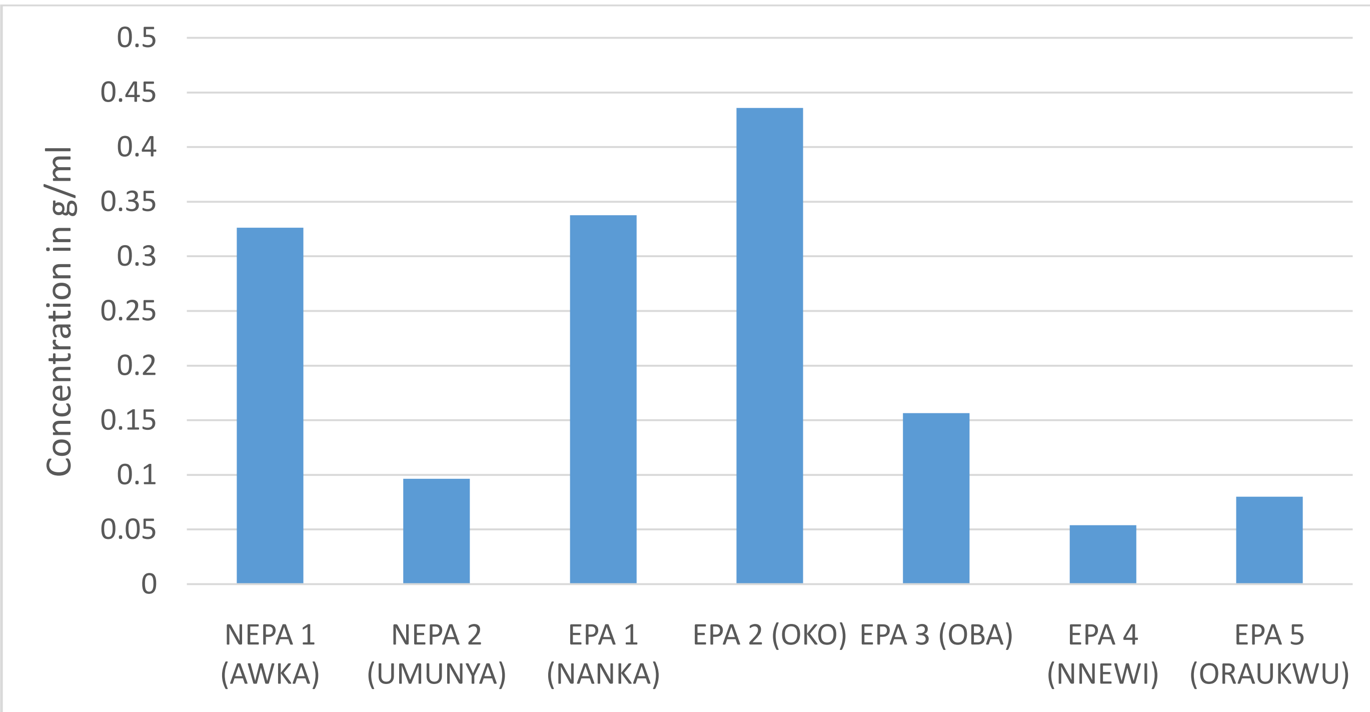

Fig 4.7: Porosity in the EPAs and NEPAs

Soil porosity is widely recognized as one of the best indicators of soil structure quality. Quantification of the pore space in terms of shape, size, continuity, orientation and arrangement of pores in soil allows us to define the complexity of soil structure and to understand its modifications induced by human activity. Characterization of the pore system provides a realistic basis for understanding the retention and movement of water, gas exchange in soil and the relationship between soil structure and biological and chemical properties (e.g., biological activity and turn-over of organic matter) [Pagliai and Vignozzi, 2006].

Musílek *et al* (2016), in their study stated that sandy soils represent a class of non-cohesive soils along the gravel. So the porosities of EPAs 1 and 2 are higher than the NEPA1 (under the same climatic condition). The same also applies to EPA 3 in relation to NEPA 2. The reason for this is due to the high porosity index in these erosion prone areas, caused by high sandy soil particles, which are mostly predominant in erosion prone areas.

For EPAs 4 and 5, their porosities, even though with higher sandy particles are still lower than the NEPA 2, which were all collected under the same climatic condition. This could be as a result of some other factors; because according to Nimmo (2004) "the porosity of a soil depends on several factors, including (1) packing density, (2) the breadth of the particle size distribution (polydisperse vs. monodisperse), (3) the shape of particles, and (4) cementing".

Parameter	NEPA 1 (Awka)	NEPA 2 (Umunya)	EPA 1 (Nanka)	EPA 2 (Oko)	EPA 3 (Oba)	EPA 4 (Nnewi)	EPA 5 (Oraukwu)
MOISTURE CONTENT (%)	11.42	0.90	3.18	46.73	0.35	0.25	0.45

Table 4.8: Percentage of Moisture Content

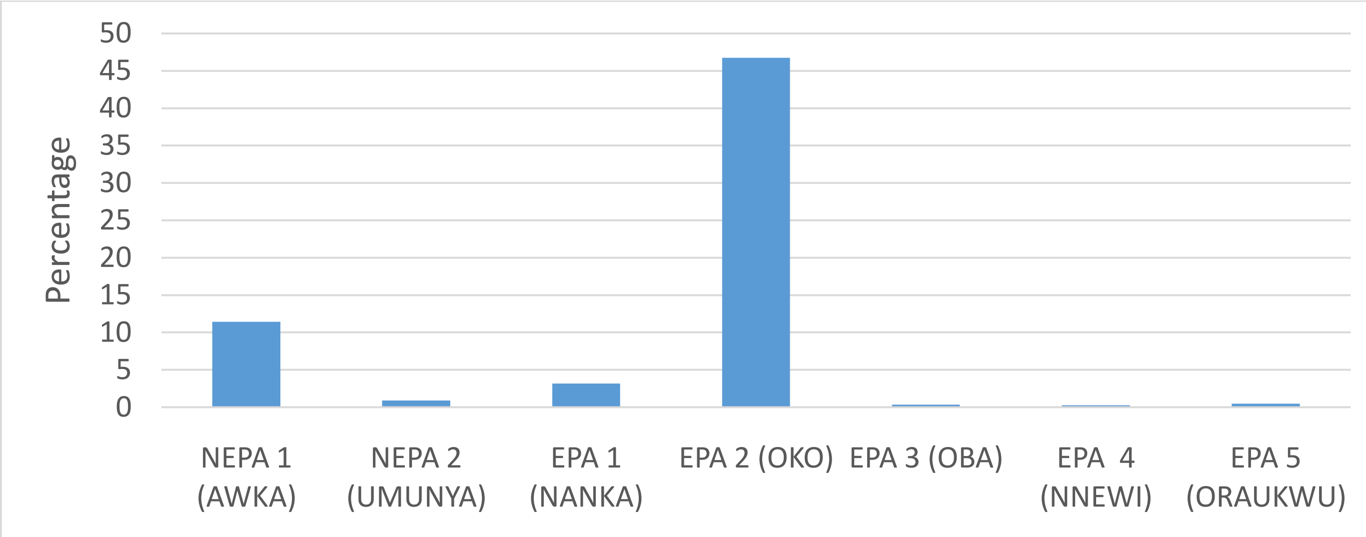

Fig 4.8: Percentage Moisture Content in the EPAs and NEPAs

The moisture content in the NEPA 2 is higher than those in the EPAs 3, 4 and 5 (collected under the same climatic condition). This is due to the high clay content in the EPA; which has high water retaining capacity. The same applies to NEPA 1 over EPA 1 (which are also collected under the same climate)

Whereas in the EPAs the moisture contents are generally smaller in comparison, (due to the high sand and silt particles found in them), nevertheless EPA 2 is exceptional, for it has a very high moisture content of 46.73%. This is possibly due to an exceptionally high level of organic matter content, which is 39.97 percentage organic matter. This explanation is supported by Rawls *et al* (2003) that carried out a research on Effect of soil organic carbon on soil water retention, and came to the finding that increase in organic matter content led to increase in water retention in sandy soils, and to a decrease in fine-textured soils. So from the literature comes the possible explanation for the high moisture content in EPA 2.

4.9. Stabilization of Soil Samples

Soil stabilizers are materials that measurably improve the physical characteristics of the soil. The purpose of stabilization is to make a soil less pervious, less compressible and stronger. They are used for erosion control, prevention of surface scaling and improvement of water infiltration and drainage [Amu *et al*, 2005].

The stabilization of the five soil samples from Nanka (EPA 1), Oko (EPA 2), Oba (EPA 3), Nnewi (EPA 4) and Oraukwu (EPA 5) were carried out using the solutions of the following chemical stabilizers.

- Aluminum Chloride ($AlCl_{3(aq)}$),
- Magnesium Chloride ($MgCl_{2(aq)}$),
- Calcium Chloride ($CaCl_{2(aq)}$) and
- Calcium Hydroxide ($Ca(OH)_{2(aq)}$).
- Calcium Trioxocarbonate(IV)($CaCO_{3(aq)}$)

1. **Aluminum Chloride** ($AlCl_{3(aq)}$): Aluminium chloride is the main compound of aluminium and chlorine. It is white, but samples are often contaminated with iron (III) chloride, giving it a yellow colour. The solid has a low melting and boiling point. The compound is often cited as a Lewis acid. Aluminium chloride is hygroscopic, having a very pronounced affinity for water [https://en.wikipedia.org/wiki/Aluminium_chloride, Date Assessed, 3/4/2018].
2. **Magnesium Chloride ($MgCl_{2(aq)}$):** Magnesium chloride is the name for the chemical compound with the formula $MgCl_2$ and its various hydrates$MgCl_2(H_2O)_x$. These salts are typical ionic halides, being highly soluble in water. The hydrated magnesium chloride can be extracted

from brine or sea water. Some magnesium chloride is made from solar evaporation of seawater. Hydrated magnesium chloride is the form most readily available [https://en.wikipedia.org/wiki/Magnesium_chloride, Date Assessed, 3/4/2018].

3. **Calcium Chloride ($CaCl_{2(aq)}$):** It is a colourless crystalline solid at room temperature, highly soluble in water. Calcium chloride is commonly encountered as a hydrated solid with generic formula $CaCl_2(H_2O)_x$, where x = 0, 1, 2, 4, and 6. These compounds are mainly used for de-icing and dust control. Because the anhydrous salt is hygroscopic, it is used as a desiccant [https://en.wikipedia.org/wiki/Calcium_chloride, Date Assessed, 3/4/2018]

4. **Calcium Hydroxide ($Ca(OH)_{2(aq)}$):** It is a colourless crystal or white powder and is obtained when calcium oxide (called *lime* or *quicklime*) is mixed, or slaked with water. Calcium hydroxide is used in many applications, including food preparation. Limewater is the common name for a saturated solution of calcium hydroxide. [https://en.wikipedia.org/wiki/Calcium_hydroxide, Date Assessed, 3/4/2018].

5. **Calcium Trioxocarbonate(IV)($CaCO_{3(aq)}$):** It is a common substance found in rocks as the minerals calcite and aragonite (most notably as limestone, which contains both of those minerals) and is the main component of pearls and the shells of marine organisms, snails, and eggs. Calcium carbonate is the active ingredient in agricultural lime and is created when calcium ions in hard water react with carbonate ions to create limescale. It is medicinally used as a calcium supplement or as an antacid, but excessive consumption can be hazardous

[https://en.wikipedia.org/wiki/Calcium_carbonate, Date Assessed, 3/4/2018].

Penetrometer was used to determine the Unconfined Compressive Strength (UCS) of the five EPAs. UCS test is by far the most popular method of soil shear testing because it is one of the fastest and cheapest methods of measuring shear strength [https://www.cyut.edu.tw/~jrlai/CE7334/Unconfined.pdf, DateAssessed, 06/03/18].

The unconfined compressive strength of soil is a load per unit area at which an unconfined cylindrical specimen of soil will fail in the simple compression test [Khalid *et al*, 2015].

Table 4.9.1: Chemical Stabilization of 10g each of the five erosion prone soils in kg/cm^2

CHEMICALS	*NANKA (EPA 1)*	*OKO (EPA 2)*	*OBA (EPA 3)*	*NNEWI (EPA 4)*	*ORAUKWU (EPA 5)*
$AlCl_3$	5.00	5.00	5.00	4.00	4.60
$MgCl_2$	5.00	2.60	3.80	2.50	5.00
$CaCl_2$	5.00	3.00	5.00	5.00	4.40
$Ca(OH)_2$	1.55	1.65	1.30	1.26	0.80
$CaCO_3$	1.10	1.74	1.70	1.24	1.45

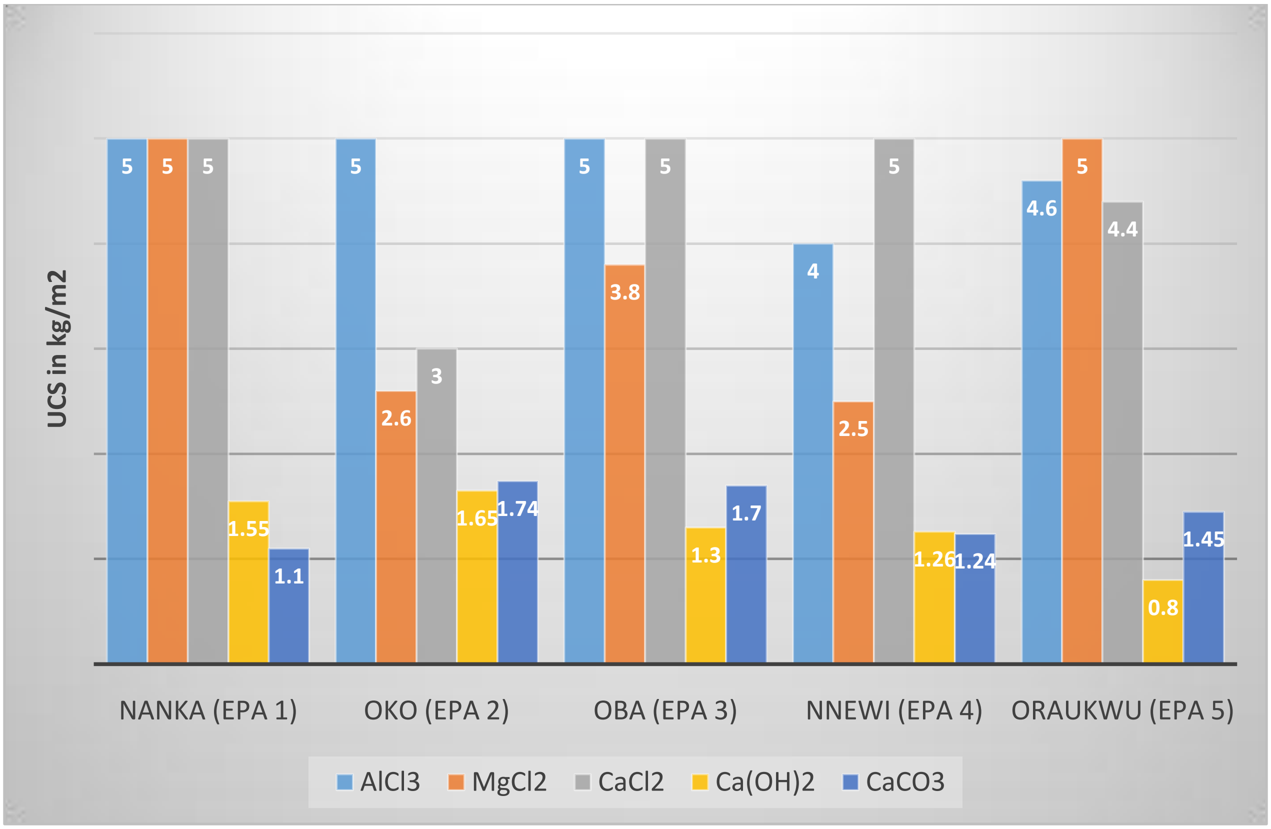

Fig. 4.9.1: Chemical Stabilization of 10g each of the five erosion prone soils

As seen from Fig 4.9.1, **$AlCl_3$** UCSvalues across the five EPAs of Nanka, Oko, Oba, Nnewi and Oraukwu are 5.00, 5.00, 5.00, 4.00 and 4.60kg/cm^2. From the values, AlCl3 best fits the soil structures of Nanka, Oko and Oba with the UCS values of 5.0kg/cm^2 respectively; followed by Oraukwu (4.60kg/cm^2) and 4.0kg/cm^2 for Nnewi. The reason for the high chemical stabilization of the Nanka, Oko and Oba soils can be traced to the relatively high porosity level of these soils, which are 0.3377, 0.4358 and 0.1566 which are higher than those in Nnewi and Oraukwu, which have values of 0.0540 and 0.0800 respectively. This relatively higher porosity of the erosion sites give room for a higher penetration and binding of the soil particles with the $AlCl_3$ salt. Secondly due to the high solubility of property of ACl_3, the soil solution penetrability into the soil matrices of the soil particles. Also, Al ions is absent in EPA 1 and 3 (Nanka and Oba respectively), so when introduced into soils did not encounter the common-ion effect which repels its ions from the soil matrix.

$MgCl_2$solution was also applied across the erosion soils. Cl^- and Mg^{2+} are both essential nutrients important for normal plant growth (www.extension.colostate.edu/docs/pubs/garden/07425.pdf, Date Assessed, 01/04/18). For $MgCl_2^-$ solution the UCS values for the EPA 1-5 are 5.0, 2.6, 3.8, 2.5 and 5.0kg/cm^2, respectively. From the values, $MgCl_2$ solution on Nanka and Oraukwu soils (which have UCS values of 5.0kg/cm^2, respectively) have optimal stabilization of their soil particles than Oba, Oko and Nnewi eroaion areas with decreasing UCS values of 3.8, 2.6 and 2.5kg/ m^2, respectively. Therefore $MgCl_2$ is best suitable for Nanka and Oraukwu erosion soils. Nonetheless, the salt solution also has agood stabilization on Oba soils, but poor for Oko and Nnewi.

$CaCl_2$ solutionwas also applied to the five EPAs 1-5 and the following values were got: 5.0, 3.0, 5.0, 5.0 and 4.40kg/cm^2. From the values it was clear that the salt is best suitable for Nanka, Oba and Nnewi soil structures; beter suitable for Oraukwu soil structure and least suitable for Oko erosion site.

$Ca(OH)_2$salt solution was also used for the stabilization of the five EPAs 1-5, and the following UCS values were obtained: 1.55, 1.65, 1.30, 1.26 and 0.80kg/cm^2 respectively. Unfortunately, from the obtained values, $Ca(OH)_2$ salt solution was unsuitable for the stabilization of all the five erosive soils. Perhaps a plausible reason for this may be due to the impenetrability of the insoluble salt solution. As a result, the salt particles could not go into the matrices of the soil structure for interaction with the soil particles. So Oko and Nanka have poor UCS values of 1.65 and 1.55kg/cm^2, while Oraukwu soil has UCS value 0.8kg/cm^2 which is very poorly suitable for the Stabilization of the site.

$CaCO_3$ solution was added to the five erosion sites Nanka, Oko, Oba, Nnewi and Oraukwu, and the results of the UCS were as follows: 1.10, 1.74, 1.70, 1.24 and 1.45kg/cm^2 respectively. Like $Ca(OH)_2$, due to the insolubility of the salt solution, when it was poured on the different erosive soils, it did not penetrate the soil matrix but hung on the soil surface, thereby not allowing for proper soil particle-salt particles interaction. Nonetheless, in terms of level of soil stabilization, Oko and Oba with UCS of 1.74 and 1.70kg/cm^2 have the highest stabilizing capacity, while Nanka with UCS 1.1kg/cm^2 has the least stabilization capacity.

Statistically, the mean variation and pairwise comparison of the stabilization capacity of the five chemicals were respectively analysed, and the following results were obtained (as seen in Table 4.9.1a and Fig. 4.9.1a below):

Table 4.9.1a: Mean variation of the different salts on 10g each of the soil samples

		OBSERVATION 10g soil samples
		Mean
SALTS	$AlCl_3$	4.72
	$MgCl_2$	3.78
	$CaCl_2$	4.48
	$Ca(OH)_2$	1.31
	$CaCO_3$	1.45

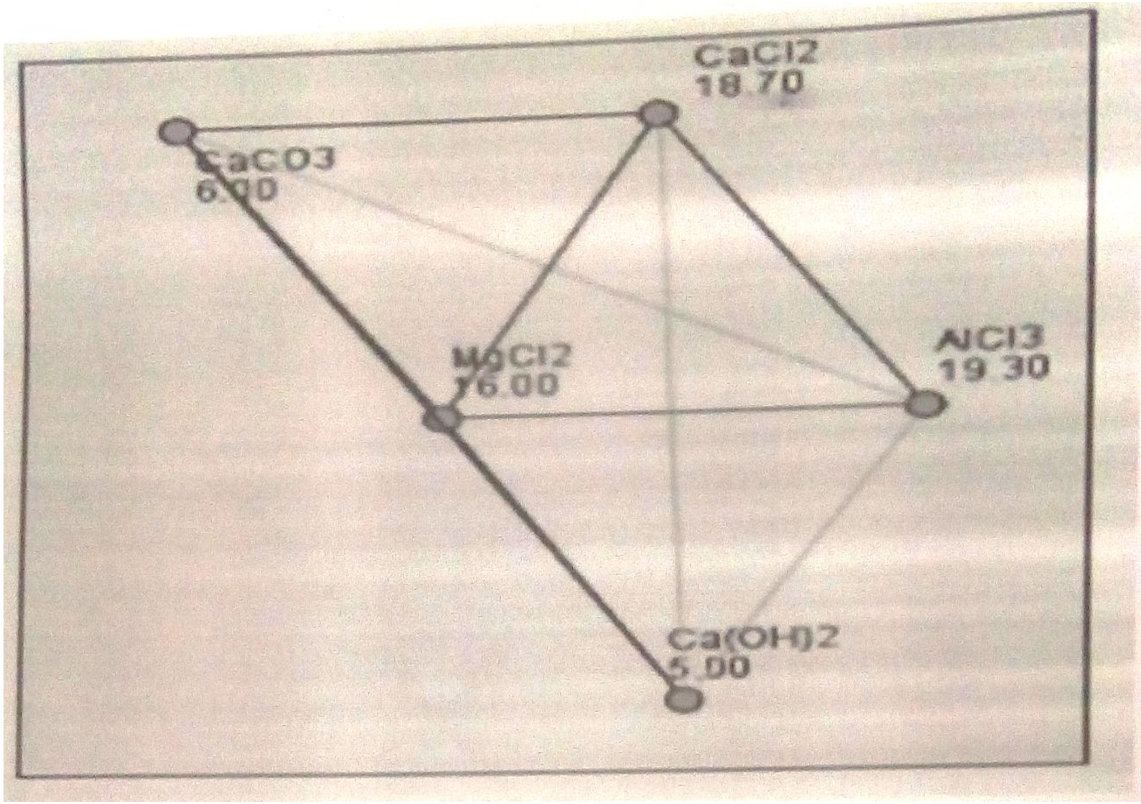

Fig. 4.9.1a: Pairwise comparisons of the salts

From the pairwise analysis, (as seen in Fig. 4.9.1a), $AlCl_3$ and $Ca(OH)_2$ have the widest pairwise comparison. This means that $AlCl_3$ stabilizing capacity is far greater in comparison with $Ca(OH)_2$, than with any other salts that are in comparison. This is followed by pairwise comparison between $CaCl_2$ and $Ca(OH)_2$, then $AlCl_3$ and $CaCO_3$. The least value for pairwise comparison of the salts is the one between $AlCl_3$ and $CaCl_2$ (which means that these salts' stabilizing capacities for 10g of the soil samples were not far apart).

Table 4.9.1b: Comparisons of the significant difference between each of the two salts

Sample1-Sample2	Test Statistic	Std. Error	Std. Test Statistic	Sig.	Adj.Sig.
Ca(OH)2-CaCO3	-1.000	4.579	-.218	.827	1.000
Ca(OH)2-MgCl2	11.000	4.579	2.402	.016	.163
Ca(OH)2-CaCl2	13.700	4.579	2.992	.003	.028
Ca(OH)2-AlCl3	14.300	4.579	3.123	.002	.018
CaCO3-MgCl2	10.000	4.579	2.184	.029	.290
CaCO3-CaCl2	12.700	4.579	2.774	.006	.055
CaCO3-AlCl3	13.300	4.579	2.905	.004	.037
MgCl2-CaCl2	-2.700	4.579	-.590	.555	1.000
MgCl2-AlCl3	3.300	4.579	.721	.471	1.000
CaCl2-AlCl3	.600	4.579	.131	.896	1.000

Note: Each row tests the null hypothesis that the Sample 1 and Sample 2 distributions are the same.

Asymptotic significances (2-sided tests) are displayed. The significance level is 0.05

From Table 4.9.1b, the following salts were found to have no significant difference $Ca(OH)_2/CaCO_3$, $Ca(OH)_2/MgCl_2$, $CaCO_3/MgCl_2$, $CaCO_3/CaCl_2$, $MgCl_2/CaCl_2$,

$MgCl_2/AlCl_3$ and $CaCl_2/AlCl_3$. This means that either of the following salts samples can be employed in place of the other in stabilizing 10g of the five erosive soil samples some of the erosive soils.

Nevertheless, for $Ca(OH)_2/CaCl_2$, $Ca(OH)_2/AlCl_3$ and $CaCO_3/AlCl_3$, there are significant differences in comparing the following salts. This means that neither of the salt can be used in the place of the other in stabilizing 10g of the five erosive soil samples.

Summary

It was deduced from the findings that for Nanka soils, salts of $AlCl_3$, $MgCl_2$ and $CaCl_2$ were more suitable for the soils, while the least suitable was $CaCO_3$.

For Oko soils: $AlCl_3$ best fits for the soil, while the salt solution of $Ca(OH)_2$ was the least suitable for the soil sample.

For Oba soils: $AlCl_3$ and $CaCl_2$ were best suitable for the soil stabilization, while $Ca(OH)_2$ was the least chemical for stabilizing the soil particles.

The chemical solution that best fitted the stabilization of the erosive soil particles of Nnewi was $CaCl_2$ while $CaCO_3$ was the least suitable.

For Oraukwu soil particles, $MgCl_2$ salt solution was the best for stabilizing it while $Ca(OH)_2$ was the least the soil particles stabilization.

Table 4.9.2: Chemical Stabilization of 15g each of the five erosion prone soils in kg/cm^2

CHEMICALS	*NANKA (EPA 1)*	*OKO (EPA 2)*	*OBA (EPA 3)*	*NNEWI (EPA 4)*	*ORAUKWU (EPA 5)*
$AlCl_3$	5.00	5.00	5.00	5.0	5.00
$MgCl_2$	2.24	5.00	5.00	3.30	5.00
$CaCl_2$	5.00	5.00	5.00	5.00	5.00
$Ca(OH)_2$	0.60	0.60	2.52	1.10	0.15
$CaCO_3$	1.14	2.26	3.65	0.90	3.74

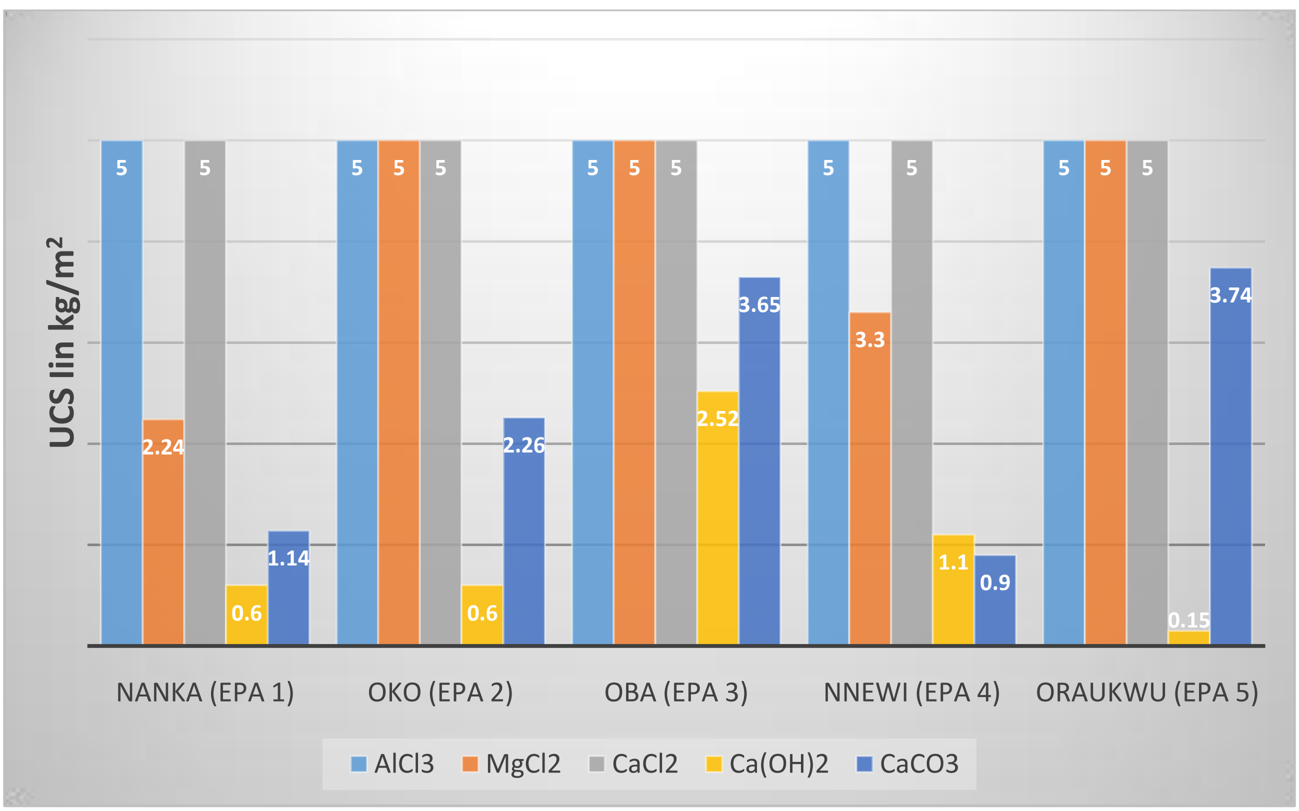

Fig. 4.9.2: Chemical Stabilization of 15g each of the five erosion prone soils

$AlCl_3$has UCS values of 5.0kg/cm^2 each for the Nanka, Oko, Oba, Nnewi and Oraukwu respectively. This means that $AlCl_3$ was suitable for the five erosion sites, therefore 15g of any of the soils sample can be adequately stabilized with 2ml of the $AlCl_3$ solution.

Like $AlCl_3$, the values of **$CaCl_2$**for each erosion sites is 5.0kg/cm^2, respectively, which shows that 2mL of $CaCl_2$ is very suitable for 15g each of the five erosion sites. Therefore any of the sites can be stabilized chemically by using 2mL of Calcium Chloride solution.

Using **$MgCl_2$**, the UCS values of the EPA 1-5 were 2.24, 5.0, 5.0, 3.0 and 5.0kg/cm^2. From the values 2mL of $MgCl_2$ best fits 15g soil samples of Oko, Oba and Oraukwu. This has clearly showed that $MgCl_2$ is a perfect stabilizing agent for these erosive sites and but has the least stabilization for the Nanka erosion site.

Two millilitres each of **$Ca(OH)_2$** solution was also applied to the five erosive soil samples, and the following results were obtained: Nanka (0.6kg/cm_2), Oko (0.6kg/cm^2), Oba (2.52kg/cm^2), Nnewi (1.1kg/cm^2) and Oraukwu (0.15kg/cm^2). From the results, $Ca(OH)_2$ salt solution was unsuitable, as a chemical stabilizer, for binding the soil particles of these five erosive soil. Nevertheless, the chemical solution shows an average (up to 50%) stabilization capacity on Oba erosion soil. This is possibly due to the high percentage of silt in the Oba erosion site, which may aid in the stabilization of the soil structure.

Using **$CaCO_3$** solution, the results obtained in the five erosion sites of Nanka, Oko, Oba, Nnewi and Oraukwu soils were 1.14, 2.26, 3.65, 0.9 and 3.74kg/cm^2 respectively. From these results, Oba and Oraukwu soils with UCS values of 3.65 and 3.74kg/cm^2 respectively gave an above-average stabilization capacity, while the least value of UCS was seen from Nnewi erosion soil. Therefore 2mL $CaCO_3$

solution is not suitable for 15g samples of the erosion soils of Nanka, Oko, and Nnewi.

Statistically, the mean variation and pairwise comparison of the stabilization capacity of the five chemicals were respectively analysed, and the following results were obtained (as seen in Table 4.9.2a and Fig. 4.9.2a below):

Table 4.9.2a: Mean variation of the different salts on 15g each of the soil samples

		OBSERVATION 15g soil sample
		Mean
SALTS	$AlCl_3$	5.00
	$MgCl_2$	4.11
	$CaCl_2$	5.00
	$Ca(OH)_2$	.99
	$CaCO_3$	2.34

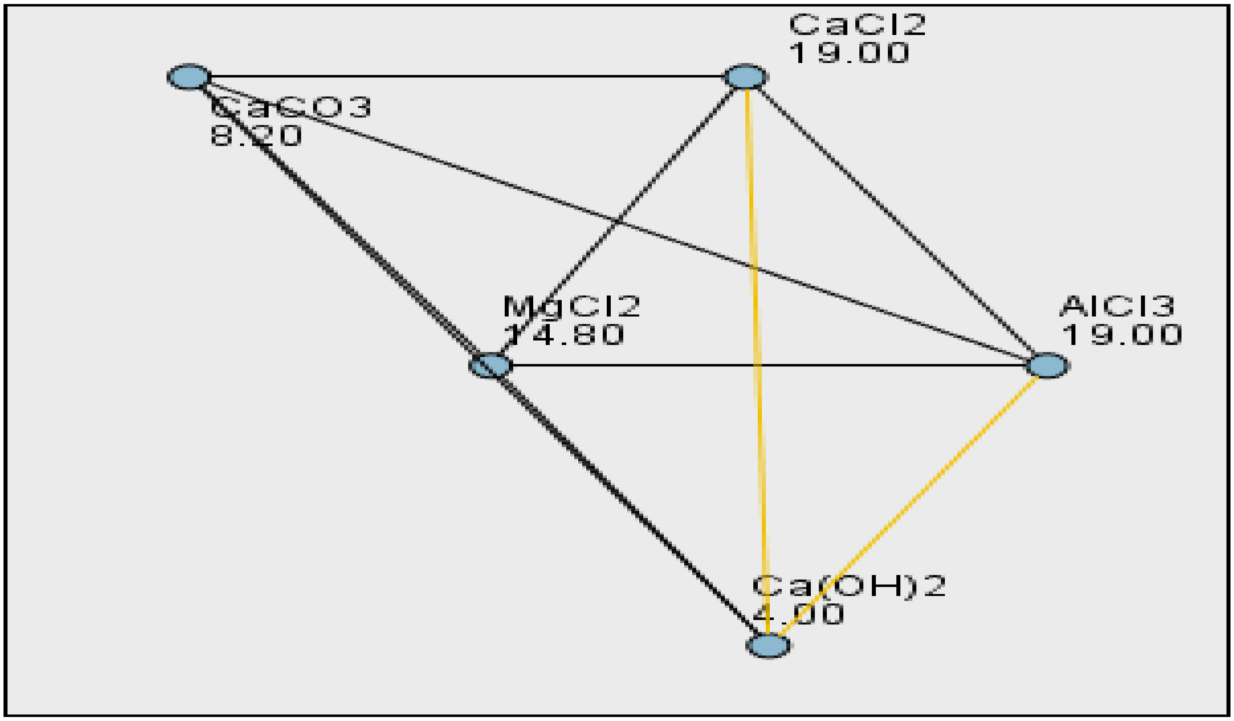

Fig. 4.9.2b: Pairwise comparisons of the salts

From the pairwise analysis in Table 4.9.2b, (as seen in Fig. 4.9.2b), $AlCl_3/CaCl_2$ and $Ca(OH)_2$ have the widest pairwise comparison. This means that $AlCl_3/CaCl_2$ stabilizing capacity are far greater in comparison with $Ca(OH)_2$, than with any other salts that are in comparison. This is followed by pairwise comparison between $AlCl_3/CaCl_2$ and $MgCl_2$; then followed $MgCl_2$ and $Ca(OH)_2$, then $MgCl_2$ and $CaCO_3$. The least value for pairwise comparison of the salts is the one between $AlCl_3$ and $CaCl_2$ (which means that these salts stabilizing capacity for 15g of the soil samples were not far apart).

Table 4.9.2b: Comparisons of the significant difference between two salts each

Sample1-Sample2	Test Statistic	Std. Error	Std. Test Statistic	Sig.	Adj.Sig.
Ca(OH)2-CaCO3	-4.200	4.316	-.973	.330	1.000
Ca(OH)2-MgCl2	10.800	4.316	2.503	.012	.123
Ca(OH)2-AlCl3	15.000	4.316	3.476	.001	.005
Ca(OH)2-CaCl2	15.000	4.316	3.476	.001	.005
CaCO3-MgCl2	6.600	4.316	1.529	.126	1.000
CaCO3-AlCl3	10.800	4.316	2.503	.012	.123
CaCO3-CaCl2	10.800	4.316	2.503	.012	.123
MgCl2-AlCl3	4.200	4.316	.973	.330	1.000
MgCl2-CaCl2	-4.200	4.316	-.973	.330	1.000
AlCl3-CaCl2	.000	4.316	.000	1.000	1.000

Note: Each row tests the null hypothesis that the Sample 1 and Sample 2 distributions are the same.

Asymptotic significances (2-sided tests) are displayed. The significance level is 0.05.

From the Table above the following salts were found to have no significant difference$Ca(OH)_2/CaCO_3$, $Ca(OH)_2/MgCl_2$, $CaCO_3/MgCl_2$, $CaCO_3/AlCl_3$,$CaCO_3/CaCl_2$, $MgCl_2/CaCl_2$, $MgCl_2/AlCl_3$ and $CaCl_2/AlCl_3$. This means that either of the following salts samples can be employed in place of the other in stabilizing 15g of the five erosive soils.

Nevertheless, for $Ca(OH)_2/CaCl_2$ and $Ca(OH)_2/AlCl_3$, there are significant differences in comparing the salt solutions. This means that neither of the salt can be used in the place of the other in stabilizing 15g of the five erosive soil samples.

Summary

It was deduced from the findings that for **Nanka soils**, salts of $AlCl_3$ and $CaCl_2$ were very suitable for the soils, while the least suitable was $Ca(OH)_2$.

For **Oko soils** $AlCl_3$, MgCl2 and CaCl2 were very suitable, while the salt solution of $Ca(OH)_2$ was the least suitable for the soil sample.

Like Oko soil, **Oba Soils** also had $AlCl_3$, $MgCl_2$ and $CaCl_2$ as best fitting soil chemical stabilizers, while $Ca(OH)_2$ was the least chemical for stabilizing the soil particles.

The chemical solution that best fitted the stabilization of the erosive soil particles of **Nnewi** were $AlCl_3$ and $CaCl_2$ while $CaCO_3$ was the least suitable.

For **Oraukwu soil** particles, $AlCl_3$, $MgCl_2$ and $CaCl_2$ salt solutions were the best for stabilizing it while $Ca(OH)_2$ was the least the soil particles stabilization.

Table 4.9.3: Composite results of the chemical stabilization of the different soil masses

CHEMICALS (2ml)	*Mass of soil particles (g)*	*NANKA (EPA 1)*	*OKO (EPA 2)*	*OBA (EPA 3)*	*NNEWI (EPA 4)*	*ORAUKWU (EPA 5)*
$AlCl_3$	10g	5.00	5.00	5.00	4.00	4.60
	15g	5.00	5.00	5.00	5.00	5.00
$MgCl_2$	10g	5.00	2.60	3.80	2.50	5.00
	15g	2.24	5.00	5.00	3.30	5.00
$CaCl_2$	10g	5.00	3.00	5.00	5.00	4.40
	15g	5.00	5.00	5.00	5.00	5.00
$Ca(OH)_2$	10g	1.55	1.65	1.30	1.26	0.80
	15g	0.60	0.60	2.52	1.10	0.15
$CaCO_3$	10g	1.10	1.74	1.70	1.24	1.45
	15g	1.14	2.26	3.65	0.90	3.74

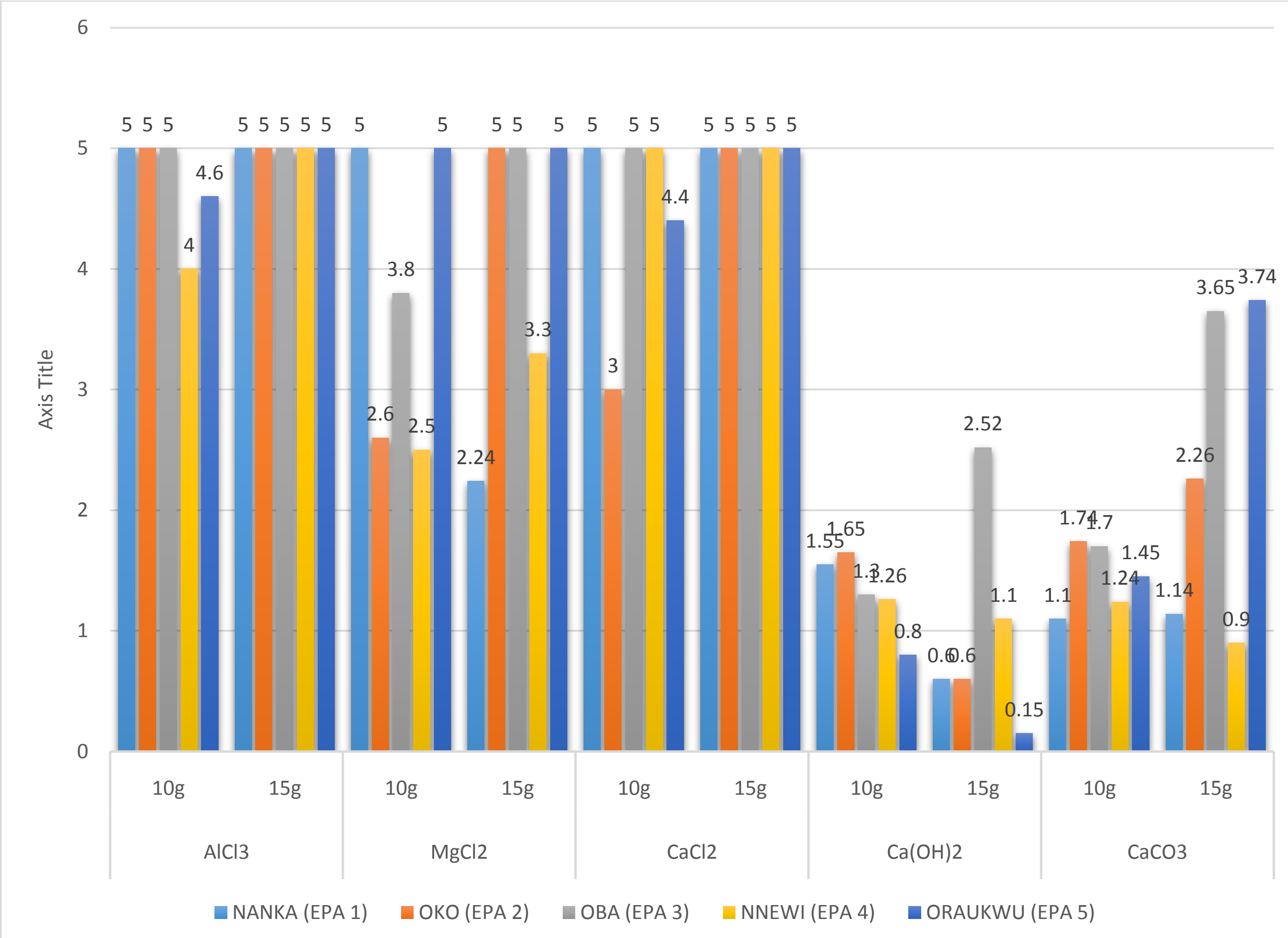

Fig. 4.9.3: Composite results of the chemical stabilization of the different soil masses

From the variation in the mass of the stabilized soil samples, the following were observed for the effect of the following chemicals:

$AlCl_3$ was suitable for 10g of Nanka, Oko and Oba soils. When the soil samples were increased to 15g it became best suitable for all the five erosion sites.

$MgCl_2$ was best suitable for 10g of Nanka and Oraukwu soils. With 15g of the soil samples, the salt was best suitable Oko, Oba and Oraukwu erosion sites.

$CaCl_2$ was best suitable for 10g of Nanka, Oba and Nnewi erosion soils; but 15g of all the five erosion soils were fully stabilized by the salt solution.

10g and 15g of the five soil samples were unsuitable for stabilization when salt solutions of $Ca(OH)_2$ and $CaCO_3$ were respectively applied.

From the overall results, the increase in the rate of stabilization of the following salts as it relates to the use of different soil-sample masses are as follows:

$AlCl_3$> $CaCl_2$> $MgCl_2$> $CaCO_3$> $Ca(OH)_2$

Table 4.9.3a: Comparative Mean variation of the different salts on 10g and 15g of the soil samples

	OBSERVATION	
	GRAMS	
	10g	15g
	Mean	Mean
$AlCl_3$	4.72	5.00
$MgCl_2$	3.78	4.11
$CaCl_2$	4.48	5.00
$Ca(OH)_2$	1.31	.99
$CaCO_3$	1.45	2.34

Table 4.9.3a is the mean of 10g and 15g of the soil samples when 2ml each of the salt solutions were applied.

Table 4.9.3b: Comparisons of the significant difference between the stabilization of 10g and 15g soil samples using $AlCl_3$

Test Statistics[a]:

	$AlCl_3$15g - $AlCl_3$10g
Z	-1.342[b]
Asymp. Sig. (2-tailed)	.180

a. Wilcoxon Signed Ranks Test

b. Based on negative ranks.

From Table 4.9.3b, there was no significant difference in the stabilization between the 10g and 15g of the soil samples when $AlCl_3$ salt was applied. This was indicated by a p-value of 0.180.

This means that either of these soil samples' masses can be stabilized by 2ml of $AlCl_3$. Nevertheless, stabilization of 15g soil samples gave a better result for stabilization, due to a higher mean value of 5.00. Also, it is economical and cost effective to stabilize 15g soil samples than the 10g soil samples.

Paired Samples Test

	Paired Differences					t	df	Sig. (2-tailed)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
Pair 1 $MgCl_2$ 10g - $MgCl_2$15g	-.32800	1.93130	.86370	-2.72603	2.07003	-.380	4	.723

Table 4.9.3c: Comparisons of the significant difference between the stabilization of 10g and 15g soil samples using $MgCl_2$

From Table 4.9.3c, there was no significant difference in the stabilization between the 10g and 15g of the soil samples when $MgCl_2$ salt was applied. This was indicated by a p-value of 0.723. This means that either of these soil samples' masses can be stabilized by 2mL of $MgCl_2$. Nevertheless, stabilization of 15g soil samples gave a better result for stabilization, due to a higher mean value of 4.11. Also, it is economical and cost effective to stabilize 15g soil samples than the 10g soil samples

Table 4.9.3d: Comparisons of the significant difference between the stabilization of 10g and 15g soil samples using $CaCl_2$

Test Statistics[a]

	$CaCl_2$ 15g - $CaCl_2$10g
Z	-1.342[b]
Asymp. Sig. (2-tailed)	.180

a. Wilcoxon Signed Ranks Test

b. Based on negative ranks.

From Table 4.9.3d, there was no significant difference in the stabilization between the 10g and 15g of the soil samples when $CaCl_2$ salt was applied. This was indicated by a p-value of 0.180.

This means that either of these soil samples' masses can be stabilized by 2ml of $CaCl_2$. Nevertheless, stabilization of 15g soil samples gave a better result for stabilization, due to a higher mean value of 5.00. Also, it is economical and cost effective to stabilize 15g soil samples than the 10g soil samples

Table 4.9.3e: Comparisons of the significant difference between the stabilization of 10g and 15g soil samples using $Ca(OH)_2$

Paired Samples Test

	Paired Differences					t	df	Sig. (2-tailed)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
Pair 1 $CaOH_2$ 10g - $CaOH_2$15g	.31800	.92681	.41448	-.83278	1.46878	.767	4	.486

From Table 4.9.3e, there was no significant difference in the stabilization between the 10g and 15g of the soil samples when $Ca(OH)_2$ salt was applied. This was indicated by a p-value of 0.486.

This means that either of these soil samples' masses can be stabilized by 2ml of $Ca(OH)_2$. Nevertheless, stabilization of 10g soil samples gave a better result for stabilization, due to a higher mean value of 1.31.

Table 4.9.3f: Comparisons of the significant difference between the stabilization of 10g and 15g soil samples using $AlCl_3$

Paired Samples Test

	Paired Differences					t	df	Sig. (2-tailed)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
Pair 1 $CaCO_3$10g - $CaCO_3$15g	-.89200	1.16789	.52230	-2.34213	.55813	-1.708	4	.163

From Table 4.9.3f., there was no significant difference in the stabilization between the 10g and 15g of the soil samples when $CaCO_3$ salt was applied. This was indicated by a p-value of 0.163.

This means that either of these soil samples' masses can be stabilized by 2ml of $CaCl_2$. Nevertheless, stabilization of 15g soil samples gave a better result for stabilization, due to a higher mean value of 2.34. Also, it is economical and cost effective to stabilize 15g soil samples than the 10g soil samples

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

This research has tried to establish why some areas in Anambra State are gully erosion prone,and while some are not. It has established the contributions of the chemical/elemental constituents (cations, anions and pH), biological components (organic matter and organic carbon) and the physical characteristics (such as moisture content, porosity, percentage clay, sand and silt) to the stability and instability of soil particles of the studied erosion and non-erosion prone areas in the State.

On the soil chemical components, it was clear from the study, that calcium, magnesium and aluminium ions in the soil help in the stability of the erosion areas, while sodium and potassium contribute to the instability of the erosion-prone areas.

In stabilizing the different soil samples, the following chemicals [($AlCl_3$, $CaCl_2$, $MgCl_2$, $CaCO_3$ and $Ca(OH)_2$]; when applied to the different soil masses of the five erosive soils gave the extent of their stabilization capacity which are as follows: $AlCl_3 > CaCl_2 > MgCl_2 > CaCO_3 > Ca(OH)_2$. This then means the menace of soil erosion in Anambra State can be curbed by the use of viable chemical solution, which when applied in the right proportions, will go a long way in dealing with the problem of soil erosion in the State.

The research has also proffered solutions on how chemical solutions can be used to stabilize the erosion prone areas; stating the chemicals with optimum stabilizing capacity.

This research has indeed been worthwhile, as this will greatly help geologists, geophysicists, environmental chemists, civil engineers etc. in bringing in, along with their expertise, the use of these chemicals in stabilizing erosion sites.

5.2. Recommendations

It is clear from this research, that solutions of these chemicals can be used to stabilize these erosion sites, if applied at the right solution/soil particle ratio.

Therefore this process of soil stabilization, using these chemicals should be speedily employed by governmental and non-governmental agencies, in order to curb the disastrous impact of soil erosion in the State.

Further analysis should be carried out using other numerous salt solutions, which are not harmful but helpful to soil particle flocculation, in both the aforementioned erosion sites and other numerous erosion sites in the State and elsewhere; at other different salt-soil particles ratios.

Also we discovered that the compositions ratios in the different soils varied seasonally: those that were collected during the dry seasons differed from those collected during the rainy season. Therefore more studies should be done on the seasonal variation of the soil compositions of these sites, in order to fully ascertain the reasons for the variations.

Also, as much as the use of synthetic chemicals for stabilizing erosion prone areas in the State is very necessary, further studies should be made to carefully study the possible impact of these chemicals on underground water contamination.

5.3 Contribution to Knowledge

1. This study proffers solution to gully erosion in Anambra State through critically looking at the soil chemical and physical characteristics. After that, it now provides chemical solutions for the stabilization of these erosive soils.

2. This study, in addition to determining the usable chemicals, further established the accurate proportions of the different stabilizing chemicals, which when appropriately applied to the different grams of the soil samples will produce optimal stability.

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