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UNIVERSITY OF NIGERIA, NSUKKA

DEPARTMENT OF SOIL SCIENCE

POSTGRADUATE (M.SC.) DISSERTATION

TOPIC

CHARACTERIZATION AND MAPPING OF GULLY EROSION FEATURES

IN TWO GEOLOGICAL FORMATIONS

OF EASTERN NIGERIA

USING GLOBAL POSITIONING SYSTEM (GPS) AND SATELLITE AERIAL PHOTO

BY

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DECEMBER, 2010

CERTIFICATION

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A DISSERTATION
SUBMITED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF
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DEPARTMENT OF SOIL SCIENCE,
FACULTY OF AGRICULTURE,
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NSUKKA.

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Prof. C.L.A. ASADU **Prof. C.L.A ASADU**
SUPERVISOR **HEAD OF DEPARTMENT**

DEDICATION

This work is dedicated to my parents, Mr. and Mrs. J. O. Nwani, my brothers and sisters my humble wife Blessing

ACKNOWLEDGEMENT

The successful completion of this project was piloted by my supervisor Prof. C.L.A. Asadu. I must thank him for directing me on and when in need.

My thanks go to all the lecturers and staff of the department of Soil Science, who have contributed in one way or the other to build me up to this level of academic statute.

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Not to forget is Mr Dennis Iyida- my field assistant- for his effort during the field work

Ani Uchechukwu Abel.

December, 2010

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ABSTRACT

With the aid of Global Positioning System (GPS) and Satellite Aerial Photo, a comparative characterization and mapping of soil gully erosion features on two geological formations were carried out in Nsukka area of eastern Nigeria. The two geological formations were Ajali and Mamu formations. The study involved the use of base map created using a Geographic Information System (GIS) (GPS Track Marker) and Satellite Photo downloaded from the internet using the same GIS (GPS Track Marker). This aided the field work for erosion site study and data collection. A total of seventy (70) erosion sites with an average length of about 1606.5 meters, average width of about 64.2 meters and average depth of 8.6 meters were visited in Ajali formation. On the other hand, only nine with an average length of about 484.2 meters, average width of about 6.5 meters and an average depth of about 3.7 meters were visited in Mamu. In Ajali formation, forty three new erosion sites were identified to add to the twenty seven old sites while in Manu formation only five new sites were identified to add to the four old sites. Three profile pits were dug in each formation to represent the soils. They are sites of Ada (Mpt_1), Agu-Orba (Mpt_2) and Agu-Ekwegbe (Mpt_3) on Mamu Formation while Iheaka (Apt_1), Ede-Oballa (Apt_2) and Aku (Apt_3) were sites on Ajali Formation. The soils from the pits were sampled and analyzed for some physical and chemical properties. The properties were, colour, texture, soil reaction, organic matter, exchangeable bases, total nitrogen and available phosphorus, exchangeable acidity, cat ion exchange capacity, and aggregate stability. There was a significant difference in the value of gully length and width while the depth was statistically the same. There was a positive significant correlation between length and width (r = 0.409), depth and width (r = 0.862), but non significant correlation between length and depth (r = 0.188) in Mamu Formation, while a positive and significant correlation was found between length and depth (r = 0.635), length and width (r = 0.578), depth and width (r = 0.689) in Ajali formation. The results of the soil percentage state of aggregation (PSA) and percentage aggregate stability (PAS) was low at both soils. There was no significant difference between their mean weight diameters (MWD). Their low MWD values (1.1mm) in the soil of Mamu formation and 1.2mm in the soil of Ajali formation were indication that the soil were highly susceptible to erosion. Both soils of the studied area have low silt content (8% in the soil of Ajali and 5% in the soil of Mamu), but moderate to high fine sand values (18% in Ajali and 49% in Mamu). These could be one of the factors promoting the soil erodibility. At micro

level, the water/calgon dispassion ratio (DR) was very high. There was no significant difference in the chemical properties of the soils of the two underlying geological formations using t-test analysis. Gully erosion affected both Mamu and Ajali formations and led to loses to all the soil nutrients. Low soil pH due to heavy rainfall and the acidic nature of the underlying geology (false bedded sand stones and coal measures) and possible acidic precipitation affected the soil structure and promoted erodibility. The organic matter content of the soils was generally low (5.8g/kg in Ajali Formation and 4.3g/kg in Mamu Formation). The total nitrogen values were low (average of 0.1g/kg in the soil of Ajali and 0.07g/kg on the soil of Mamu formation) .The effective cat ion exchange capacity (ECEC) (cmol kg^{-1}) values were also very low. The available phosphorus (mg/kg) was very low (6.6m/kg in Mamu formation and 6.7m/kg in Ajali formation) compared to the critical value 8-15m/kg. All these signify low soil fertility status partly due to severe land wash by soil erosion. This is getting worse due to anthropogenic effects on the soil cover (deforestation) and soil disruption due to sand and stone excavation. To this, effort is urgently needed to rescue the inhabitants of the agricultural areas such as Agu-Ukehe, Agu Ekwegbe, Agu-Orba, Imilike-Agu, Ezimo and Obollo-Eke where threatening gullies were identified. Farmers should be encouraged to practice conservation tillage and use more organic manure as against inorganic fertilizer. These should be reforestation especially at the eastern aspect of the Ajali formation where the soil structure is becoming poorer year after year. Government should set-up a task-force to control sand and stone excavation which was identified as part of the major initiator of gullies in the studied area.

CHAPTER ONE
INTRODUCTION

Land degradation was a significant global issue during the 20th century and remains of high importance in the 21st century as it affects the environment, agronomic productivity, food security, and quality of life (Eswaran *et al.,* 2001). No soil phenomenon is more destructive worldwide than the erosion caused by wind and water (Brady and Weil, 1999). Soil erosion remains the world's biggest environmental problem, threatening sustainability of both plant and animal in the world and over 65 percent of the soil on earth is said to have displayed degradation phenomena as a result of soil erosion, salinity and desertification (Okin, 2002).

The damage done to our soil by erosion has brought damage to agricultural land which is now becoming limiting in farming; while homes, many highways, electric and telephone lines which cost billions of naira to build, are all at the mercy of erosion in many parts of Nigeria (Asadu, 1990a). Plaster (1992) observed that over the past 40 years, a stream of technological improvements, including fertilizer and improved crops varieties, have masked the effect of erosion on productivity.

Wikipedia (2008) documented that approximately 40% of the world's agricultural land is seriously degraded and a large area of fertile soil is lost every year because of drought, deforestation and climate change. Since the late 1960's, nearly one-third of the world's arable land has been lost to erosion and continues to be lost at a rate of more than 10 million hectares (25 million acres) per year. They added that in Africa, if current trends of soil degradation continue, the continent might be able to feed just 25% of its population by 2025. According to Brady and Weil (1999), the degraded productivity of farm, forest, and range land tell part of the sad erosion story while the soil particles washed or blown from the eroding areas are subsequently deposited else-where-in nearby low-lying landscape; in streams; or in down streams reservoirs, lakes and harbours. Wikipedia (2008) maintained that such lands will end up being waste lands especially under heavy population and mismanagement.

The World Bank (1990) recognized three main environmental problems facing Nigeria: soil degradation and loss, water contamination and deforestation. In addition, six others (problem areas) were specified: gully erosion, fishery loss, coastal erosion, wildlife and biodiversity losses, air pollution and the spread of the water hyacinth. According to them, gully erosion contributes to each of the three main problems and causes damage with an annual cost to the nation (Nigeria) estimated at $100 million in 1990. In Nigeria, FGN (1997) recorded an estimate of over 90% of the land mass under severe interrill, rill and gully, with the severest gully erosion occurring on 80% of Nigeria's total land area.

In Southeastern Nigeria, Akamigbo *et al.,* (1987) reported that the worst hit area by gully erosion in Enugu, Anambra and Ebonyi States (former Anambra state) include the former Aguata, Nnewi, Njikoka, Ihiala, Udi, Awka, Idemili, Ezeagu, Oji River, Isi-Uzo and Onitsha Local Government Councils. As at then, the land area engulfed by gullies in these states were estimated to cover about 10% of the total land mass of the states and this is approximately 176, 750 ha (Akamigbo *et al.,* 1987).

A lot of research interests on erosion and its control have amply been demonstrated over the years by various groups, individuals and stakeholders. The Food and Agriculture Organization of the United Nations summarized attempts to check gully erosion in eastern Nigeria, from the establishment of the Udi Forest Reserve in 1918 to the formation of the Anambra State Task Force on Soil Erosion Control in 1990 (FAO, 1990). In general, these initiatives were "top down" in design and yielded some success, especially in vegetation established, but largely unsuccessful and expensive engineering solutions (Akamigbo *et al*., 1987).

According to Ihediwa, (1998) soil erosion is influenced by many pedogenic processes and their interactions with climate and management systems. He added that processes governing soil erodibility in the eastern part of Nigeria are not well understood and so more research is required to understand the principles influencing it. Ihediwa (1998) recorded that with continuous intensive cultivation and ever increasing emphasis on urban development; soil vulnerability to erosion is likely to increase. He pointed out that soil erosion is now becoming a national problem; the first stage in solving the problem includes the identification of potential risk areas, which requires detailed studies and evaluation of the soil properties, land use and strategies as they influence soil erosion in various geological formations.

Asadu (1990a) emphasized that the cost of the survey is often far less than the benefit accruing from the results. He insisted that soil survey is a capital intensive activity which is often considered too expensive by government and individuals to embark upon. This ugly situation according to him has led many nations and individuals to focus their attention and effort towards ameliorating degradation problems instead of eradicating it.

The use of grid technique of soil survey as employed by most Nigerian soil scientists is a major factor discouraging the involvement of many soil scientists in the crusade against soil erosion (Asadu, 1990a). Reacting to this, Brady and Weil (1999) proposed that Global Positioning System (GPS) is an obvious prerequisite for delineating the location of a soil body in the field. According to them, the soil surveyors will be aware of where they themselves are located as they traverse a landscape and thus can take advantage of satellite technology to identify precise locations anywhere in the world.

This is done following the fact that when a location is required, the GPS unit displays the coordinates and stores the coordinates for geo-referencing (Turenne, 1996).

In this study, emphasis was laid on erodibility of the soil in relation to its geological formations. The general objective of this work was to identify, characterize and map the erosion gullies in two geological formations in Eastern Nigeria with the help of the Global Positioning System (GPS) for proper land use planning, erosion control and prevention and academic research development. The specific objectives were to:

a. compare the contributions of two geologic formations to the erodibility of the overlying soils.
b. provide a composite soil erosion map of the study area.
c. proffer preventive and control measures for the identified erosion types
d. relate erosion phenomenon in the two geological formations to the soil physical and chemical properties.

CHAPTER TWO
LITERATURE REVIEW

2.1 Land Degradation

Land degradation is a reduction or loss, in arid, semi-arid and dry sub-humid areas of biological or economic productivity or complexity of rain fed crop land, irrigated cropland, or range, pasture, forest and woodlands resulting from land use, or combination of processes, including process arising from human activities and habitation of physical, chemical and biological or economic properties of; and long term loss of natural vegetation (Maitima and Olson, 2001). United Nations (UN) Convention to Combat Land Degradation (CCD) opines that soil erosion automatically results in reduction or loss of the biological and economic productivity and complexity of terrestrial ecosystems, including soil nutrients, vegetation, other biota, and the ecological processes that operate therein (Claassen, 2004). Oldeman (1990) earlier pointed out that this reduces to a greater or lesser degree the land's capacity to provide for the requirements of human life. According to Wall *et al.,* (2003), land degradation includes; soil erosion, soil compaction, low organic matter, loss of soil structure, poor internal drainage, salinisation, and soil acidity problems. Brady and Weil (1999) recorded that much of this degradation (on about 7.6 billion ha) is linked to desertification which they emphasized is caused majorly by overgrazing by cattle, sheep and goats, a factor that likely account for about a third of all land degradation in dry regions like sahel in Northern Africa and the rangeland of the American southwest. They added that indiscriminate felling of forest trees has already degraded nearly 0.5 billions ha in the humid tropics while inappropriate agricultural practices continue to degrade land in all the climatic religions.

2.1.1 Causes of Land Degradation

An inappropriate land use accelerates the erosion rate beyond the tolerable level (Lal, 1990). Ofomata (1975) recorded that land use abuse is made manifest on the surface through agricultural activities, especially on the clearing and burning of the original vegetation. He added that this indiscriminate bush clearing and burning expose the soil to excessive insolation, wind and runoff and perhaps contribute to reduce the organic matter contents of the soils as well as beneficial soil organism. The adverse effects of inappropriate land use are more severe and harsh than in moderate climate, for example, regions with intense rains or prolonged dry periods with strong directional winds (Lal, 1990). Ofomata (1975) opined that although there is no doubt that agricultural activity provides the most potential example of human interference, there are a number of other activities worth mentioning because of their cumulative effects on soil erosion and land degradation. Responding to the serious impacts of degradation on land resources, Anecksamphant *et al.,* (1999) pointed out that the use of fragile ecosystems by resources poor farmers, the continuing conversion of forests to agriculture, the systematic loss of water storage capacity of soils, and in reservoirs through siltation, the systematic loss of biodiversity requires monitoring and attention. They further emphasized that the decline in the land resources base due to deterioration and degradation in important areas of developing countries, will significantly increase the challenge to feed a growing population from a diminishing land area of declining quality, sulting in food security, reduced agricultural income, and slower economic growth.

2.1.1.1 Erosion

Erosion (Latin, *erred*, to gnaw a way) is a comprehensive term applied to the wearing away and removal of the earth's surface material by geomorphic agents (Efiong-Fuller, Sourced on 4th August 2008).

2.1.1.2 Types of Erosion

Wikipadea (2009), enumerated the following types of erosion;

2.1.1.2.1 Gravity erosion

Mass wasting is the down-slope movement of rock and sediments, mainly due to the force of gravity. Mass movement is an important part of the erosional process, as it moves soil materials from higher elevations to lower elevations where other eroding agents such as streams and glaciers can then pick up the materials and move it to even lower elevations. Mass-movement processes are always occurring continuously on all slopes; some mass-movement processes act very slowly; others occur very suddenly, often with disastrous results. Any perceptible down-slope movement of rock or sediment is often referred to in general terms as a landslide. However, landslides can be classified in a much more detailed way that reflects the mechanisms responsible for the movement and the velocity at which the movement occurs. One of the visible topographical manifestations of a very slow form of such activity is a scree slope.

Slumping happens on steep hillsides, occurring along distinct fracture zones, often within materials like clay that, once released, may move quite rapidly downhill. They will often show a spoon-shaped isostatic depression, in which the material has begun to slide downhill. In some cases, the slump is caused by water beneath the slope weakening it. In many cases it is simply the result of poor engineering along highways where it is a regular occurrence.

Surface creep is the slow movement of soil and rock debris by gravity which is usually not perceptible except through extended observation. However, the term can also describe the rolling of dislodged soil particles 0.5 to 1.0 mm in diameter by wind along the soil surface.

2.1.1.2.2 Shoreline erosion

Shoreline erosion, which occurs on both exposed and sheltered coasts, primarily occurs through the action of currents and waves but sea level (tidal) change can also play a role.

Hydraulic action takes place when air in a joint is suddenly compressed by a wave closing the entrance of the joint. This then cracks it. Wave pounding is when the sheer energy of the wave hitting the cliff or rock breaks pieces off. Abrasion or corrasion is caused by waves launching seaload at the cliff. It is the most effective and rapid form of shoreline erosion (not to be confused with corrosion). Corrosion is the dissolving of rock by carbonic acid in sea water. Limestone cliffs are particularly vulnerable to this kind of erosion. Attrition is where particles/seaload carried by the waves are worn down as they hit each other and the cliffs. This then makes the material easier to wash away. The material ends up as shingle and sand. Another significant source of erosion, particularly on carbonate coastlines, is the boring, scraping and grinding of organisms, a process termed bioerosion.

Sediment is transported along the coast in the direction of the prevailing current (longshore drift). When the upcurrent amount of sediment is less than the amount being carried away, erosion occurs. When the upcurrent amount of sediment is greater, sand or gravel banks will tend to form. These banks may slowly migrate along the coast in the direction of the longshore drift, alternately protecting and exposing parts of the coastline. Where there is a bend in the coastline, quite often a build up of eroded material occurs forming a long narrow bank (a spit). Armoured beaches and submerged offshore sandbanks may also protect parts of a coastline from erosion. Over the years, as the shoals gradually shift, the erosion may be redirected to attack different parts of the shore.

2.1.1.2.3 Ice erosion

Ice erosion is caused by movement of ice, typically as glaciers. Glaciers erode predominantly by three different processes: abrasion/scouring, plucking, and ice thrusting. In an abrasion process, debris in the basal ice scrapes along the bed, polishing and gouging the underlying rocks, similar to sandpaper on wood. Glaciers can also cause pieces of bedrock to crack off in the process of plucking. In ice thrusting, the glacier freezes to its bed, then as it surges forward, it moves large sheets of frozen sediment at the base along with the glacier. This method produced some of the many thousands of lake basins that dot the edge of the Canadian Shield. These processes, combined with erosion and transport by the water network beneath the glacier, leave moraines, drumlins, eskers, ground moraine (till), kames, kame deltas, moulins, and glacial erratics in their wake, typically at the terminus or during glacier retreat.

Cold weather causes water trapped in tiny rock cracks to freeze and expand, breaking the rock into several pieces. This can lead to gravity erosion on steep slopes. The scree which forms at the bottom of a steep mountainside is mostly formed from pieces of rock (soil) broken away by this means. It is a common engineering problem wherever rock cliffs are alongside roads, because morning thaws can drop hazardous rock pieces onto the road.

In some places, water seeps into rocks during the daytime, then freezes at night. Ice expands, thus, creating a wedge in the rock. Over time, the repetition in the forming and melting of the ice causes fissures, which eventually break the rock down.

2.1.1.2.4 Wind erosion

Wind erosion is the result of material movement by the wind. There are two main effects. First, wind causes small particles to be lifted and therefore moved to another region. This is called deflation. Second, these suspended particles may impact on solid objects causing erosion by abrasion (ecological succession).

Wind erosion generally occurs in areas with little or no vegetation, often in areas where there is insufficient rainfall to support vegetation. An example is the formation of sand dunes, on a beach or in a desert. Windbreaks (such as big trees and bushes) are often planted by farmers to reduce wind erosion.

The removal by erosion of large amounts of rock from a particular region, and its deposition elsewhere, can result in a lightening of the load on the lower crust and mantle. This can cause tectonic or isostatic uplift in the region.

2.1.1.2.5 Water erosion

Splash erosion is the detachment and airborne movement of small soil particles caused by the impact of raindrops on soil.

Interril erosion is the detachment of soil particles by raindrop impact and their removal downslope by water flowing overland as a sheet instead of in definite channels or rills. The impact of the raindrop breaks apart the soil aggregate. Particles of clay, silt and sand fill the soil pores and reduce infiltration. After the surface pores are filled with sand, silt or clay, overland surface flow of water begins due to the lowering of infiltration rates. Once the rate of falling rain is faster than infiltration, runoff takes place. There are two stages of interrill erosion. The first is rain splash, in which soil particles are knocked into the air by raindrop impact. In the second stage, the loose particles are moved downslope by broad sheets of rapidly flowing water filled with sediment known as sheetfloods. This stage of interrill erosion is generally produced by cloudbursts, sheetfloods commonly travel short distances and last only for a short time.

Rill erosion refers to the development of small, ephemeral concentrated flow paths, which function as both sediment source and sediment delivery systems for erosion on hillslopes. Generally, where water erosion rates on disturbed upland areas are greatest, rills are active. Flow depths in rills are typically on the order of a few centimeters or less and slopes may be quite steep. These conditions constitute a very different hydraulic environment than typically found in channels of streams and rivers. Eroding rills evolve morphologically in time and space. The rill bed surface changes as soil erodes, which in turn alters the hydraulics of the flow. The hydraulics is the driving mechanism for the erosion process, and therefore dynamically changing hydraulic patterns cause continually changing erosional patterns in the rill. Thus, the process of rill evolution involves a feedback loop between flow detachment, hydraulics, and bed form. Flow velocity, depth, width, hydraulic roughness, local bed slope, friction slope, and detachment rate are time and space variable functions of the rill evolutionary process. Superimposed on these interactive processes, the sediment load, or amount of sediment in the flow, has a large influence on soil detachment rates in rills. As sediment load increases, the ability of the flowing water to detach more sediment decreases.

Where precipitation rates exceed soil infiltration rates, runoff occurs. Surface runoff turbulence can often cause more erosion than the initial raindrop impact.

Gully erosion results where water flows along a linear depression eroding a trench or gully. This is particularly noticeable in the formation of hollow ways, where, prior to being tarmacked, an old rural road has over many years become significantly lower than the surrounding fields.

A conservative assessment shows the distribution of know gully sites in different stages of development in south eastern Nigeria as follows; Abia (300), Anambra (700), Ebonyi (250), Enugu (600), Imo (450), Igbokwe *et al.,* (2008). (Tab 1) The went further to conclude that these statistics were not exhaustive as small size site were not included and now once keep on developing during each raining season due to flooding and torrential rainfall. On the global level Abegunde *et al.,* (2006) reported that the erosion carries off over 22 billion tones of soil every year world wide.

Having in mind the different types of erosion, emphases would be laid on soil gully erosion in this work

Table. 1 Gully Erosion Distribution in Eastern Nigeria

S/N	Sate	No of Gully sites	State	Control measures
1	Anambra	700	Mostly active	Not successful
2	Abia	300	Some active some dormant	Not successful
3	Ebonyi	250	Mostly minor Gully sites	No records
4	Enugu	600	Some active some dormant	None
5	Imo	450	Some active some dormant	Not successful

Source; Igbokwe *et al.,* 2008.

2.1.1.2.5.1 Causes of Soil Erosion

The inherent susceptibility of a soil to erosion is collectively determined by its structural and hydrological properties (Gabriels, 1993). Aggregation and particle size detachment depend on aggregate stability and particle size distribution characteristics (Gabriels, 1993). Lal (1977) emphasized that tropical rainfall is more erosive than temperate rainfall, because of the high intensity of tropical storms. He pointed out that majority of the tropical rainstorms fall in the category of erosive rain fall.

Due to gradual replacement of bush fallow by shifting cultivation, soil erosion has become a serious problem in the humid tropics (Lal, 1977). Supporting this fact, Akamigbo *et al* (1987) emphasized on the effects of rooting system and added that using corrugated iron sheets and cemented roofs was singled out as a major contributor along side with construction of roads and house across natural drainage routes. The effect of erosion on track roads has been view to be on two forces;

(1) Misappropriation of natural resources by the rich for luxury consumption

(2) The struggle for survival which leads the poor farmers to extend outward to marginal farm lands, working the edges of ravines reaching up steep slopes that had been wisely left alone, destroying forests and encroaching on already limited grazing lands (Okorie 1986).

Mbagwu (1986a) pointed out that only 25% variation in the type of erosion is due to population density, 75% due to relief, 75% due to vegetation and 25% due to surface material (Lithology). To this, Okorie (1986) emphasized that massive shift in land use, generated both by rapidly growing population, seeking substance and by commercial interests responding to growing demands, have led to equally deleterious results.

2.1.1.2.5.1.1 Rainfall Intensity

Both rainfall and runoff factors must be considered in assessing a water erosion problem. The impact of raindrops on the soil surface can break down soil aggregates and disperse the aggregate material. Lighter aggregate materials such as very fine sand, silt, clay and organic matter can be easily removed by the raindrop splash and runoff water; greater raindrop energy or runoff amounts might be required to move the larger sand and gravel particles (Wall *et al.,* 2003). Rainfall is the real agent of soil erosion by water in the tropics by virtue of its role as the source of water or the only form of precipitation contributing to the hydrologic cycle (Salako, 2003). The amount of rainfall and how long it takes to fall influences how much of water infiltrates and run off the soil. Problems of flooding and soil erosion are basically related to amount and duration of rainfall. The amount of soil that is detached by a particular rain event is related to the intensity at which this rain falls. He insisted that smaller drops that dominated low intensity rainfall are less efficient in detaching soil (Bobe, 2004). Although the erosion caused by long-lasting and less-intense storms is not as spectacular or noticeable as that produced during thunderstorms, at all amount of soil loss can be significant, especially when compounded over time (Wall *et al.,* 2003). Runoff can occur whenever there is excess water on a slope that cannot be absorbed into the soil or trapped on the surface. The amount of runoff can be increased if infiltration is reduced due to soil compaction, crusting or freezing. Runoff from the agricultural land may be greatest during raining season when the soils are usually saturated (Wall *et al.,* 2003).

2.1.1.2.5.1.2 Soil Erodibility

Soil erodibility is actually defined as the susceptility of soils to erosion. Particle size distribution, soil dispersion and aggregate stability have been used for many years as indices of soil erodibility (Bryan, 1968, Salako, 2003). The process of soil erosion involves detachment, transportation and deposition (Salako, 2003). Soil erodibility is an estimate of the ability of soils to resist erosion, based on the physical characteristics of each soil. Sand, sandy loam and loam textured soils tend to be less erodible than silt, very fine sand, and certain clay textured soils (Wall *et al.,* 2003). Silt dominated soil were found by Bobe (2004) to be more susceptible to particle detachment in terms of sediment yield than sandy soil. This he attributed to relative transportability of fine and none aggregated silt particles. Silt dominated soils have lower infiltration rates than sandy soil which will enhance runoff and sediment yield (Bobe, 2004).

Tillage and cropping practices which lower soil organic matter levels cause poor soil structure, increase soil erodibility. Decreased infiltration and increased runoff can be a result of compacted subsurface soil layers. A decrease in infiltration can also be caused by a formation of a soil crust, which tends to "seal" the surface. On some sites, a soil crust might decrease the amount of soil loss from sheet or rain splash erosion, however, a corresponding increase in the amount of runoff water can contribute to greater rill erosion problems (Wall *et al.,* 2003).

Erosion has an effect on a soil's erodibility for a number of reasons. Many exposed subsurface soils on eroded sites tend to be more erodible than the original soils because of their poorer structure and lower organic matter. The lower nutrient levels often associated with sub-soils contribute to lower crop yields and generally poorer crop cover, which in turn provides less crop protection for the soil (Wall *et al.,* 2003).

From wind erosion, very fine particles can be suspended by the wind and then transported great distances. Fine and medium size particles can be lifted and deposited, while coarse particles can be blown along the surface (commonly known as the saltation effect). The abrasion that results can reduce soil particle size and further increase the soil erodibility (Wall *et al.,* 2003).

2.1.1.2.5.1.3 Slope Gradient

In 2007, Olatunji reported that the main environment factors that predispose the soil to serious and accelerated erosion are long, gentle to relatively steep slopes, degree of slope, heavy and prolonged rainfall, high erodible soil, inadequate storm drains and unplanned land use types in the build-up parts of Ala water shade in Akure South Western Nigerian. Naturally, the steeper the slope of a field, the greater will be the amount of soil loss from erosion by water. Soil erosion by water also increases as the slope length increases due to the greater accumulation of runoff (Wall *et al.,* 2003). Consolidation of small fields into larger ones often results in longer slope lengths with increased erosion potential, due to increased velocity of water which permits a greater degree of scouring (carrying capacity for sediment). Among the topographic features, slope affects soil erosion through its morphological characteristics and aspect (Bobe, 2004). The effect of slope on erosion has been studied extensively, with conclusions that over all erosion rates increase with increase in slope steepness (Bobe, 2004). Bobe, (2004) indicated that runoff and erosion usually increase with increase in slope gradient. Slope has the most direct effect on the erosivity of overland flow by determines its stream power and runoff which increase with increase in slope gradient even though soil surface condition and storm characteristics also modify its effect on runoff and soil loss (Bobe, 2004). In contrast, ridges and steep slope acts as break to the speed of wind. Soil surfaces that are not rough or ridged offer little resistance to the wind. However, over time, ridges can be filled in and the roughness broken down by abrasion to produce a smoother surface susceptible to the wind. Excess tillage can contribute to soil structure breakdown and increased erosion (Wall *et al.,* 2003). Bobe (2004) reported in a laboratory rainfall simulation that the effect of soil texture and rainfall intensity on runoff seems to be more pronounced than that of slope gradient.

2.1.1.2.5.1.4 Poor Vegetation

Wall *et al.,* (2003) documented that soil erosion potential is increased if the soil has no or very little vegetative cover of plants and/or crop residues. Plant and residue cover protects the soil from raindrop impact and splash, tend to slow down the movement of surface runoff and allow excess surface water to infiltrate.

The erosion-reducing effectiveness of plant and/or residue covers depends on the type, extent and quantity of cover. Vegetation and residue combinations that completely cover the soil, and which intercept all falling raindrops at and close to the surface are the most efficient in controlling soil erosion (e.g. forests, permanent grasses). Partially incorporated residues and residual roots are also important as these provide channels that allow surface water to move into the soil.

The effectiveness of any crop, management system or protective cover also depends on how much protection is available at various periods during the year, relative to the amount of erosive rainfall that falls during these periods. In this respect, crops which provide a food, protective cover for a major portion of the year (for example, maize or leguminous cover crops) can reduce erosion much more than can crops which leave the soil bare for a longer period of time (e.g. row crops) and particularly during periods of high erosive rainfall.

Soil erosion potential is affected by tillage operations, depending on the depth, direction and timing of plowing, the type of tillage equipment and the number of passes. Generally, the less the disturbance of vegetation or residue cover at or near the surface of the soil, the more effective the tillage practice in reducing erosion.

In terms of wind erosion, lack of permanent vegetation cover in certain locations has resulted in extensive erosion by wind. Loose, dry, bare soil is the most susceptible; however, crops that produce low levels of residue also may not provide enough resistance. As well, crops that produce a lot of residue also may not protect the soil in severe cases. The absence of windbreaks (trees, shrubs, residue, etc.) allows the wind to put soil particles into motion for greater distances thus increasing the abrasion and soil erosion.

2.1.1.2.5.2 Effects of Erosion on the Society

For many years, accelerated erosion, land slide and general land degradation have ravaged many parts of South Eastern Nigeria (Efiong-Fuller, Sourced on 4th August 2008). Wall et al., (2003) recorded that sediment which reaches streams or watercourses can accelerate bank erosion, clog drainage ditches and stream channels, silt in reservoirs, cover fish spawning grounds and reduce down stream water quality. He added that pesticides and fertilizers, frequently transported along with eroding soil can contaminate or pollute downstream water sources and recreational areas.

Efiong-fuller (Sourced on 4th August 2008). observed that live and properties have been lost, people have been forced to desert their ancestral homes, schools and colleges have been devastated, and even University Campuses are not left out in the menace of erosion hazards.

Mbagwu (1986b) opined that the most spectacular form of erosion is the gully type but from the point of view of fertility depletion and reduction in land productivity, the more widespread form of interril erosion is more serious problems. Responding to this, Efiong-fuller (Sourced on 4th August 2008) added that beautiful fertile agricultural land has been completely lost; such loss of fertile agricultural land has inevitably led to lower food production. Lal (1977) opined that soil erosion includes both physical removal of surface soil and deterioration in soil physical properties resulting in low productivity. He insisted that failure to appreciate the significant of soil erosion problems in the society can lead not only to large areas of shallow, badly eroded and unproductive soils in the tropics, but also to the replacement of forests by savanna.

Erosion causes destruction of lives and properties, vegetation, aquatic life and negates efforts at improving both urban and rural life (Akamigbo *et al.,* 1987). Blue Mountains (1992) opined that our natural environment is continually under threat from increasing urbanization, adding that one such threat is soil erosion and sedimentation which leads to degradation of our land and waterways. Sediments block local urban drainage and water course which adversely affects natural biological systems and potentially leads to in-stream systems being unsuitable habitats for aquatic life.

2.1.1.2.5.3 Erosion Control

In 1957, the food and Agricultural Organization of the United Nations (FAO) officially condemned the cut and burn technique of shifting cultivation as a waste of land and human resources and a major causes of soil erosion, and land degradation (Asadu, 1998). Okorie (1986) observed that many agronomists have proposed a zero-tilling farming system as a remedy for the soil degradation. He insisted that this gives an effective soil management, provides least-cost approach that supports continuous land use with sustained productivity. Brady and Weil (1999) opined that if soil vegetative cover is improved, macro porosity and aggregation are increased as active organic mater builds up and earthworms and other organisms establish themselves. They added that infiltration and internal drainage are generally improved, as in soil water-holding capacity. Okorie (1986) observed that minimized soil regeneration becomes more rapid especially if combined with cover crop immediately after clearing. He added that this would promote earthworm activities, thereby improving soil structure and porosity, as well as mineralization of organic matter.

2.1.1.2.5.3.1 Land Reclamation

Incipient gullies threatening rural and urban habitation qualify for immediate attention as well as others threatening intercommunity communication (Akamigbo *et al,* 1987). Recently, the international fora and conventions have provided impetus for some nations to prepare new environmental law, environmental policies and strategies including the preparation of law and policy specially aimed at the control and management of land degradation (Anecksamphant, 1999). Akamigbo *et al,* (1987) enumerated two approaches towards reclaiming an eroded land;

(i) Engineering curative methods coupled with suitable land management techniques. To be employed for high and low level gullies.

(ii) Biological/Engineering methods aimed at protecting the soil from gully initiation and growth.

He further noted that erosion prone areas will be protected with suitable species of both fruit and timber trees. Minor engineering works may be necessary for effective management of runoff water. According to him, the purpose of biological protective measures will aim at reducing the erosion capacity of runoff by reducing its energy, improving the resistance of the soil to erosion, and keeping the topsoil in place in the biological measure, fast growing plants that are capable of fixing nitrogen, producing high biomass and deep rooting will be used. Other qualities of needed species will include low nutrient demand, drought resistance and ability to regenerate by copping. Grasses will be used where necessary.

2.1.1.2.5.4 Erosion Prevention

The forest cover maintains good soil structure and reduces erosion to a minimum, thereby maintaining adequate natural vegetative cover and reasonable balance (Akamigbo *et* *al.,* 1987). In support to this fact, Zhou (1997) emphasized that the dribbling water drops from leaves of broad-leaved trees generally have larger diameter than those from coniferous trees, grasses or atmospheric precipitation, thus increasing the dash of water drops to the forest land; especially in the situation of low intensity of rainfall. He added that such broad-leaved forest without under story generally hampers the topsoil conservation of forestland. According to Akamigbo (1988) traditional bush fallow system, or land rotation, where fallow period are still long enough (up to 10 years or more), a reasonable balance can be maintained, and erosion minimized but there most be effort to ensure some covering during clearing and by growing severed crops which protects the soil and also weeding kept to a minimum.

Orvil (Sourced on 14th July, 2009) opined that preventing soil erosion requires political, economic and technical changes. According to him, political and economic changes need to address the distribution of land as well as the possibility of incentives to encourage farmers to manage their land in a sustainable manner. Aspects of technical changes include: The use of contour unploughing and wind breaks, leaving unploughed grass strips between unploughed land, making sure that there are always plants growing on the soil, and that the soil is rich in humus (decaying plant and animal remains- organic matter which is the "glue" that binds the soil particles together and plays an important part in preventing erosion), avoiding overgrazing and the over-use of croplands, allowing indigenous plants to grow along the riverbanks instead of plowing and planting crops right up to the water's edge, encouraging biological diversity by planting several different types of plants together and finally conservation of wetlands. Even though the above possibilities are suggested, Akamigbo *et al,* (1987) regret that despite the adoption of the above and its implementation in addressing the Agulu, and other gully erosion prone areas, the ravaging soil erosion menace has continued unabated to take its wanton toll of indispensable soil and water resources. He added that this menace has affected civil infrastructure, property and life, and placed agriculture and other entire environment in a very serious Jeopardy, pointing out that the situation assumes more serious dimension as the rains comes and go every year.

2.2 Assessment and Mapping of Soil Erosion

Soil survey is a fundamental basis for land use planning because it contains both quantitative and qualitative data which enable prediction of many kinds to be made (Akamigbo 1986). Young (1976) recorded that soil survey is one of a group of activities collectively known as natural resource survey, which involves the study of natural environment with special reference to its resource potential and may cover the geology, land form, climate, hydrology, soils and vegetation of the area under study. Forth (1978) emphasized that soil survey at present time is a process of studying and mapping the earths surface in terms of units called soil types; hence is an-on-the land inventory of soil resource which in addition to indicating the suitability and limitations of various soils, provides valuable information to planning and zoning of soil groups as used by farmers, engineers, developers etc. This involves distinguishing the various mapping units that occur in the land scape, classifying, describing and mapping them to predict their responses to management within the scope of the survey (FDALR, 1981). Soil mapping consists of delineating areas where the soil has similar properties and characteristics that are the same under different land use practices (Dwain, 2003). These properties determine the limitations, suitability, and potential for rural and urban land use of soils (Soil Survey Manual; Online Edition, Sourced on 4th August 2008). This is the sub-division of the soil continuum into soil mapping units according to criteria which are dictated by the purpose of the survey which may be based on either external or internal properties or a combination of both (Akamigbo, 1986). Soil survey manual (Online Edition; Sourced on 4th August 2008) documented that soil survey implies the plotting or designing of map units to indicate significant differences in behaviour among soils bearing in mind to meet the current objectives of the survey. Akamigbo (1986) opined that soil survey implies the plotting of the units on a map and describing the properties of either constituent of soil or soils. He further declared that soil survey is not only an inventory of soil properties but also of many land features because soils are the product of five soil forming factors; climate, parent material, organism, topography and time.

2.2.1 Types of soil survey

In a table format, Soil Survey Manual (Sourced on 4th August 2008) described five orders of soil survey and relates them to how to choose an order to work with in a giving soil survey.

Table 2: Five orders of soil survey.

Level of data needed	Field procedures	Minimum-size delineation (hectares)[1]	Typical components of map units[2]	Kind of map units	Appropriate scales for field mapping and publications
1st order - Very intensive (i.e., experimental plots or individual building sites.)	The soils in each delineation are identified by transecting or traversing. Soil boundaries are observed throughout their length. Remotely sensed data are used as an aid in boundary delineation.	1 or less	Phases of soil series, miscellaneous areas.	Mostly consociations, some complexes, miscellaneous areas.	1:15,840 or larger
2nd order - Intensive (e.g. general agriculture, urban planning.)	The soils in each delineation are identifies by field observations and by remotely sensed data. Boundaries are verified at closely spaced intervals.	0.6 to 4	Phases of soil series, miscellaneous areas, few named at a level above the series.	Consociations, complexes; few associations and undifferentiated groups.	1:12,000 to 1:31,680
3rd order - Extensive (i.e., range or community planning.)	Soil boundaries plotted by observation and interpretation of remotely sensed data. Soil boundaries are verified by traversing	1.6 to 16	Phases of soil series or taxa above the series; or miscellaneous areas.	Mostly associations or complexes, some consociations and undifferentiated groups.	1:20,000 to 1:63,360

Table 2: Continued

4th order - Extensive (e.g., general soil information for broad statements concerning land-use potential and general land management.)	representative areas and by some transects.Soil boundaries plotted by interpretation of remotely sensed data. Boundaries are verified by traversing representative areas and by some transects.	16 to 252	Phases of soil series or taxa above the series or miscellaneous areas.	Mostly associations; some complexes, consociations and undifferentiated groups.	1:63,360 to 1:250,000
5th order - Very extensive (e.g., regional planning, selections of areas for more intensive study.)	The soil patterns and composition of map units are determined by mapping representative ideas and like areas by interpretation of remotely sensed data. Soils verified by occasional onsite investigation or by traversing.	252 to 4,000	Phases of levels above the series, miscellaneous areas.	Associations; some consociations and undifferentiated groups.	1:250,000 to 1:1,000,000 or smaller

1.This is about the smallest delineation allowable for readable soil maps (see Table 2-2). In practice, the minimum-size delineations are generally larger than the minimum-size shown.
2.Where applicable, all kinds of map units (consociations, complex, associations, undifferentiated) can be used in any order of soil survey.

Soil Survey Manual (Sourced on 4th August 2008)

http://soils.usda.gov/technical/manual/print_version/complete.html

The order of a survey as detailed by Soil Survey Manual (Online Edition; Sourced on 4th August 2008) is a consequence of field procedures, the minimum size of delineation, and the kinds of map units that are used.

(1) First-order surveys are made for very intensive land uses requiring very detailed information about soils, generally in small areas. The information can be used in planning for irrigation, drainage, truck crops, citrus or other specialty crops, experimental plots, individual building sites, and other uses that require a detailed and very precise knowledge of the soils and their variability.

Field procedures permit observation of soil boundaries throughout their length. The soils in the delineations are identified by traversing and transecting. Remotely sensed data are used as an aid in boundary delineation. Map units are mostly consociations with few complexes and are phases of soil series or are miscellaneous areas. Some map units named at a categorical level above the series may be appropriate. Delineations have a minimum size of about 1 hectare (2.5 acres) or less, depending on scale, and contain a minimum amount of contrasting inclusions within the limits permitted by the kind of map unit used. Base map scale is generally 1:15,840 or larger.

(2) Second-order surveys are made for intensive land uses that require detailed information about soil resources for making predictions of suitability for use and of treatment needs. The information can be used in planning for general agriculture, construction, urban development, and similar uses that require precise knowledge of the soils and their variability.

Field procedures permit plotting of soil boundaries by observation and by interpretation of remotely sensed data. Boundaries are verified at closely spaced intervals, and the soils in the delineations are identified by traversing and in some map units by transecting. Map units are mostly consociations and complexes.

Delineations are variable in size with a minimum of 0.6 to 4 hectares (0.6 to 400 km^2), depending on landscape complexity and survey objectives. Contrasting inclusions vary in size and amount within the limits permitted by the kind of map unit used. Base map scale is generally 1:12,000 to 1:31,680, depending on the complexity of the soil pattern within the area.

Table 3. Guide to map scale and minimum delineation size.

Map Scale	Inches per Mile	Minimum size delineation[1]	
		Acres	Hectares
1:500	126.7	0.0025	0.001
1:2,000	31.7	0.040	0.016
1:5,000	12.7	0.25	0.10
1:7,920	8.00	0.62	0.25
1:10,00	6.34	1.00	0.41
1:12,00	5.25	1.43	0.57
1:15,840	4.00	2.5	1.0
1:20,000	3.17	4.0	1.6
1:24,000 (7.5')	2.64	5.7	2.3
1:31,680	2.00	10.0	4.1
1:62,500 (15')	1.01	39.0	15.8
1:63,360	1.00	40.0	16.2
1:100,000	0.63	100.0	40.5
1:125,000	0.51	156.0	63.0
1:250,000	0.25	623.0	252.0
1:300,000	0.21	897.0	363.0
1:500,000	0.127	2,500.0	1,000.0
1:750,000	0.084	5,600.0	2,270.0
1:1,000,000	0.063	10,000.0	4,000.0
1:5,000,000	0.013	249,000.0	101,000.0
1:7,500,000	0.0084	560,000.0	227,000.0
1:15,000,000	0.0042	2,240,000.0	907,000.0
1:30,000,000	0.0021	9,000,000.0	3,650,000.0
1:88,000,000	0.0007	77,000,000.0	31,200,000.0

1. The "minimum size delineation" is taken as a 6-mm square area (1/16 sq. in.). Cartographically, this is about the smallest area in which a symbol can be printed readily. Smaller areas can be delineated, and the symbols lined in from outside; but such small delineations reduce map legibility. On maps at the smaller scales, delineations are commonly 1 ½ to 2 times the size of the minimum area that can be shown.

Source, Soil Survey Manual (Sourced on 4th August 2008)

http://soils.usda.gov/technical/manual/print_version/complete.html

(3) Third-order surveys are made for land uses that do not require precise knowledge of small areas or detailed soils information. Such survey areas are usually dominated by a single land use and have few subordinate uses. The information can be used in planning for range, forest, recreational areas, and in community planning.

Field procedures permit plotting of most soil boundaries by observation and interpretation of remotely sensed data. Boundaries are verified by some field observations. The soils are identified by traversing representative areas and applying the information to similar areas. Some additional observations and transects are made for verification. Map units include associations, complexes, consociations, and undifferentiated groups. Components of map units are phases of soil series, taxa above the series, or they are miscellaneous areas.

Delineations have a minimum size of about 1.6 to 16 hectares (4 to 40 acres), depending on the survey objectives and complexity of the landscapes. Contrasting inclusions vary in size and amount within the limits permitted by the kind of map unit used. Base map scale is generally 1:20,000 to 1:63,360, depending on the complexity of the soil pattern and intended use of the maps.

(4) Fourth-order surveys are made for extensive land uses that need general soil information for broad statements concerning land-use potential and general land management. The information can be used in locating, comparing, and selecting suitable areas for major kinds of land use, in regional land-use planning, and in selecting areas for more intensive study and investigation.

Field procedures permit plotting of soil boundaries by interpretation of remotely sensed data. The soils are identified by traversing representative areas to determine soil patterns and composition of map units and applying the information to like areas. Transects are made in selected delineations for verification. Most map units are associations, but some consociations and undifferentiated groups may be used in some surveys. Components of map units are phases of soil series, of taxa above the series, or are miscellaneous areas.

Minimum size of delineations is at least 16 to 252 hectares (40 to 640 acres). Contrasting inclusions vary in size and amount within the limits permitted by the kind of map unit used. Base map scale is generally 1:63,360 to 1:250,000.

(5) Fifth-order surveys are made to collect soils information in very large areas at a level of detail suitable for planning regional land use and interpreting information at a high level of generalization. The primary use of this information is selection of areas for more intensive study.

Field procedures consist of mapping representative areas of 39 to 65 square kilometers (15 to 25 square miles) to determine soil patterns and composition of map units. This information is then applied to like areas by interpretation of remotely sensed data. Soils are identified by a few onsite observations or by traversing. Most map units are associations, but some consociations and undifferentiated groups may be used. Components of map units are phases of taxa at categorical levels above the series and miscellaneous areas. Minimum size of delineations is about 252 to 4,000 hectares (640 to 10,000 acres). Contrasting inclusions vary in size and amount within the limits permitted by the kind of map unit used. Base-map scale ranges from about 1:250,000 to 1:1,000,000 or smaller.

2.2.2 Importance of Soil Survey

Udensi (1983) appreciated soil survey as an important element in the program for world wide sustained food production. He added that practical purpose of soil survey provides a systemic basis for the study of crop and soil relationships with a view to increasing productivity and to help in soil conservation and reclamation.

In a detailed form, the Soil Survey Manual (Sourced on 4th August 2008) highlighted the importance and uses of soil survey as;

Predictions for uses of soils other than farming, grazing, wildlife habitat, and forestry have tended to concentrate on limitations of soils for the intended uses. Where investment per unit of area is high, modifying the soil to improve its suitability for the intended use may be economically feasible. Soil scientists work with engineers and others to develop ways of improving soils for specific uses. Such predictions are increasingly important in areas where the demand on soil resources is high.

The information assembled in a soil survey may be used to predict or estimate the potentials and limitations of soils for many specific uses. The information must be interpreted in forms that can be used by professional planners and others. A soil survey represents only part of the information that is used to make workable plans, but it is an important part.

The predictions of soil surveys serve as a basis for judgment about land use and management for both small tracts and regions of several million hectares. The predictions must be evaluated along with economic, social, and environmental considerations before recommendations for land use and management become valid.

Soil surveys are used to appraise potentials and limitations of soils in local areas having a common administrative structure. Planning at this level is sometimes called community planning. It applies to community units-villages, towns, townships, counties, parishes, and to trade areas that include more than one local political unit.

Soil surveys also may be used to evaluate soil resources in multi-county or multi-State areas that have problems that cannot be resolved by local political units. Regional planning deals with land use in broad perspective and appraises large areas. Regional planning is done in less detail than community planning. Soil surveys and their interpretations for regional planning are correspondingly less detailed and less specific. Soil maps and their interpretations for regional planning must provide graphic presentations of the predominant kinds of soil of similarly large areas.

Soil surveys provide basic information about soil resources needed for planning development of new lands or conversion of land to new uses. Failures of trial-and-error land settlements influenced the start of the soil survey in the United States. The use of soil surveys avoids the waste caused by ignorance of soil limitations when major changes of land use are contemplated or when new lands are to be brought into use.

Soil survey information is important in planning specific land use and the practices needed to obtain desired results. For example, if recreational use is being considered, a soil survey can indicate the limitations and potential of the soil for recreation. The soil survey can help a landscape architect properly design the area. A contractor can use the soil survey in planning, grading, and implementing an erosion control program during construction. A horticulturist can use it in selecting suitable vegetation.

Soil surveys provide a basis for decisions about the kind and intensity of land management needed, including those operations that must be combined for satisfactory soil performance. For instance, soil survey information is useful in planning, designing, and implementing an irrigation system for a farm. The kind of soil and its associated characteristics help in determining the length of run, water application rate, soil amendment needs, leaching requirements, general drainage requirements, and field practices for maintaining optimum soil conditions for plant growth.

Soil surveys are also useful in helping to locate possible sources of sand, gravel, or topsoil. They are an important component of technology transfer from agricultural research fields and plots to other areas with similar soils. Knowledge about the use and management of soils has been spread by applying experience from one location to other areas with the same or similar soils and related conditions.

The hazards of nutritional deficiencies for plants, and even for animals, can be predicted from soil maps if the relationships of deficiencies to soils have been established. In recent years, important relationships have been worked out between many soils and their deficiencies of such elements as copper, boron, manganese, molybdenum, iron, cobalt, chromium, selenium, and zinc. The relationships between soils and deficiencies of phosphorus, potassium, nitrogen, magnesium, and sulfur are widely known. Relationships of soils to some toxic chemical elements have also been established. By no means have all of the important soils been characterized, especially for the trace elements. More research is needed.

2.2.3 Stages in Soil Survey

There are stages through which certain processes are put in place before a soil survey is accomplished. The stages as described by Faniran and Areola (1978) include;

(1) Reconnaissance or preliminary investigation

(2) Field survey

(3) Office and laboratory work

(4) Publication of soil map and soil reports. The soil report was categorized into three;

- (a) The soil map
- (b) The legend
- (c) The survey report.

The soil Report contents includes;

- (i) A general description of the environment
- (ii) An explanation of the system of soil classification and the soil mapping units.
- (iii) An account of field survey and mapping procedures
- (iv) A description of the distribution and special relationship of the major soil groups.
- (v) A detailed description of the morphological characteristics of the different soil classes.

(vi) Analytical data on soil properties

(vii) A brief note on the use of the resources e.g.

(a) Land use

(b) Soil erosion and

(c) Conservation

2.2.4 Methods of Soil Survey

Three methods of soil survey have been identified (Udensi 1983);

(a) Grid mapping

(b) Free survey;

(c) Physiographic mapping.

In general, soil survey techniques may be grouped into three; namely; the conventional techniques; remote sensing techniques and the combination of conventional and remotes sensing techniques

2.2.5 Modern Soil Survey

Soil survey work is generally tedious and expensive, requiring a lot of labour input depending, however, on the scale and intensity (Udensi, 1983). Attempting to offer solution to this, Iyalla (2004) recorded that the basic aim of introducing precision farming technique through the use of Geographic Information System (GIS), Remote Sensing (RS) and Global Positioning System (GPS), is to divert from the traditional composite system into computer-based and more accurate grid sampling techniques. He added that preliminary results have shown that grid soil sampling (intensity plot sampling using GPS) may be more advantageous than composite soil sampling. A significant part of the time spent in the production of a soil survey by the soil scientist involved in the project is not in an office but on-site.

There are new technological developments that may diminish the necessity for as much on-site work by individuals through predictive models using remote sensing derivatives (Dwain, 2003). As effective as these new tools may prove to be, he added, there will always need to be on-site work preformed during the course of a soil survey project, and considered to improve production. The two categories of this on-site work are field mapping and supporting documentation. Furthermore, he added that an additional function that mobile devices (GPS) provide is the capability to have digital reference material available in the field. CIESIN Thematic Guide (No Date) documented that Satellite Remote Sensing Technology and the science associated with evaluation of its data offer potentially valuable information for assisting human dimensions research material. He added that satellite remote sensing is an evolving technology with the potential for contributing to studies of the human dimension of global environmental change by making globally comprehensive evaluation of many human actions possible. To this, he pointed out that satellite image data enable direct observation of the land surface at repetitive intervals and therefore allow mapping of the extent-and monitoring of the changes in land cover. Dwain (2003) supported these facts and added that information such as soil descriptions and standards and methods frequently reviewed, which would require thick cumber-some three-ring binders, can be assessed digitally whenever needed on the mobile device (GPS)

2.2.5.1 Satellite

Nigeria launched her first earth observation satellite (Nigeria sat-1 on 27th September 2004). The 100kg micro-satellite with 32m spatial resolution, three spectral bands and revisit period of five days was built by survey satellite technology UK (GIM International).

Both Land and Sea satellite are available but only the land satellite is readily and mostly used. An ideal Land-sat is a butterfly-shaped system about 3m tall and 1.5m in diameter with solar panels extending to about 4m. Land-sat orbits pass within 9% the North and South Pole, circling the earth once each 103 minutes resulting in 14 orbits per day. The land sat keeps pace within sun's westward progress as the earth rotates (Lillesand and Kiefer., 1979). Udensi (1983) added that the satellite always crosses the equator at precisely the same local sun-time meaning that it is sun-synchronous. The satellite covers a very large area on a small number of prints, and coverage of 34,000 km on a single print of uniform quality.

2.2.5.2 Global Positioning System (GPS)

The official name for GPS by the USA Department of Defense is Navigation Satellite Timing and Ranging (NAVSTAR). It consists of a space segment (the satellite) and a control segment (the ground station), and a user segment (you and your GPS receiver). The earth orbiting satellites transmit very lower power radio signals allowing anyone with a GPS receiver to determine their location. This remarkable system was not cheap to build, costing the U.S.A billons of dollars. Ongoing maintenance, including the launch of replacement satellite, adds to the cost of the system. Fortunately, an executive decree in the 1980's made GPS available for civilian use also (GERMIN, 2000).

2.2.5.2.1 Importance of Global Positioning System (GPS)

The increasing use of Geographic Information System (GIS) and earth observation techniques in land resources analysis has highlighted the need for quantitative data on the spatial distribution pattern of soil characteristics (FAO, 1998). GPS also aids in the determination of physical, chemical, and biological characteristics of the soil at different locations. These data are plotted unto maps corresponding to each location for application of farm inputs such as fertilizer, pesticide and water within fields in ways that optimizes farm return and minimize chemical and environmental hazards (Iyalla, 2004). A very accurate topographic map can be made of the field of interest. Field boundaries, roads, yards, trees, stands, and wetlands can all be accurately mapped to aid in farm planning (Iyalla, 2004).

The GPS offers an incredible cost saving by drastically reducing setup time at the survey site. It also provides amazing accuracy down to one meter and to within a centimeter for high expensive systems. GPS is becoming increasingly popular among hikers, hunters, snowmobiles, mountain bikers, and cross country skiers just to mention a few. Clients want to know the reliability of soil survey products, several statistically techniques have been developed to deal with this problem (Rossiter, 2006).

2.2.5.2.2 Operation of Global Positioning System (GPS)

When a location is required, the GPS Unit displays the coordinates and stores the location for geo-referencing. The easiest coordinate system to use is the Universal Trace Marcator (UTM) coordinate system (Turenne, 1996). He added that conducting survey with GPS should be performed like any other survey with detailed notes of waypoints recorded so that the data can be checked for accuracy after it is downloaded. The GPS will provide the XY coordinates for the contour map. The Z value will represent the variable you are collecting the data such as elevation, depth to the interface etc.

During field scouting, the portable GPS enables the surveyor to identify and record the location of problems or events that affect production (Iyalla, 2004). Each location at which an observation is made can be captured as a point feature using the coordinates obtained from the GPS. Using the handheld data collector and software that came with the GPS receiver, surveyors record descriptive (or attribute) data as well as positions as they walk or drive an area of interest. These data are later downloaded to either the base's desktop computer or to a laptop, where the information is integrated into a GIS encompassing the entire fort (Kroeker, 1999)

2.2.5.2.3 Other Uses of Global Positioning System (GPS)

The GPS Technology as enumerated by GARMIN (2000) is rapidly changing how people find their way around the Earth. Whether it be for fun, saving lives, getting there faster, or whatever use you can dream up, GPS navigation is becoming more common every day. Basically; GPS allows you to record or create locations from the earth and help you navigate to and from those spots. It can be used everywhere except where it's impossible to receive signal such as inside building; in caves, parking garages, and other sub-terranean locations, and underwater. The GPS is typically used for navigation by recreational boaters and fishing enthusiasts. Scientists' community uses GPS for its precision timing capability and a myriad of other applications. Surveyors use GPS for an increasing portion of their work.

2.2.5.2.4 Efficiency of Global Positioning System (GPS) in Agriculture

During field spray, GPS based guidance system can allow operators to achieve greater efficiency under difficult condition. They can reduce overlap and missed applications of inputs, helping fatigued operators to maintain high field efficiency (Iyalla, 2004). The GPS aids in the identification of variability of nutrients levels within fields and provides appropriate fertilizer recommendation for increased yield and sustainable agriculture. This technology allows yield samples to be collected from accurately located position and then compared to soil test results. Using this technology, producers can pinpoint location of significant soil variability (Iyalla, 2004).

2.2.5.2.5 Use of Global Positioning System (GPS) in soil Survey

The use of GPS allows soil sample sites to be accurately located within a filed, and fertility level mapped (Iyalla, 2004). The GPS Unit can store several hundred points, or location, called "way points" such as ones house, airport, parked car, erosion channel, river canal, a great fishing/hunting spot or even some scenic spots you like to revisit are just a few examples of the location you could store. To connect between any two or more of this points, the GPS would draw a straight line to that point and guide you there with a pointer arrow, compass bearing (The directions to the point) desired course line, or a 3D “highway” representation. As one travels, the GPS Unit will automatically record the journey in a “track log” (GARMIN, 2000).

2.2.5.2.6 A Handy Cam

According to Kroeker (1999), this is a system that merges GPS, GIS, and video imagery to provide a visually oriented method for collecting and reviewing data, It consists of a battery powered "black box" measuring about 5 inches long, weighing about 11 ounces, and containing an internal eight-channel, L1, C/A-code GPS receiver, as well as proprietary software. The device's attached GPS antenna measures about 1.5-inches square and include a magnetic mount for rooftop use as well as a day pack with a shoulder strap for use on foot. As film is captured, the video runs through the GPS box where GPS data, including coordinates and time, are converted into a digital signal (in a manner similar to the workings of a fax machine) and then recorded onto one of the videotape's two audio tracks. The second audio track is used for voice narration. This enables the filmmaker to describe pertinent site information that might not show up well on the video such as depth and width of a gulley, water-flow direction, and composition of channel surface material.

CHAPTER THREE

MATERIALS AND METHODS.

3.1 PHYSICAL ENVIRONMENT OF THE AREA

3.1.1 Location of Study

The study area Ajali and Mamu formations in Nsukka zone of Enugu State Nigeria falls within latitudes $06^0 30'$ N and $7^0 10'$ N', and longitude 7^0 00' E and $8^0 15'$ E in the Derived Savanna zone of Enugu state. The formations are within eastern Nigeria, which extends from the Atlantic Coast at Latitude 04^0 $15'$ to the North of Nsukka and Ogoja on longitude 07^0E (Ofomata, 1975).

The area falls within the humid tropical climate according to the Koppen (1936) classification (Koppen's AW). There are two major seasons across the entire region; the rainy and dry seasons (Asadu, *et al.,* 2001). The rainy season lasts from April to October, and is characterized by high rainfall which decreases continuously from the south and the east toward the north. The variability in the mean annual rainfall is in the range of 1750mm in the north to 2000-3000mm in the south and eastern states (Akamigbo *et al.,* 1987). The distribution is bimodal with peaks in July and September. The dry season lasts from November to March. The temperature is generally high and rarely falls below 21^0C throughout the year. The mean annual minimum and maximum temperature are 22^0C and 23^0C. Relative humanity rarely falls below 60 percent throughout the year except during the desiccating period of the "Harmattan"-a short season (about three weeks) of hazy and very dry weather usually from December through January (Asadu, *et al.,* 2001). Another dry period experienced in the study area is called the "August break" which generally occurs in July and August (Akamigbo *et al.,* 1987). Asadu (1990b) recorded that the area has an Ustic soil moisture regime and an Isohyperthemic soil temperature.

3.1.2 Geology

Three major tectonic cycles could be found in southeastern Nigeria (Efiong-Fuller, Sourced on 4th August, 2008). The first major tectonic phase (Aptian early Santonian) directly followed, and was related to the initial rifting of the southern Nigeria continental margin and the opening of the Benue Trough (Figure 1). This phase produced two principal sets of faults, trending NE-SW and NW-SE. The NW-SE set defined the Calabar Flank. The second tectonic phase (Turonian Santonian) was characterized by compressional movements resulting in the folding of the Abakaliki Anticlinorium and the Complementary Afigbo

Synchline. The third phase (late Campanian-middle Eocene) involved rapid subsidence and uplift in alternation, with subsequent progradation of a delta (Efiong-Fuller, Sourced on 4th August, 2008)

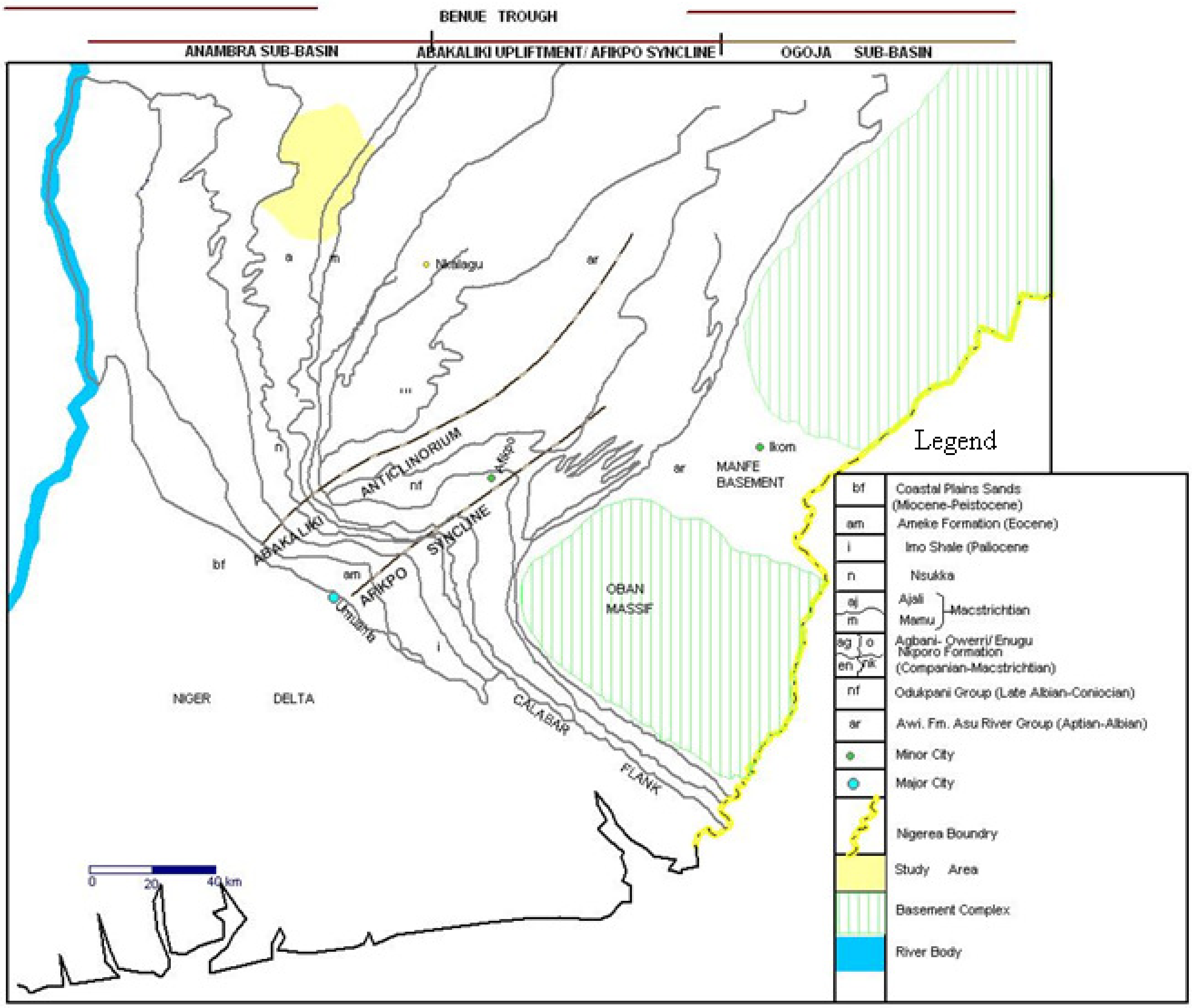

Fig. 1 Geological sketch of south-eastern Nigeria. (Sourced From Geological Map of Nigeria 1994 and Sketched By Ani U. A. 2010)

Table 4. Lithostratigraphic Units in South Eastern Nigeria

Geologic Age	Period (M.Y)	Geologic Formation	Lithologic Description
Pleistocene – Holocene	2.588-0.0	Alluvium and Quaternary Deposits	Unconsolidated Freshwater sands and gravels with silt and clay admixtures
		Beach Ridges	Fine grained greyish white sands
Oligocene – Pilocene	5.332-2.588	Coastal Plains sands	Coarse to medium grained unconsolidated sands, with gravels ferruginous sandstones and clays.
Oligocene Miocene	37.2-5.332	Ogwasi-Asaba Formation	Gritty clays and pebbly sandstones with lignite layer.
Eocene	55.8-37.2	Bende-Ameke Formation	Sandstone and shale sequence with bouldery and shelly limestone.
Paleocene	65.5-55.8	Imo Shale Group	Grey Calcareous shale and siltstones with bands of sandstone and ironstone
Maastrichtian	70.6-65.5	Nsukka Formation	Alternating sequence of shale and sandstones with coalseams (the Coal Measures).
		Ajali Sandstones **Mamu Formation**	
Campanian	83.5-70.6	Nkporo Formation	Dark grey shale and soft mudstones with occasional thin beds of sandstones and limestones
Coniacian	88.6-85.8	Awgu-Ndeaboh Shale Group	Shale with thin limestone bands and lenticular sand bodies
		New Netim Marl Formation	Thick Marl unit with intercallations of thin bands of dark shales
Turonian	93.6-88.6	Amaseri Sandstone Formation	Highly bioturbated fine to medium grained calcareous sandstones with fossiliferous shale at the base.
		Ezillo Formation	Dark grey shale with fine sandstone and siltstone Intercalations
		Eze-Aku Formation	Alternating Shale, siltstones and limestone with lateralfacies changes to sandstones
Cenomanian	93.6-88.6	Ekenkpon Shale Formation	Thick black highly fissile shale with intercalations of marlscalcareous mudstones and shell beds.
Albian	112.0-93.6	Asu River Group	Poorly bedded sandy shale with fine to medium grained sandstones lenses.
		Mamfe Formation	Cross bedded coarse to medium grained immature Sandstones with basal conglomerates and arkoses.
		Mfamosing Formation	Massive bedded, grey chalky limestone with fossils
Aptian-Neocomian	125.0-112.0	Awi Sandstone Formation	Fluvio-deltaic clastics consisting of grits, sand stones, mudstones and shale.

M.Y = Million years. Source; Efiong- Fuller**:** on 4th August 2008
http://www.ces.iisc.ernet.in/energy/HC270799/LM/susLUPTheemaz/592/592.pdf

3.1.3 Soils

The soils of the study area are mainly of sedimentary origin with sand stone and shales as the two dominant parent rocks (Figure 2) (Asadu 1996). According to Jungerius (1964) the soils of eastern Nigeria are divided into five classes. These are; Lithosols (Orthent), Young soils derived from recently deposited materials (Fluvent), Ferruginous tropical soils (Alfisol), Hydromorphic soils and (Tropaquept), Ferralitic soils. (Ultisols)

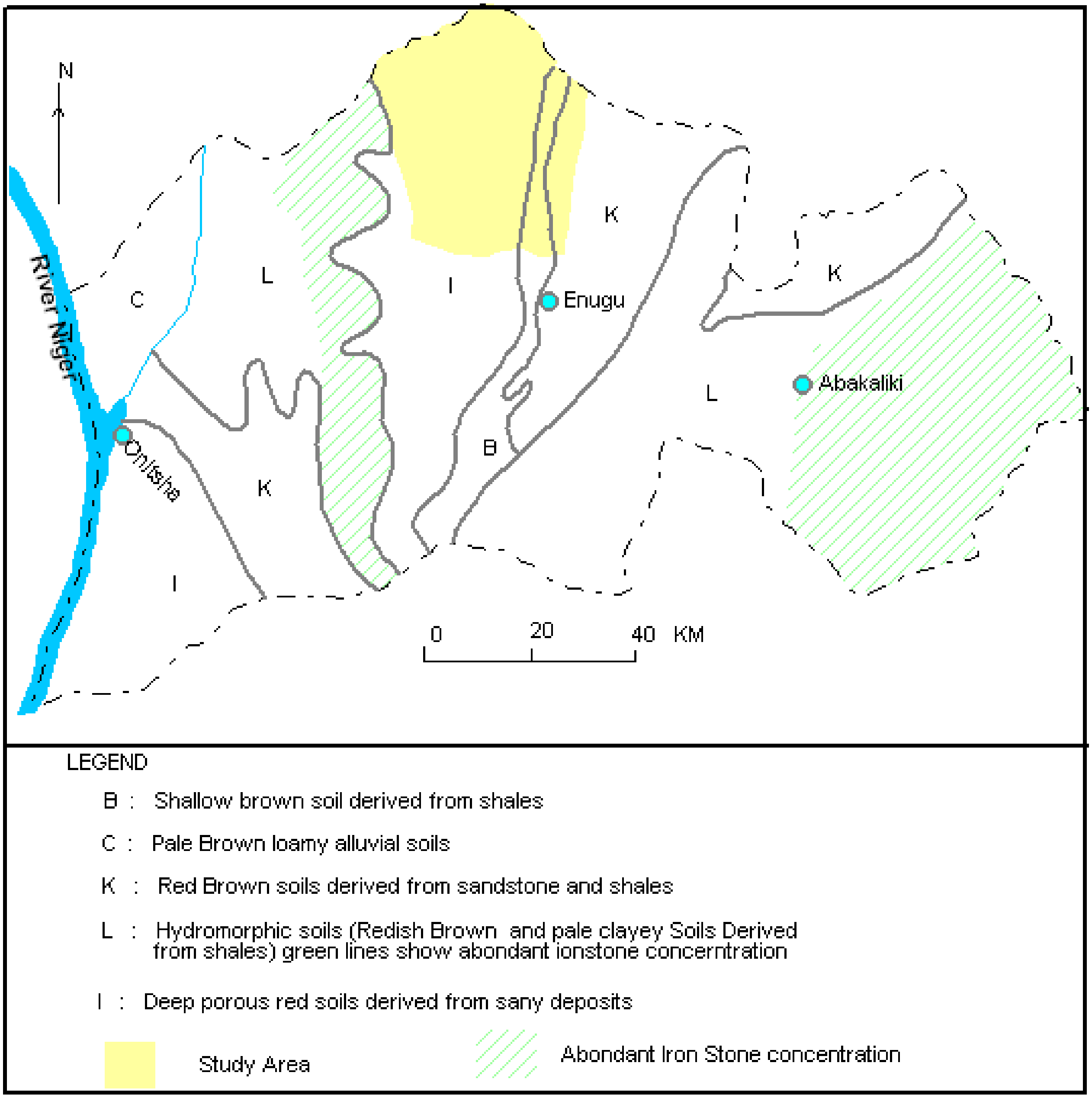

Fig.2: Soil Associations found in Anambra, Enugu and Ebonyi States.
(Source: P. D. Jungerius (1964))

3.1.4 Land Form

Ofomata (1974) recorded that Nsukka area falls into four landform divisions

(a) Western lowland.

(b) A plateau

(c) An escarpment and

(d) An eastern lowland

Akamigbo *et al.* (1994) reported that the plateau landform (Nsukka area) is characterized by residual hills separated by generally wide and flat-bottomed dry valleys. The western lowland forms the Northern section of Anambra plains of the Niger landforms; it is a gentle rolling plain which slopes gradually westwards to the Niger River. Udi-Nsukka plateau falls gently towards the lowlands along the Niger Rivers. In Nsukka area, the plateau is about 48km wide and slopes from 459m to 249m along the escarpment to about 214m to the west and finally merges with the low land areas of the Anambra plains (Ofomata, 1975).

3.1.5 Vegetation.

The study area falls within the humid tropical rainforest characteristically green and is complemented in the Nsukka area by tropical grassy vegetation. In their contribution, Akamigbo *et al,* (1987) listed the following as the dorminant plant species; spear grass (*Impretata cylindrica*), Northern Gamba grass (*Andropogan gayanus*), Southern Gamba grass (*A. tectorum*), Siam weed (*Chlotolataria odorata* Formarly *Eupatorium odoratum*), Elephant grass (*Penisetum pupureum*), Guinea grass (*Panicum maximum*), Cashew (*Anacadium occidentales*), Oil palm (*Elaeis guinensis*) and Oil bean tree (*Pentaclathra macrophylla*). Asadu (1982) had earlier found *Irvengia* spp, and *Calapogium mucunoides* in some part of the area as dominant species

3.1.6 Agricultural Land Uses

Terrace farming is important on the hill slopes of Nsukka, Lejja, Udi and Mmaku. Floodplain agriculture is practiced in parts of the Niger/Anambra plains especially at Adani and Omor. It is based on comparatively large-scale cultivation of rice and yam, and also, fish farming. A number of agricultural enterprises have been established to tap the agricultural potentialities. They include the Adarice Production (Nigeria) Ltd. and the Enugu

State River Basin Development Project (ESRDP) which are public production projects located at Adani in Uzo Uwani Local government Area. Others are the United Palm Produce Ltd. at Ibite Olo, Ugwuoba and lnyi, and the Premier Cashew Industry Ltd at Oghe (Online Nigeria Portal, 2007). The hydromorphic nature of some soils in the area tends to be the important determining factor in the pattern of agriculture in the area concerned. The major crops grown in the area include; Rice (*Oryza sativa*), Maize (*Zea mays*), Yam (*Diascorea* spp), Cassava (*Manihort* spp), Cowpea (*Vigna unguiculata*), Bambara groundnuts (*Voadzeia subterranea*), Groundnuts (*Arachis hypogeae*), Banana (*Musa sepientium*), plantain (*Musa paradisiaca*), Oranges (*Citrus* spp), Oil beans (*Pentaclethra macrophylla*), Oil palm (*Elaeis guineansis*), Coconuts (*Cucus nucifera*).

3.2 Methodology

The study involved four stages;

i) Base map creation using the Global Positioning System (GPS) and Aerial photograph.
ii) Field investigation, erosion data collection and soil sampling.
iii) Erosion map creation using GPS TrackMaker (software)
iv) Laboratory analysis.

3.2.1 Base map creation

The GPS contributes a lot to soil resource survey guide. As against grid technique of soil survey which Asadu (1990a) regarded as a major factor discouraging the involvement of many soil scientist in the crusade against soil erosion. The GPS played the following role in the soil survey. Firstly, when an aerial photo and a Map creating Software (GPS Track Maker) are synchronized, a base map for proper field investigation would be created. The aerial photo will help to map known features (crossing, house, road, erosion market). Secondly the created base map would be uploaded into the GPS handset which would display any uploaded point at the point of reaching there. With this, field delineation can then be easy to handle and areas of interest such as sample points marked and delineated. With the help of the Geographic Information System (GIS) (GPS Track Maker) the Aerial Photograph updated to 31st December, 2008 covering the study area was downloaded from Google map using the GPS Track Maker, saved and used to create a digital base map. Information such as Environmental hazards, Road networks, Rivers, Gullies, Forest areas, Lakes, etc. were made clear by the Aerial Photograph. These were considered in the base map creation in addition to access roads. The base map was later uploaded into the Global Positioning System (GPS) Hand set, and used for field scouting.

With the help of the aerial photo, all the large gullies were traced, sketched and identified. The nearest road to each was also identified, and remarked for easy field identification.

3.2.2 Field Investigation

This was aided by the help of the carter (150) motorcycle, Digital camera, GPS etc. The use of the GPS saves tremendous time and provided maps that were geo-refereed in real world coordinates. The GPS Hand set tracks the route during field scouting and on reaching an erosion site; it shows it on the screen. GARMIN (2000) documented that the GPS unit can store several hundred points, or locations, called 'way points'. They maintained that to connect between any two or more of such points; the GPS would draw a straight line to those points and guide you there with a pointer arrow, compass bearing (the direction to the point), desired course line or a 3D "high way" representation. As you travel, your GPS unit will automatically record your journey in a "track log" (GARMIN, 2000). Your current location can be viewed in the GPS in the form of coordinates- latitude and longitude (GARMIN, 2000). The unit allows soil sample sites to be accurately located within a field and mapped (Iyalla, 2004).

For small erosion sites, the town union of each town helped to show any erosion sites in their town. The work by Akamigbo *et al.,* (1987) (tables 5, 6, 7, and 8.) gave details of erosion sites in all the local governments in the then Anambra state was also very helpful. The already known erosion sites were identified along side with others. At each point data on the erosion features as length, altitude, Geo-reference and slope were collected and documented by the GPS. Manual data on erosional depth and width were also recorded in the field note book. Data on erosion depth and width were collected using rope. Also the GPS was used for large gullies too large to get using rope.

Considering the variation in depth and width along the length, data on both parameters were collected at three points in each erosion site; the beginning (x_1), the center (x_2) and the end (x_3) and an average X calculated using the formula bellow.

$X = \frac{x_1 + x_2 + x_3}{3}$. The values of X for depth, and width were calculated and documented. The GPS was used to track the length of the erosion which later was measured using the GIS (GPS TrackMaker). Three Profile pits were made by side clearing of the gully wall using hand trowel in each geological formation. Soil samples were collected at horizons O, AB, Bt_1 and Bt_2. At intervals, auger samples totaling five were also collected from each geological formation. A total of thirty four (34) soil samples were collected and processed for laboratory analyses.

Table 5: Towns and gully status in former Isi-Uzo Local Government Area

L.G.A	TOWN	LOCATION	STATUS OF GULLY
ISI-UZO	Ogbodu Aba	Umuosigide Road, along the River Bank	Active/Advanced
	Ogbodu Aba	Okum	Active
	Amalla	Ogurute farm land	Active
	Ikem	Um Azutu Road, near Ogo Community Secondary School, Ikem	Active
	Obollo Etiti	Umuosigide along Express Road	Active
	Ezimo	Igbonemegini	Active/Advanced
	Ezimo Etiti	Amaogu (Iyi-Uzu)	Active/Advanced
	Neke	Ugwu Okwu na nne near the road leading to Neke Secondary School.	Active/Advanced
	Amalla	Umuamachi Farm land, bhind Ikem/Otukpe Road.	Active
	Orba		Active
	Orba	Ugwuokanya (along Nsukka Orba Road)	Active
	Imilike	Imilike Etiti	Active
	Obollo Afor	Ugwu Egbe Towards the road	Active/Advanced
	Orba	Agu Orba Road.	Active/Advanced
	Orba	Ngboroko (Iyi Ocha)	Advanced
	Total		**15**

Source; Akamigbo *et al*., 1987

Table 6: Towns and gully status in former Igbo Eze Local Government Area

L.G.A	TOWN	LOCATION	STATUS OF GULLY
IGBO EZE	Enugu Ezike	Amufia/Amachara Rd., near Igbele Primary School.	Active
	Enugu Ezike	Near Igogoro Boys Secondary School	Active
	Enugu Ezike	Opposite Co-operative And Commerce Bank,	Active
	Enugu Ezike	Opposite Community Primary School. Olido.	Active
	Enugu Ezike	Umuadokpa/Umuida/Unadu Road	Incipient
	Unadu	Unadu/Afor Agu Road, near Aho Unadu.	Dormant
	Ibagwa	Ebrumiri/Nkalagu Rd., near Ibagwa Aka.	Incipient
	Ibagwa	Ibagwa Aka/Itchi Rd.	Advanced
	Iheaka	Akoyi/Ovoko Rd.	Incipient
	Iheaka	Likee/Akoyi Rd.	Active
	Iheakpu Aroka	Community Secondary School, Iheakpu-MCC Road.	Active
	Nkalagu Obukpa	With Nkalagu hill near Community Primary School	Dormant
	Ovoko	Ovoko/ Obollo Road near Boys Secondary School, Ovoko	Active
	Ovoko	Near Unadi Hill	Dormant
	Uhunowere	Olido-Uhunowere Road	Incipient
	Total		**15**

Source; Akamigbo *et al*., 1987

Table 7: Towns and gully status in former Igbo-Etiti Local Government Area

L.G.A	TOWN	LOCATION	STATUS OF GULLY
IGBO-ETITI	Aku	Ahokwe Aku	Acti/Advanced
	Aku	Elueke Aku	Active/ Advanced
	Aku	Aku Maternity (Amuwani Obie)	Advanced
	Aku	Ogboze Farm Settlement	Active
	Umunko	Agu Ogwa Akanalo and Agukparuzoru	Active
	Ekwegbe	Agu Ekwegbe	Advanced
	Ekwegbe	Agu Ekwegbe	Active
	Ohodo	Ndiagu Amojo	Active
	Ukehe	Amadim/Uhehe Agu Road	Active
	Onyohor	Agu Umunko Amoji	Active
	Ozalla	Enua'to	Active
	Total		**11**

Source; Akamigbo *et al.*, 1987

Table 8: Towns and gully status in former Nsukka Local government Area

L.G.A	TOWN	LOCATION	STATUS OF GULLY
NSUKKA	Lejja	Agu-Oku Main road.	Active
	-do-	Agu Aku/Umoda	-do-
	-do-	Agu Oweri Ani	-do-
	Obukpa	Elu-agu Obukpa	-do-
	Obimo	Along Ikwoka-Amegu Road	-do-
	Opi	Ugwuogo/Abakpa Nike Road	-do-
	Ede Oballa	Nsukka/Enug Road	-do-
	Eha-Alumona	Along Obreme Road.	-do-
	Nsukka	University of Nigeria, Nsukka main gate through university of Nigeria, Nsukka Secondary School to Onuiyi.	Active and Severe.
	Total		**9**

Source; Akamigbo *et al.,* 1987

3.2.3 Erosion Map Creation.

There are several ways to download the GPS data to your personal computer. There are many software programmes available that will download GPS waypoint data directly into a GIS programmes. For example if you are using a PLAGS GPS, there is an Arcview script (Plgr2shp.avx.) If you are using a Garmin GPS, download the GPS TrackMaker (http://www.brothersoft.com/gps-trackmaker-download-66568.html). The Gully erosion information gathered from the field was merged with the aerial photos to identify and sketch erosion channels on the map. To make the sites more conspicuous, green colour on bold lines was used to mark erosion channels (Figs. 3, 5, 9, 10, 11, 16). A composite map containing the entire field data collected was provided on page 149.

3.3 Laboratory Analysis.

The thirty four (34) soil samples were air dried, gently crushed and sieved using the 4mm and 2mm sieves for physical and chemical analysis as follows; Particle size Analyses was done using Bouyoucos (1965) hydrometer method. Sodium Hydroxide (NaOH) was used in place of Sodium Hexametaphosphate $(NaPO_3)_6$ as dispersing agent. The USDA textural triangle was used to determine the textural class. Water Stable Aggregate (WSA) of the samples were determined using the Set of sieves 4mm, 2mm, 1mm, 0.5mm and 0. 25mm in diameter as described by Kemper and Rosenau (1986). Organic carbon was determined using Walkley and Black method as modified by Allison (1965). The percentage organic mater was calculated by multipling the figures for organic carbon by the conventional "Van Bernmelen factor" of 1.724. Total nitrogen was determined by micro Kjeldahl distillation method of Jackson (1962). The available phosphorus was determined using Bray II method after Bray and Kurtz (1945). The complexometric Titration method of Jackson (1962) was used to determined calcium and magnesium. Sodium and Potassium were determined from 1N (NH4OAAc) ammonium acetic using the flame photometer. Exchangeable Acidity was determined by the titrimetric method of Mclean (1965) using 1N KCl extract. Effective cation exchange capacity (ECEC) was obtained by adding the values of the Exchangeable acidity (Al^{3+} and H^+) and Base saturation. The percentage base saturation was calculated by using the formula bellow

$$\%B.\ S = \frac{\text{Exchangeable Base (E.B)}}{\text{Effective Cat ion Exchange Capacity (ECEC)}} \times \frac{100\%}{1}$$

Where %B.S = percentage base saturation

3.4 Data Analysis

The values of the depth length and width of the various gullies were tested using t-test to compare the two locations (Ajali and Mamu Geological formations). The chemical analysis values; Organic Carbon (OC), Phosphorus (P), Nitrogen (N), Magnecium (Mg^{2+}) Calcium (Ca^{2+}), Sodium (Na^{+}), Potacium (K^{+}) and Hydrogen (H^{+}) were also compared using t-test using the Statistical Package for Social Sciences (SPSS) programme.

CHAPTER FOUR

RESULTS

The results of this work were presented in two stages. The first stage dealt with the result of erosion data collection, data analysis and map creation. The second stage dealt with the result of the laboratory analyses.

4.2 Erosion Data.

A total of seventy (70) erosion sites were visited in the Ajali Formation while only nine sites were identified on the Mamu Formation. Among these, 43 new erosion sites (Table 9) and 27 old erosion sites (Table 10) were identified in the Ajali Formation. On the other hand, five new ones (Table 11) and four old one (Table 12) were visited at the Mamu Formation.

The Erosion sites visited varied in length, depth and width. Most of the erosion sites were found at the sloppy areas of Ajali Formation especially at the Ajali Formation **aspect** (between Ajali and Mamu formations). Gully erosion inception over the years in the study area is quite alarming considering the rate since 1987 when Akamigbo *et al,.* (1987) recorded 31 gullies within the study area (27 in Ajali and four in Mamu formations), but the study identified 48 new gullies (43 in Ajali and five in Mamu). The erosion advancement rate was 61% in Ajali and 51% in Mamu within the space of 22years (1987 to 2008).

Table 9: New erosion sites in the Ajali Formation within Nsukka Area of Enugu State.

S/NO	Erosion	Location / town	L.G.A	Length	Width	Depth	Remarks
1	AE 5	Ogurute/Umuida road	Igbo-Eze Nouth	489	0.8	1.0	New
2	AE 6	Umuogba, Ichi	Igbo-Eze Nouth	1141	1.2	0.8	New
3	AE 8	Ibakwa-Aka	Igbo-Eze South	205	1.4	2.5	New
4	AE 11	Ugwu Anyasuru, Amalla	Udenu	688	1.6	1	New
5	AE 16	Obukpa/Okpanigbo road	Nsukka	258	8	3.3	New
6	AE 17	Ugwu Egbe road, Obollo-Afor	Udenu	3449	9.2	3	New
7	AE20	Ibagwa Ezimo	Udenu	293	6.8	0.6	New
8	AE21	Ezimo/Obollo road	Udenu	1216	8.3	2.1	New
9	AE22	Ugwu Utobo,Ezimo	Udenu	148	8.3	2.1	New
10	AE26	Ugwu Eya Orba 2	Udenu	1082	20.5	11.1	New
11	AE27	Imilike-Etiti, end in Iyi Awo	Udenu	4505	120	34	New
12	AE28	Agu-Amayi Orba 2	Udenu	518	6	4.1	New
13	AE29	Ugwu-Amayi Orba	Udenu	2558	9.5	2.1	New
14	AE31	Nkalagu-Orba	Udenu	1030	4.7	2.4	New
15	AE32	Agu Amayi Orba 1	Udenu	246	3.3	3.4	New
16	AE33	Ugwu Eke-Eha, Ehalumona	Nsukka	89	41	4.5	New
17	AE34	Akwari 1, end in Iyi Ayo, Ehandiagu road	Nsukka	908	23	9.5	New
18	AE35	Akwari 2, end in Iyi Ayo, Ehandiagu road	Nsukka	797	23	9.5	New
19	AE36	Akwari along Ehandiagu road	Nsukka	1016	1.3	1.6	New
20	AE38	Umabor, Near Ehalumona/Ehandiagu road 2	Nsukka	1159	5.5	2.7	New
21	AE39	Umabor beside the road	Nsukka	1138	7	8	New
22	AE41	Amaegbu, Ede-Oballa	Nsukka	1785	4	4.3	New
23	AE43	Uruani Amube, lejja	Nsukka	478	3	3.1	New

AE = Ajali Erosion site, L.G.A = Local Government Area

Table 9: Continued

24	AE45	Ogbozalla Opi 1	Nsukka	2266	4.5	3.8	New
25	AE46	Ogbozallo Opi 2	Nsukka	2469	4.5	3.8	New
26	AE47	Opi/Neke road 2	Nsukka	1009	4.4	1.5	New
27	AE48	Opi-Agu road	Nsukka	2455	13.5	11.1	New
28	AE49	Onu-Eme	Nsukka	317	8.7	7	New
29	AE50	Umabor	Nsukka	2614	3.5	3	New
30	AE51	Agu-Umogbuji, Lejja	Nsukka	1794	6.1	5.2	New
31	AE52	Ngboko, Aku	Igbo-Etiti	185	5.2	7.6	New
32	AE53	Ohemje, Aku	Igbo-Etiti	54	1.8	3.9	New
33	AE56	Ogboze, Aku 3	Igbo-Etiti	929	1.8	3.8	New
34	AE58	Agu Ekwegbe road 1	Igbo-Etiti	113	7.3	3.5	New
35	AE59	Agu Ekwegbe road 2	Igbo-Etiti	709	1.6	2	New
36	AE60	Ohebe-Hill, Ohebe-dim	Igbo-Etiti	344	4.9	4.1	New
37	AE61	Uwelle-Amakofia, Ukehe, along Enugu road	Igbo-Etiti	211	5	4.3	New
38	AE62	Umuofiagu, Ukehe	Igbo-Etiti	1194	4.5	3.5	New
39	AE64	Amanefi, Ukehe	Igbo-Etiti	6121	53	20	New
40	AE66	Amanefi, Agu-Ukehe road	Igbo-Etiti	384	7	5.1	New
41	AE68	Ugwu Umuoka	Udi	479	3.1	1.7	New
42	AE70	Ezimo Agu	Nsukka	3069	54	22	New
43	AE71	Agu-Opi	Nsukka	4996	122	55	New
	Total						**43**

AE = Ajali Erosion site, L.G.A = Local Government Area

Table 10: Old erosion sites in the Ajali Formation within Nsukka Area of Enugu State.

S/NO	Erosion	Location / town	Length	L.G.A	Width	Depth	Remarks
1	AE 1	Agu-Afor,Unadu	461	Igbo-Eze South	0.7	1.2	Old
2	AE 2	Umuida/Unadu road	509	Igbo-Eze South	0.9	1	Old
3	AE 3	Ogurute, Opposite Cooperative Bank	408	Igbo-Eze North	0.8	1	Old
4	AE 4	Itchi/Ibagwa road	519	Igbo-Eze South	0.9	1.3	Old
5	AE 7	Eburummiri, Ibagwa Aka	2569	Igbo-Eze South	1.4	2.1	Old
6	AE 9	Olido, Near Health Center	513	Igbo-Eze North	0.6	1	Old
7	AE 10	Olido, Near Primary School	1095	Igbo-Eze North	1	1	Old
8	AE 14	Iheakpu-Awka Near Secondary School	1303	Igbo-Eze South	2.3	3.6	Old
9	AE 15	Elu-Agu, Oburkpa	363	Nsukka	2.9	3.3	Old
10	AE 18	Umuosigidi, Obollo-Etiti	221	Udenu	2	1.3	Old
11	AE 19	Iyi Nzu, Ibagwa, Ezimo	8381	Udenu	56	23.8	Old
12	AE23	Iyi Ocha, Ezimo	891	Udenu	52	8.9	Old
13	AE24	Imilike-Etiti end in Iyi Awo	3725	Udenu	110	19.4	Old
14	AE25	Nkporoko Iyi Ocha, Ezimo	4156	Udenu	158	37.2	Old
15	AE30	UNN, end at Erouno	3355	Nsukka	6	5	Old
16	AE37	Umabor near Ehalumona/Ehandiagu road	792	Nsukka	5.5	2.7	Old
17	AE40	Ede-Oballa, Nsukka/Enugu road	315	Nsukka	7.1	8	Old
18	AE42	Umuoda lejja	52	Nsukka	1.5	1	Old
19	AE44	Opi-Neke road 1	1840	Nsukka	21.4	4	Old
20	AE54	Ogboze, Aku 1	289	Igbo-Etiti	1.3	0.9	Old
21	AE55	Ogboze, Aku 2	1054	Igbo-Etiti	5.2	7.6	Old
22	AE57	Agu-Ekwegebe bad land 1	1439	Igbo-Etiti	121	55	Old
23	AE63	Agu Umunko road	215	Igbo-Etiti	7.5	3.5	Old
24	AE65	Amadim, Bad Land, Agu-Ukehe road	16833	Igbo-Etiti	1484	53	Old
25	AE67	Amorji, Ovnyohor	249	Igbo-Etiti	4.5	3.8	Old
26	AE69	Iheaka/Akoyi road	1189	Igbo-Eze South	1.8	1.4	Old
27	AE72	Agu-Ekwegbe Bad Band 2	2809	Igbo-Etiti	1806	60	Old
	Total						**27**

AE = Ajali Erosion site, L.G.A = Local Government Area

Table 11: new erosion sites on Mamu Formation within Nsukka Area of Enugu State.

	Erosion	Location / Town	L.G.A	Length	Width	Depth	Remarks
1	ME 2	Akwari, Eha- Ndiagu road	Nsukka	763	9.5	5.0	New
2	ME 4	Agu-Ekwegbe, beside the road1	Igbo-Etiti	330	7.3	3.5	New
3	ME 6	Agu-Ekwegbe, beside the road 3	Igbo-Etiti	975	7.5	3.5	New
4	ME 8	Agu-Ukehe, Beside the road 1	Igbo-Etiti	322	5.0	3.8	New
5	ME 9	Agu-Ukehe, Beside the road 2	Igbo-Etiti	466	2.4	2.4	New

ME = Mamu Erosion site, L.G.A = Local Government Area

Table 12: Old Erosion Sites on Mamu Formation within Nsukka Area of Enugu State.

	Erosion	Location / Town	L.G.A	Length	Width	Depth	Remarks
1	ME 1	Igboneme-Agu Orba	Udenu	299	9.5	5.0	Old
2	ME 5	Agu-Ekwegbe, beside the road 2	Igbo-Etiti	858	7.3	3.5	Old
3	ME 7	Agu-Umunko Beside the road	Igbo-Etiti	277	7.5	3.5	Old
4	ME 10	Amanefi/Agu-Ukehe road	Igbo-Etiti	68	2.7	2.8	Old

ME = Mamu Erosion site, L.G.A = Local Government Area

4.3 Erosion Features and Mapping

The soil gully erosions identified in the field were mapped as can be seen in the composite map (Figure 4)

4.2.1 Agu-Ukehe

Dangerous gully erosion sites were identified at Ukehe, (Figure 5) which made a way into the land forming a bad undulated land form. Year after year, the erosion keep encroaching the land of Ukehe from Amadim side at the eastern side of Ukehe. This erosion area advances through land slide as revealed in figure 5. At the time of visitation, the tree in figure 5 was uprooted and carried by the run off.

Clear information of the impact of the erosion was in figure 6 (area photograph) and figure 7 (area map). The effect of the erosion has led to a vast area of land left for no use except for the Hausa/Fulani cattle herdsmen who were met with their cattle in a make-shift settlement during the field visit.


Figure 5 Erosion site at Agu-Ukehe road, Amadim (Photo by Ani U. A. Nov. 2008)

Figure 6 Area photo of Ukehe showing the gully starting point at Amadim (Goggle Map Dec. 2008)

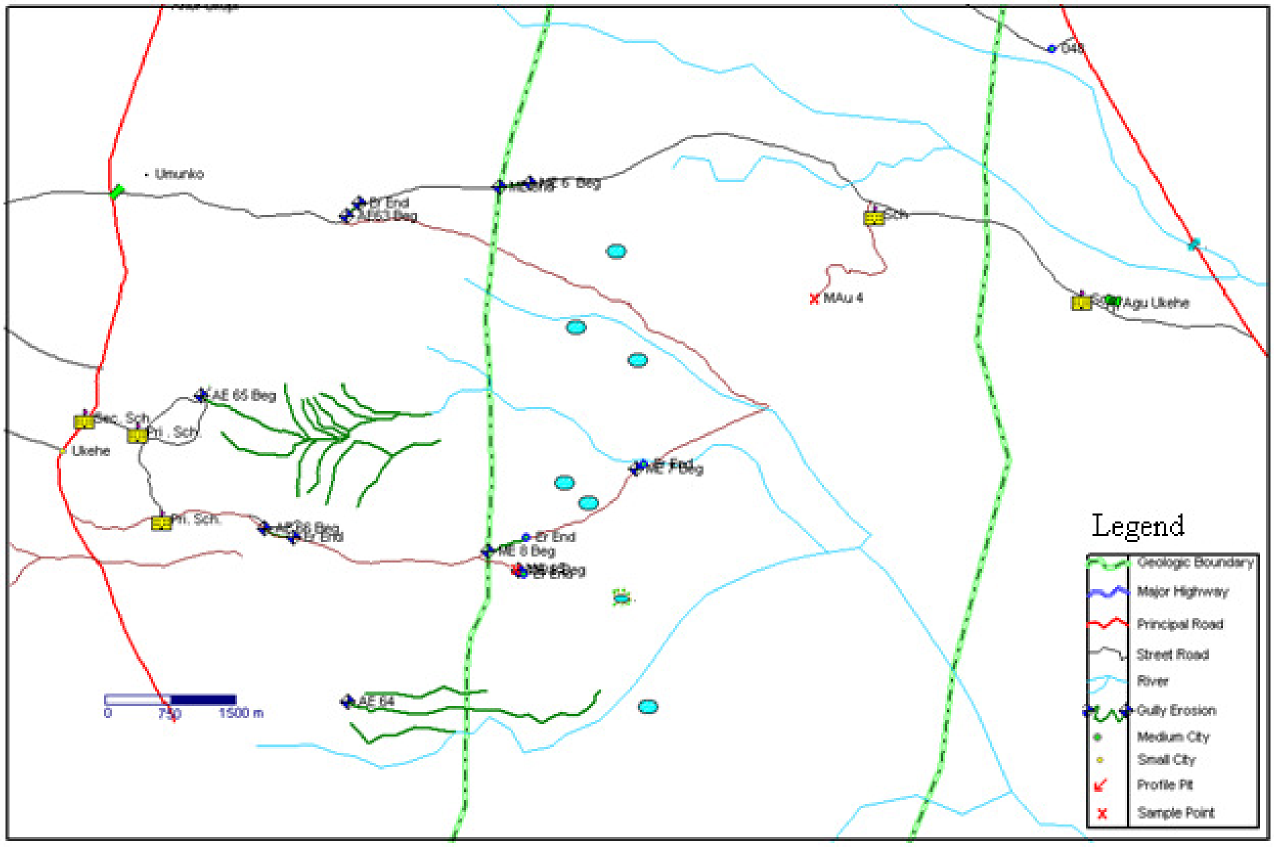

Figure 7 Map of some parts of Ukehe showing the gullies at Agu-Ukehe. (Ani U. A., 2010)

4.2.2 Agu-Ekwegbe.

The area was also as bad as Ukehe along the same aspect of the Udi-Nsukka table land. The severity of the erosion was high that transportation was severely hindered. The area even though has thick forests but like Ukehe area was badly affected by run off. Figure 8 is an aerial photo revealing the nature of this erosion and the position on map was in figure 9. Despite the erosional impact, there are still some residential homes near the sites. This evidence reveals that there is serous land demand, while erosion is advancing to the available few.

The Gully erosion intensity can be visualized looking at figure 10. This was snapped at the time the area was visited. The depth, width and length of this gully were so terrifying that one feels dizzy while standing near it. Despite the presence of much trees and shrubs, the land slide which was due to run off would carry every thing as it flows. Excessive overgrazing by the cattle belonging to the Housa/Fulani remove the surface grasses and expose the sloppy land to agents of degradation thus creating more channels for run off.

Figure 8 Area photo Agu-Ekwegbe showing the gully areas (Goggle Map Dec. 2008)

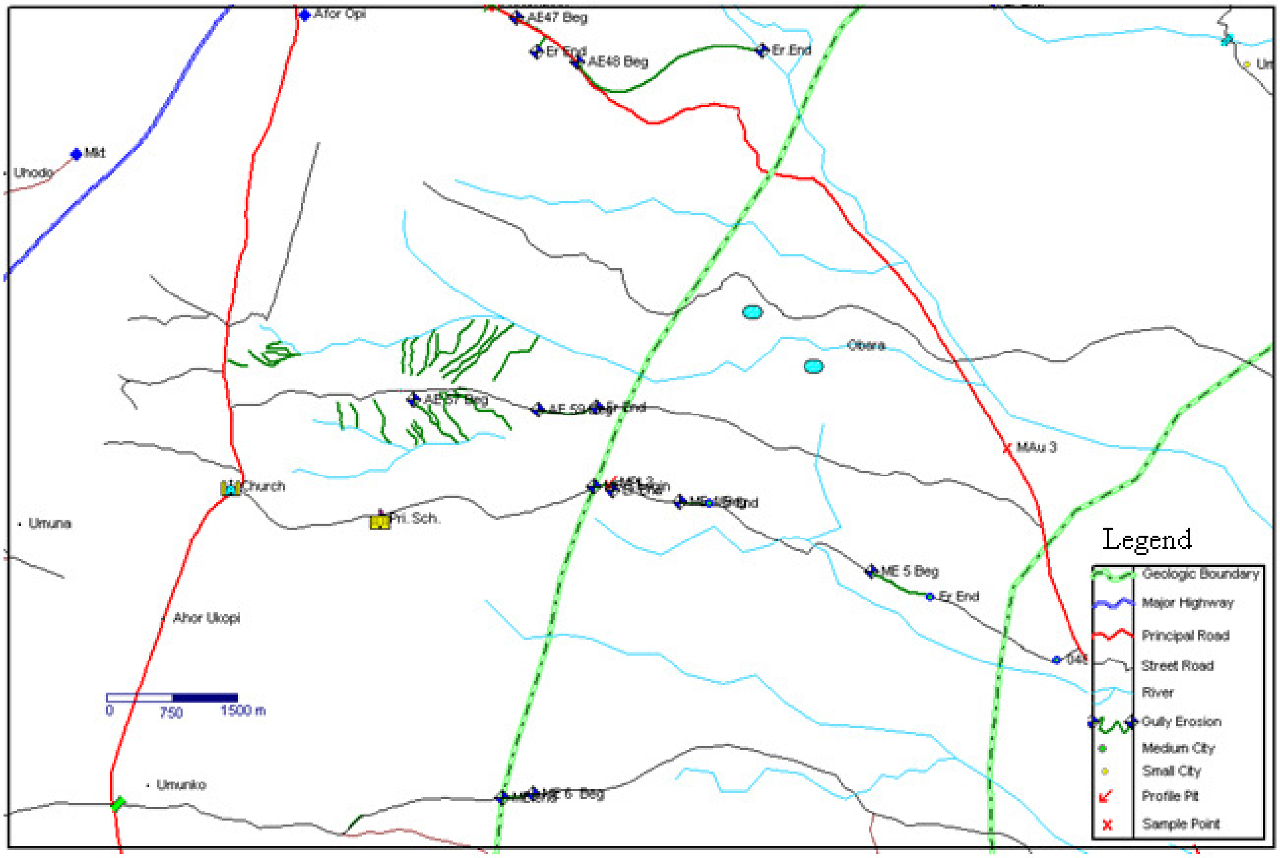

Figure 9 Map of Agu-Ekwegbe showing the gully areas (Ani U. A., 2010)


Figure 10 Agu Ekwegbe gully site (Photo by Ani U. A. Jan. 2009)

4.2.3 Agu Opi

Starting from the Opi–Ugwogo Nike Road, the story was a different thing. The tarred road was grossly devastated by erosion despite the control measures (Figure 11). The prevalence was to the point of road cut. One may find it difficult to believe that the gully in figure 12 was formally a tarred road before erosion invaded. Instead of looking for a lasting solution, the sand harvesters who use their heavy trucks on the road only diverted and created another route for their selfish illegal business. These sand harvesters even though are worsening the road situation created similar problem at Ogbozala Opi and Agu Opi respectively. Each road after being abandoned would turn into a dangerous gully (Figure 12) while they (the sand Harvesters) would create another route. The area map reveals that this erosion ended with a river head (Figure 13) EA 47 and EA 48. At Ogbozalla Opi, the vast excavation there has created much erosion above imagination.


Figure 11 Gully at Opi Agu - Enugu Road (Photo by Ani U. A. Jan. 2009).

Figure 12 Opi Agu - Enugu Road gully site (Photo by Ani U. A. Jan. 2009)

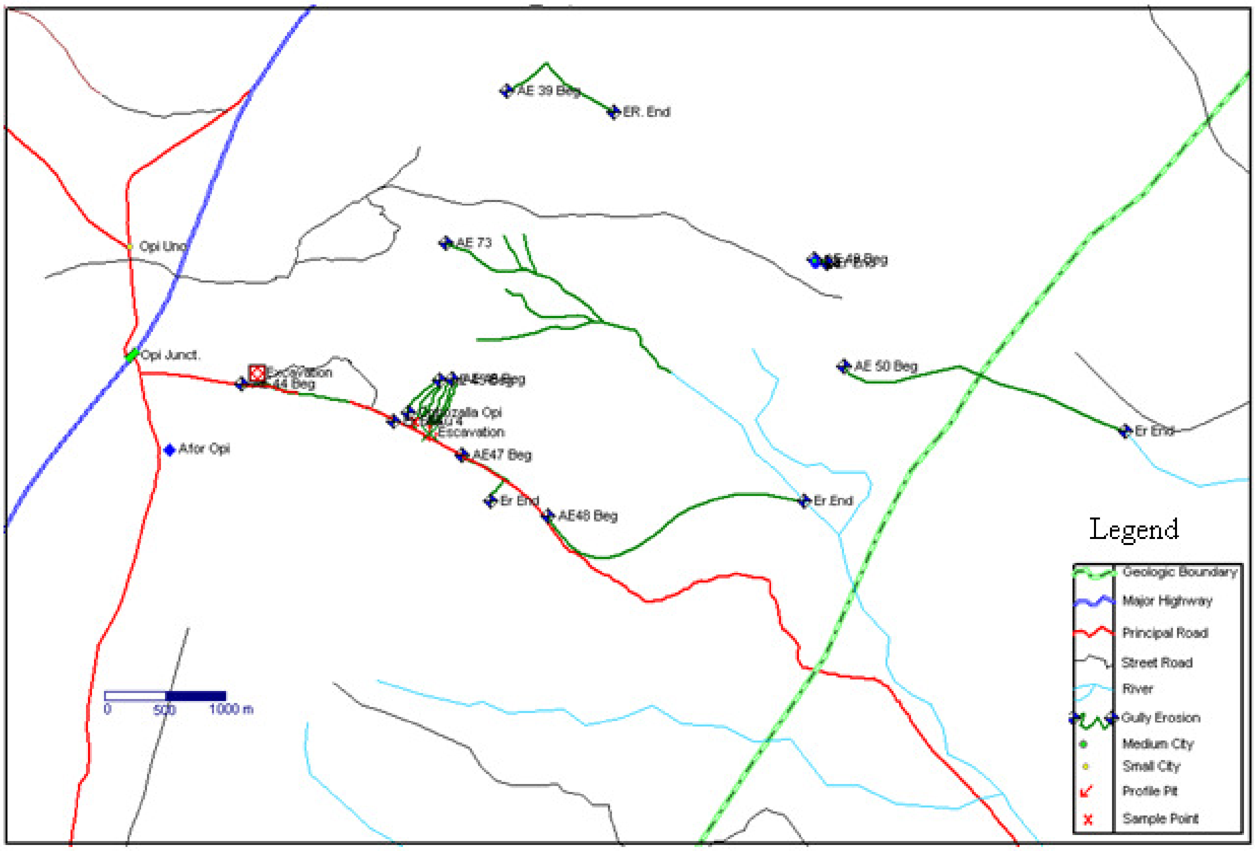

Figure 13 Map of Opi Agu showing the erosion sites (Ani U. A., 2010)

4.2.4 Orba.

The case was the same in terms of land slide due to run off, excavation and heavy gullies. The Orba area recorded heavy erosion sites due to water movement at the inter phase between Ajali and Mamu formations. Heavy gullies especially at Agu Amayi Orba were identified. Each gully looks so significant that each ends with a river canal. Other gullies are AE 24 and AE 25 (Figure 14)

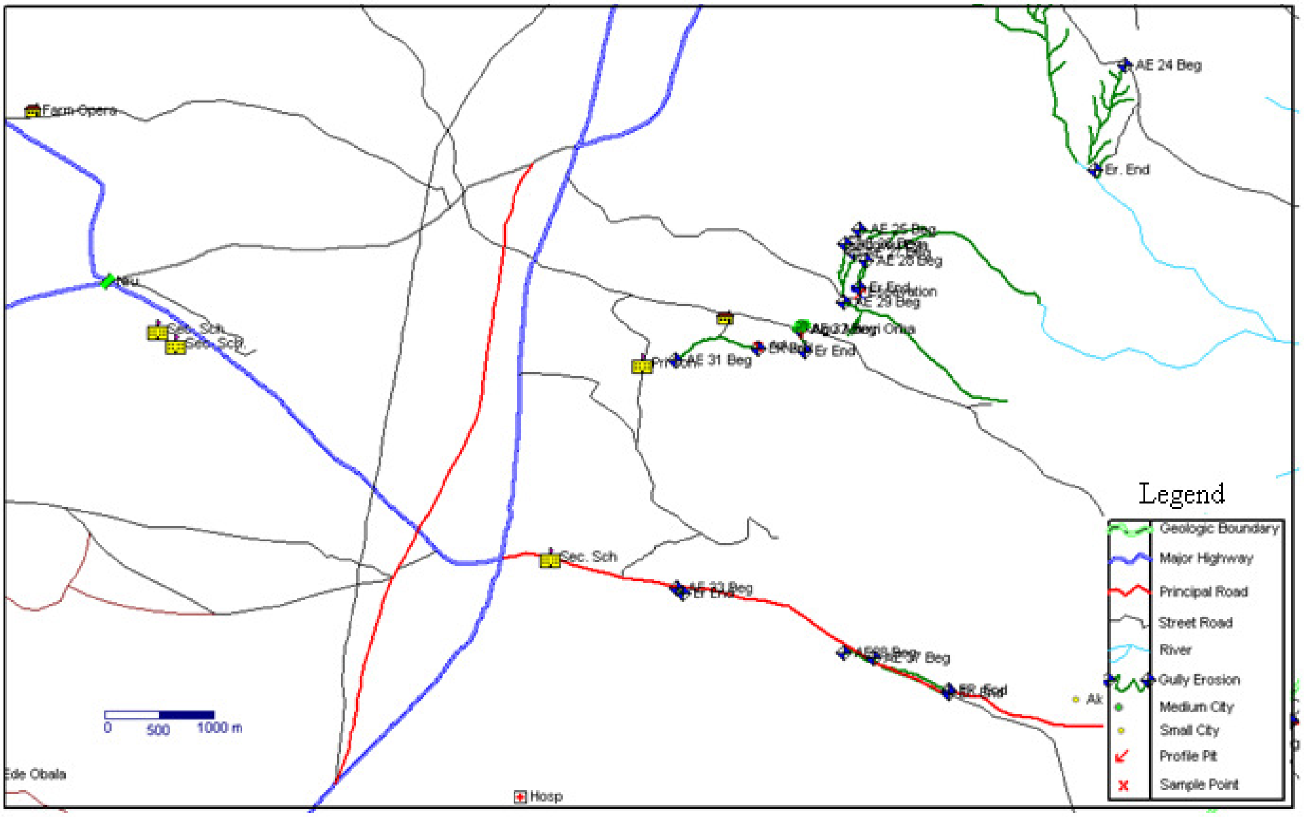

Figure 14 Map showing erosion sites at Agu Amayi Orba (Ani U. A., 2010)

4.2.5 Ezimo.

Ezimo area unlike Ukehe, Ekwegbe, Opi and Orba had highest number of residential area within the Ajali-Mamu inter phase. The area has many deep, wide and lengthy gullies, each ending with a stream (Figure 15) even though the area was covered with thick forests, few shrubs and grass land. In terms of intensity, the map revealed that Ezimo recorded the high intensity of erosion channels. These channels are newer than the advanced gully at Ukehe and Ekwegbe lands.

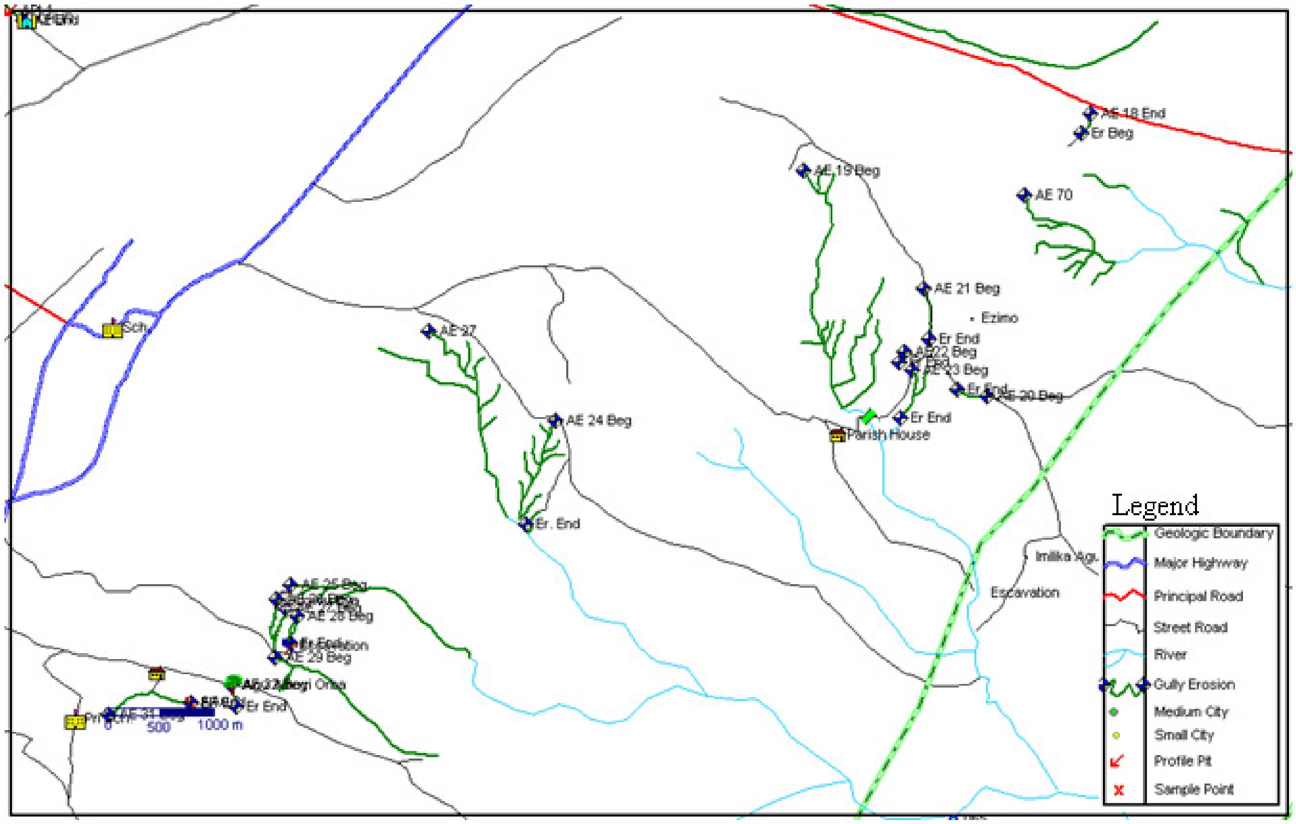

Figure 15 Map showing erosion sites at Ezimo area (Ani U. A., 2010).

4.2.6 Obollo

Obollo-Afor had serous gullies but much work have been done to control them. The control measure was done during the construction of the Obollo-Eheamufu federal high way. Despite the control through engineering concrete channels, the gully erosion site had diverted and is even worse along the road AE 17 (Figure 15 above) this was severest at Umuosigidi in Obollo-Etiti.

4.2.7 Iheakpu-Awka.

Figure 16 revealed a gully channel at Iheakpu-Awka along the road to Iheakpu-Awka Secondary School. The road even though looks as if resistant to run off, was heavily degraded and hinders traffic movement.


Figure 16 Erosion site at Ihakpu Awka near Secondary School (Photo by Ani U. A. Dec. 2008)

4.2.8 University of Nigeria, Nsukka (UNN)

At the University of Nigeria, the gully channel as a result of run off from the University Community started near the University Secondary School. Even though the University has done much engineering construction work to control this gully, the channel is still on down to Onuiyi and ended at Ero-Uno (figure 17)


Figure 17 Gully site at Onuiyi, Nsukka from the University of Nigeria (Photo by Ani U. A. Dec. 2008)

4.2.9 Ede Oballa

Near Nsukka-Opi Express way was a dangerous gully about to cut the road at the time of visit. The gully was threatening to the point that people had lost their residential house to gully (Figure 18). The house in the picture was abandoned as a result of erosion which has lead to the collapse of one of the side walls. The same erosion has rendered some of the nearby farm land useless. Similar gully was identified at Amaegbu, Ede-Oballa.


Figure 18 Gully site at Ede Oballa near Enugu Road (Photo by Ani U. A. Dec. 2008)

4.2.10 Ohebe-Dim.

The excavation site at Ohebe-Dim near the Igbo-Etiti local government head quarters created a deep gully that is threatening the access road and residential houses. Figure 19 reveals the extent of the gully.


Figure 19 Gully site at Ohebe-Dim (Photo by Ani U. A. Dec. 2008)

4.2.11 Aku.

At the Ogboze farm settlement where the new Ogboze Local Government Development Center was sited, the run off from ***'Ugwu egbe'*** hill has created a threatening gully that has left some part of the area useless. (Figure 20) AE 55 and AE 56. Due to the nature of the soil of this area, the road connecting Ozalla and Aku was grossly condemned by erosion resulting to a useless road. At the same Aku, mild gullies were also identified at Ohemje.

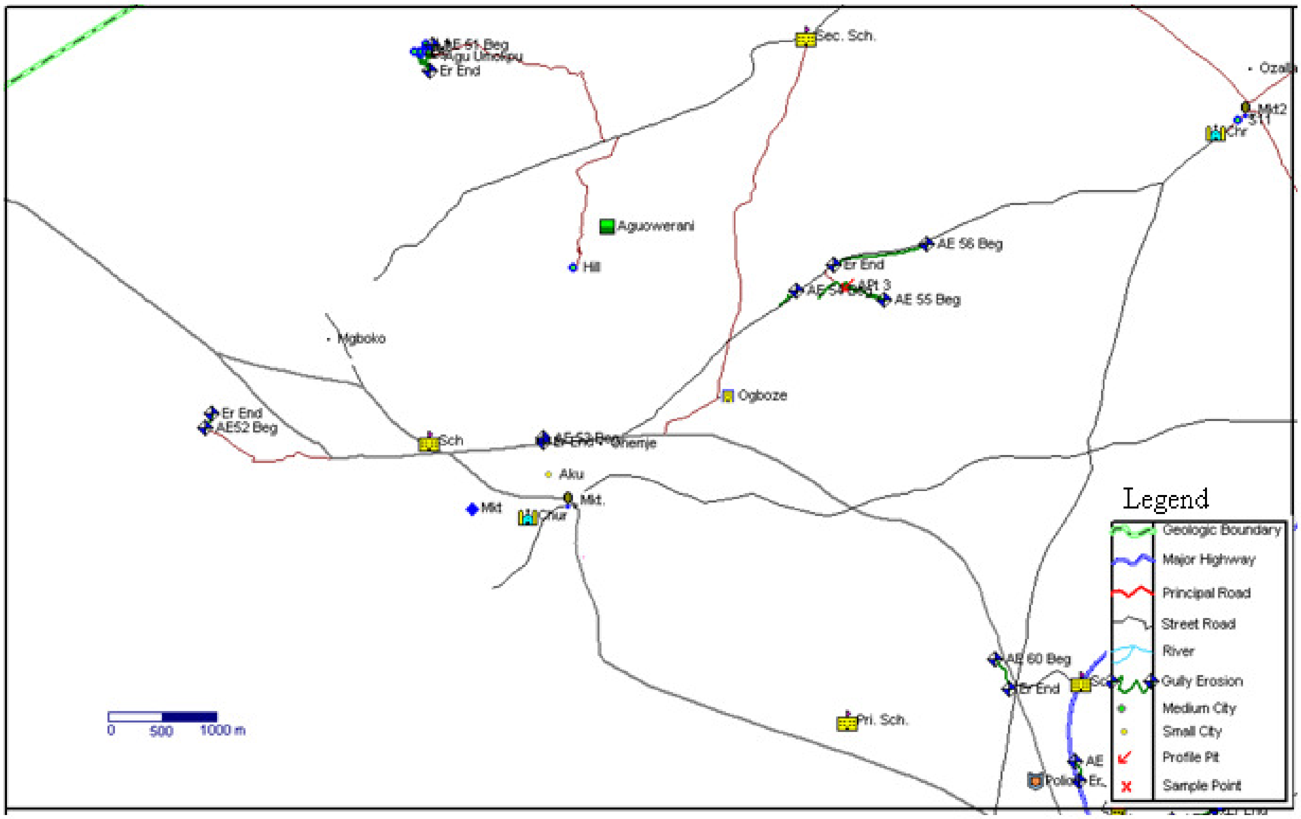

Figure 20 Map of Aku showing gully sites (Ani U. A., 2010).

4.2.12 Enugu-Ezike.

At Enugu-Ezike, major gullies have been controlled. However, erosion sites observed at Olido, Ogurute, Umuida, and Unadu are remnants of the controlled gullies. Figures 21 and 22 are examples.


Figure 21 Umuida↔Unadu road gully site (Photo by Ani U. A. Jan. 2009)

Figure 22 Gully site at Olido near Health Center (Photo by Ani U. A. Jan. 2009)

4.2.13 Lejja.

At Lejja, gully erosion sites such as the one at Umuoda resisted the local control measure (Figure 23). The impact has lead to the damage of the control canal. Similar erosion channels were located at Uruani Amube and Agu-Umogbuji. The Gully at Agu Umogbuji is highly advanced and fairly dormant (Figure 24). The area is characterized by grass land with shrubs. The hilly nature of the area may be the source of the water run off.

Figure 23 Umuoda Lejja erosion damaged drainage canal (Photo by Ani U. A. Jan. 2009)

Figure 24 Agu-Umogbuji, Lejja dormant gully site (Photo by Ani U. A. Jan. 2009)

4.2.14 Obukpa.

This area had two gully sites identified. One is the gully at Obukpa/Okpanigbo road and the other one at Eluegu Obukpa. Both can be likened to have resulted from run off from roads. At Eluegu Obukpa, the biological control measures proved abortive since the planted trees were uprooted and carried by the runoff as can be seen in figure 25.


Figure 25 Eluagu Obukpa gully channel (Photo by Ani U. A. Jan. 2009)

4.2.15 Imilike Agu.

At Imilike-Agu, the gully site has developed a tremendous depth and width that going near makes one fearful. Evidence from figure 26 shows how devastating the erosion was at the time visited. The erosion at this area was similar to those at Ezimo in terms of newness and catastrophy. Evidence from aerial map (Figure 15) reveals the nature of the degradation. One peculiar feature is that these Gullies usually end with river heads.


Figure 26 Imilike-Agu deep gully site (Photo by Ani U. A. Jan. 2009)

Field Identified Causes of the Gullies

In the field, there are some identified causes and promoters of gully erosion. Some are documented bellow;

4.3.1. Bush burning.

Bush burning was noticed in almost all the communities visited. The most dangerous effect of bush burn was identified at areas with sandy soil and sloppy land form. In places like Agu-Ukehe, Agu-Ekwegbe, Ezimo and Agu-Opi, the devastating effect cannot be over emphasized. A clear evidence can be seen in figure 27 revealing the impact of bush burning which removed all the surface cover, and exposed the soil to agents of denudation. The soil would be left in this condition and the rain splash would detach the soil which the run off would carry away.


Figure 27 Amadim, Ukehe land blazed by bush fire. Photo (by Ani U. A. Jan 2009).

4.3.2. Sand Harvesting.

Economic activities have led to rampant, indiscriminate sand digging and harvesting in areas like Agu-opi, Agu-Orba, Ogboze in Aku, and Imilike-Agu. The above area experience heavy truck on earthly road which constitutes the number one source of Gully formation. If any road gets bad, they would divert to another which the run off continues to deepen.

Secondly, the run-off at the harvested area would flow with a high velocity and intensity leading to heavy gullies. Figure 28 showa the sand harvesting area at Agu-Orba. At that area, the wide space harvested results in heavy water collection. This was due to compaction of the underlying soil by the tyre of the heavy trucks.

Figure 28 Sand harvesting at Agu-Amayi Orba (Photo by Ani U. A. Jan 2009)

4.3.3. Deforestation:

At Agu-Ukehe, tree harvesters were met felling trees indiscriminately (Figure 29). The harvesters claimed that the trees belong to no body, (even though the area is a communal land to Ukehe people) and so would fell any tree within their reach without replanting. These activities predisposes the soil to agents of denudation.


Figure 29 Natural forest under deforestation at Agu-Ukehe. Truck was found in the bush going to carry wood (Photo by Ani U. A. Jan 2009).

4.3.4 Uncontrolled grazing:

The Hausa/Fulani cattle rearers were met at Agu-Ukehe and Agu-Ekwegbe with their cattle in patches of makeshift settlements. The heaviness (weight) of the animals and their large population result in scraping off of the surface soil in any place they pass. Their fraction impacts were observed on roads, rivers and pasture areas, which usually turn to gullies. Pictures not available.

4.3.5. Gravel harvesting:

At Ohebe-Dim and Ugwu-Umoka, the gravel harvesters are more interested in how much money they would make not in the good condition of the soil. The exposed and compacted soils are collection centers while the collected run-off would follow the nearby entrance road which ends into a deep gully

4.3.6 Un-tarred busy road:

The road leading to Agu-Opi, Agu-Orba, Eburimiri Ibagwaaka, Ohodo and so many similar untarred busy roads are at risk due to run off. The most dangerous form of these was observed at roads leading to markets, sand harvesting and gravel harvesting areas. Erosion starts from the road sides in form of rill to interril and finally to gullies. Figure 30 is the road leading to Aku from Ozalla which even though busy but was untarred. The water run-off has affected it badly.


Figure 30 Untarred busy road with erosion channel; Aku to Ozalla road (Photo by Ani U. A. Jan 2009).

4.3.7 Indiscriminate dumping of refuse:

The impact of dumping refuse indiscriminately was found within the urban areas more than the rural areas. The urban areas especially the market location do have accrued wastes which are dumped at bad places. During rainfall, the run off would collect these refuse as it flows. The result of this would be clogging of the drainage canals (if any) and the heavy run off would divert and erode the unprotected soil.

4.4 Soil Properties of the two geological Formations.

The soils of the two geological formations were studied, characterized and used as a guide in offering recommendation for control and preventive measures. The morphological properties of the representative profiles were summarized in Table 13, while the pictures are in figures 31, 32, 33, 34, 35, and 36

Table.13 Morphological properties of representative Profiles

Horiz.	Soil Depth (cm)	Moist Colour	Munsell	Consistency			Structure	CLay Skins	Boundry
				Dry	Moist	Wet			
Soils of Mamu Formation				**Mpt₁ (Ada Soil)**					
AO	0-22	rd. br.	5yr 4/6	so	vfr	ss	weak ag.	none	diffused
AB	22-50	dull rd. br.	5yr 5/3	so	vfr	ss	weak sbag.	few	diffused
Bt_1	50-90	bri. rd. br.	5yr 5/6	sh	fi	sps	weak sbag.	few	diffused
Bt_2	90-170	dull rd. br.	5yr 4/3	h	fi	sp	mod. sbag.	few	diffused
				Mpt_2 (Agu-Orba Soil)					
AO	0-22	dull rd. br.	2.5yr 4/4	so	vfr	ss	weak gran.	none	irregular
AB	22-46	rd. br.	2.5yr 4/6	so	vfr	ss	weak gran.	none	gradual
Bt_1	46-100	orange	2.5yr 6/8	sh	fi	sps	weak sbag.	none	irregular
Bt_2	100-180	bri. brown	2.5yr 5/8	sh	fi	sps	mod. sbag.	none	irregular
				Mpt_3 (Agu-Ekwegbe Soil)					
AO	0-20	gr. red	10r 5/2	sh	fi	sps	weak gran.	none	irregular
AB	20-46	dull rd. or.	10r 4/3	h	fi	sp	weak gran.	none	gradual
Bt_1	46-80	gr.red	10r 6/2	vh	vfi	sp	weak sbag.	none	gradual
Bt_2	80-150	rd. br.	10r 5/4	vh	vfi	sp	mod. sbag.	none	irregular
Soils of Ajali Formation				**Apt_1 (Iheka Soil)**					
AO	0-35	dark rd. br.	2.5yr 3/6	h	fi	sp	mod. gran.	none	gradual
AB	35-56	rd. br.	2.5yr 4/6	h	fi	sp	weak gran.	few	irregular
Bt_1	56-100	bri. brown	2.5yr 5/8	vh	vfi	sp	weak sbag.	few	diffused
Bt_2	100-180	orange	2.5yr 6/8	vh	vfi	sp	mod. sbag.	few	gradual
				Apt_2 (Ede-Oballa Soil)					
AO	0-21	rd. br.	2.5yr 4/6	h	fi	sp	weak gran.	none	gradual
AB	21-46	rd. br.	2.5yr 4/8	h	fi	sp	weak gran.	few	gradual
Bt_1	46-80	bri. brown	2.5yr 5/6	vh	vfi	sp	weak sbag.	few	irregular
Bt_2	80-180	orange	2.5yr 6/8	vh	vfi	sp	weak sbag.	few	irregular
				Apt_3 (Aku Soil)					
AO	0-30	br. brown	2.5yr 5/6	sh	fi	sp	mod. fi. gran.	none	gradual
AB	30-53	br. brown	2.5yr 5/8	h	fi	sp	mod. fi. ms.	none	smooth clear
Bt_1	53-100	rd. br.	2.5yr 4/6	vh	vfi	sp	mod. fi. ms.	few	smooth clear
Bt_2	100-180	dull rd.. br.	2.5yr 6/4	vh	vfi	sp	mod. mass.	few	gradual wavy

Horiz. = horizon, so. = soft, vfr. = very firm, ss. = slightly sticky, sh. = slightly hard, ssp. = sticky, slightly plastic, vh. = very hard, h. = hard, rd = reddish, br.= bright, ag. = angular, sbag. = sub-angular, gr. = granular, md. = moderate, mas.= massive, fi. = fine, br. = brown, or. = orangegr. grayish

Figure 31 Ada soil profile (Mpt_1)

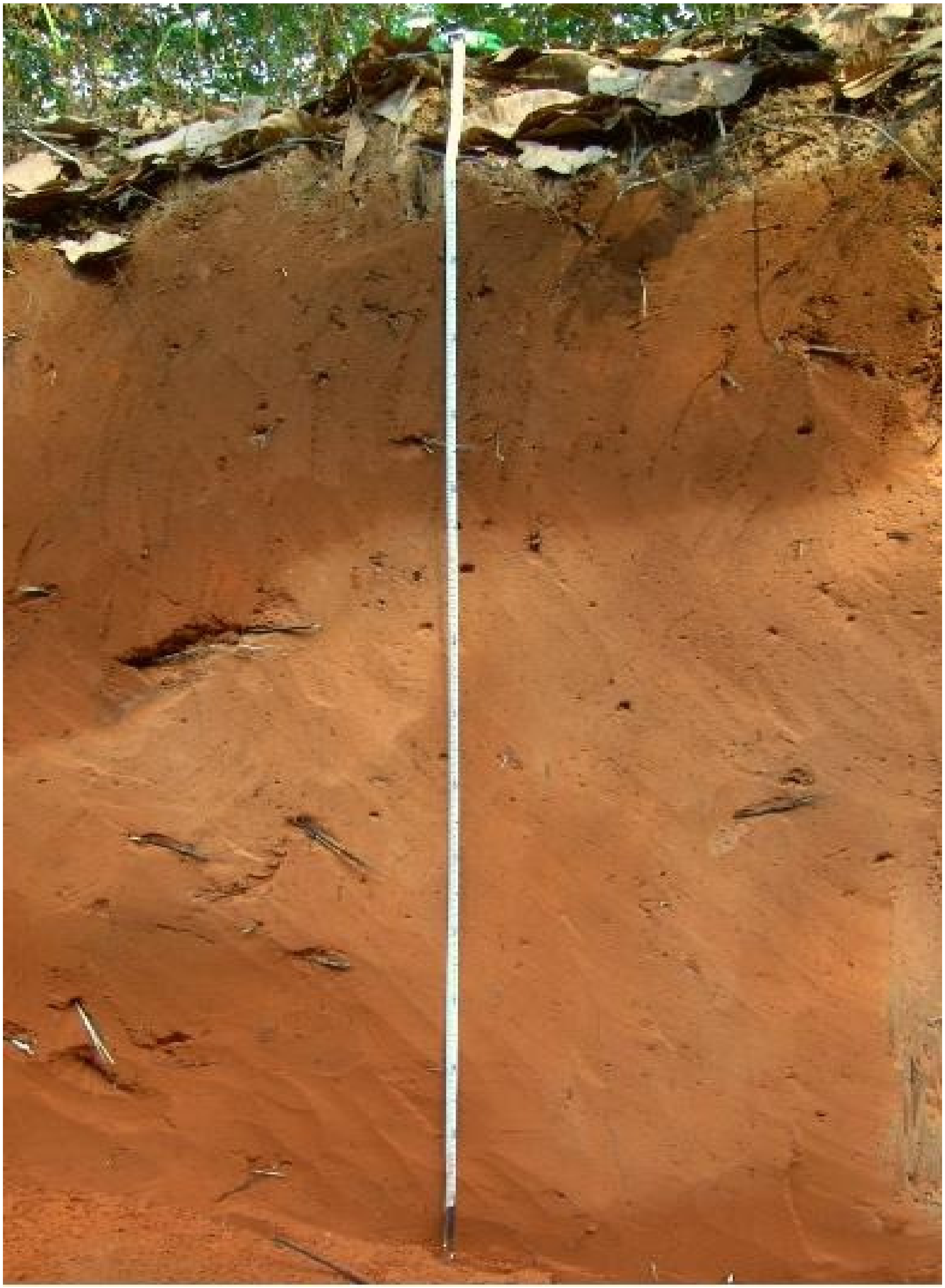

Figure 32 Agu Orba soil profile (Mpt_2)


Figure 33 Agu Ekwegbe soil profile (Mpt_3)

Fig. 34 Iheaka soil profile (Apt_1)

Fig. 35 Amaegbe, Ede- Oballa soil profile (Apt_2)

Fig. 36 Ogboze, Aku Farm Settlement soil profile (Apt_3)

4.5 Statistical Analysis

Data on length, width and depth were subjected to statistical analysis using t-test to compare their level of significance. There was a significant difference in the lengths and depths at 95% confident interval (Tables 14 and 15) on the other hand; there was no significant difference between the widths at 95% confidence interval (Table 16).

Table 14 Summary of gully depth t-test analysis in Ajali and Mamu Formations

Sample	Size	Mean	Variance	Standard deviation	Standard error of mean
DTAF	72	8.375	183.3	13.54	1.596
DTMF	9	3.667	0.7550	0.8689	0.2896

Standard error for difference of means 1.622

95% confidence interval for difference in means: (1.478, 7.939)

Probability = 0.005

Where DTAF = Depth of Ajali Formation. DTMF = Depth of Mamu Formation

Table 15 Summary of gully Length t-test analysis in Ajali and Mamu Formations

Sample	Size	Mean	Variance	Standard deviation	Standard error of mean
LTAF	72	1570	5697332	2387	281.3
LTMF	9	484.2	94901	308.1	102.7

Standard error for difference of means 299.5

95% confidence interval for difference in means: (489.3, 1681)

Probability < 0.001

Where LTAF = Length of Ajali Formation. LTMF = Length of Mamu Formation.

Table 16 Summary of gully width t-test analysis in Ajali and Mamu Formations

Sample	Size	Mean	Variance	Standard deviation	Standard error of mean
WTAF	72	62.49	74371	272.7	32.14
WTMF	9	6.522	6.847	2.617	0.8722

Standard error for difference of means 32.15

95% confidence interval for difference in means: (-8.141, 120.1)

Probability = 0.086

Where WTAF =Width of Ajali Formation.

WTMF = Width of Mamu Formation

In Mamu Formation there was a positive significant correlation between length and width (r = 0.409), depth and width (r = 0.862), but non significant correlation between length and Depth(r = 0.188) (table 17).

In Ajali Formation, there was a positive and significant correlation between length and depth (r = 0.635), length and width(r = 0.578), depth and width (r = 0.689) (Table18)

Table 17 Pearson correlation for gully parameters in Mamu Formation

	Length	Depth	Width
Length	-		
Depth	.188^{ns}	-	
Width	.409*	.862**	-

**Correlation is significant at the 0.01 level (2-tailed),
*Correlation is significant at the 0.05 level (2-tailed)
ns None Significant

Table 17 Pearson correlation for gully parameters in Ajali Formation

	Length	Depth	Width
Length	-		
Depth	.635**	-	
Width	.578**	.689**	-

**Correlation is significant at the 0.01 level (2-tailed),

4.6 Result of Laboratory Analysis:

The results of the physical and chemical properties of the soils of the two formations are presented below.

4.6.1 Physical Properties.

4.6.1.1 Mean Weight Diameter (MWD)

The result of the water stable aggregate shows that Mpt_1 (Mamu Profile Pit One) had highest mean weight diameter (MWD) value varying from 0.804812 to 2.753 with a mean of 1. 583, while intermediate value range from 0.644 to 0.157 with a mean of 0.361 in Mpt_2. Mpt_3 has the lowest values ranging from 0.634 to 2.452 with a mean of 1.359 (Table 19).

In Ajali formation, the highest MWD was obtained at Apt_2 with a range of 0.577 to 2.842 and a mean of 4.170. Apt_1 had the lowest value with a range of 0.518 to 1.519 (mean 0.841). Apt_3 hasan intermediate value ranging from 0.711 to 1.995 with a mean of 1.384 (Table 20)

4. 6.1.2 State of Aggregation (%)

The percentage state of aggregation had no defined pattern. The highest value ranging from 28.6% to 65.6 % (mean = 42.48%) was observed at Mpt_3. This was followed by Mpt_1 (ranges from 8.64% to 61.88% a mean value of 36.49%) while the least value (range = 0.44% to 23.04%, mean = 9.56%) was obtained at Mpt_2 (table 19).

Ajali formation recorded the highest mean at $Apt_{2,}$ (mean = 35.85, ranges range = 13.72 to 66.8) followed by Apt_3 (mean = 33.81 and ranges = 15.08 to 25.64), while the least value (mean 22.40 with a range of 7.76 to 43.48), was obtained at Apt_1 (Table 20).

4. 6.1.3 Aggregate Stability (%)

The percentage aggregate stability value for Mamu formation had no defined pattern along the profile. The highest value was obtained at Mpt_1 with a range of 15.67% to 84.12% and mean value of 51.83%. The least value was at Mpt_2 with a range of 0.45 to 23.37% and mean value of 9.71%. Mpt_3 ranges from 29.9% to 77.03% a mean value of 47.18% (Table19).

Ajali formation had a defined downward decrease in values along the profile in Apt_1 and Apt_2 while Apt_3 was not well defined. Highest value was obtained at Apt_3 with a range of 22.27% to 72.83% and mean value of 49.18%. The least value was obtained at Apt_1 with a range of 10.18% to 53.95% and mean value of 28.06%. Apt_2 ranges from 18.19% to 91.61% and a mean value of 48.46% (Table 20)

Table 19 Summary of the Aggregate Stability values of the soils of Mamu Formation

Mapping Units /Horizons (cm)	MWD	Stat of Aggregation (%)	Aggregate Stability (%)
MPt_1			
AO 0-25	2.75	61.88	84.12
AB 25-50	1.06	34.8	47.77
Bt1 50-90	1.71	40.64	59.76
Bt1 90-170	0.80	8.64	15.67
Range	0.80-2.75	8.64-61.88	15.67-84.12
Mean	1.58	36.49	51.83
MPt_2			
AO 0-22	0.64	23.04	23.37
AB 22-46	0.16	0.44	0.45
Bt1 46-100	0.38	9.6	9.75
Bt2 100-180	0.26	5.16	5.28
Range	0.16-0.64	0.44-23.04	0.45-23.37
Mean	0.36	9.56	9.71
MPt_3			
AO 0-20	2.45	65.6	77.03
AB 20-46	1.39	42.72	47.30
Bt1 46-80	0.96	33.00	34.48
Bt2 80-150	0.63	28.6	29.90
Range	0.63-2.45	28.60-65.60	29.90-77.03
Mean	1.36	42.48	47.18
Over all Average	**1.10**	**36.24**	**29.5**

Mpt_1 = Ada Soil, Mpt_2 = Agu Orba Soil, Mpt_3 = Agu-Ekwegbe Soil, MWD = mean weight diameter.

Table 20 Summary of the Aggregate Stability values of the Soils of Ajali Formation

Mapping Units /Horizons (cm)	MWD	State of Aggregation (%)	Aggregate Stability (%)
APt1			
AO 0-35	1.52	43.48	53.95
AB 35-56	0.66	20.08	24.78
Bt1 56-100	0.67	18.28	23.34
Bt2 100-180	0.52	7.76	10.18
Range	0.52-1.52	7.76-43.48	10.18-53.95
Mean	0.84	22.40	28.06
APt2			
AO 0-21	2.84	66.80	91.61
AB 21-46	1.50	43.00	56.17
Bt1 46-80	0.75	19.88	27.86
Bt2 80-180	0.58	13.72	18.19
Range	0.58-2.84	13.72-66.80	18.19-91.61
Mean	1.42	35.85	48.46
APt3			
AO 0-30	2.00	52.64	80.59
AB 30-53	1.92	47.72	72.83
Bt1 53-100	0.91	20.20	31.58
Bt2 100-180	0.71	15.08	22.27
Range	0.71-2.00	15.08-52-64	22.27-72.83
Mean	1.38	33.91	49.18
Over all Average	**1.22**	**30.72**	**42.78**

Apt_1 = Iheaka Soil, Apt_2 = Ede-Oballa Soil, Apt_3 = Aku Soil, MWD = mean weight diameter,

4. 6.1.4 Clay

In the Mamu formation, the percentage maximum value was obtained at Mpt_1 with a range of 10-12% and mean value of 11%. The least value was at Mpt_2 with a range of 2 to 8% and mean of 5%. Intermediate value was obtained at Mpt_3 ranging from 1 to 19% and has a mean value of 9% (Table 21).

In the Ajali formation, highest value was obtained at Apt_1, with a range of 8 to 22% and mean value of 17%. The least value was at Apt_3 with a range of 10% to 12% and mean of 11%. Intermediate value was obtained at Apt_2 with a range of 10% to 16% and mean of 14% (Table 22).

4. 6.1.5 Silt

In the Mamu and Ajali formations, percentage silt fraction fluctuated along the horizons in all the sample areas. In Mamu formation, the highest percentage silt fraction was obtained at Mpt_3 (range = 9% to 14%, mean = 11%) followed by Mpt_2 (range = 4% to 15%, range of 9%), while the least value was obtained at Mpt_1 (range = 3% to 10% mean = 6%. (Table 21)

In Ajali formation, highest value was recorded at Apt_2 (range = 3% to 16%, mean = 8%) followed by Apt_1 (range = 5% to 7%, mean = 6%, while the least value was obtained at Apt_3 (range = 2% to 4%, mean = 3% (Table 22).

4. 6.1.6 Sand

In both formations, there was no defined pattern for sand fraction along the profile. In Mamu formation, the percentage maximum sand fraction value was obtained at Mpt_2 with a range of 81-89% and mean of 87%. The least value was at Mpt_3 with a range of 69 to 89% and mean of 5%. Mpt_2 had a range of 78 to 85% and ranges from 83% (Table 21).

In the Ajali formation, highest value was obtained at Apt_3, with a range of 84 to 88% and mean of 86%. The least value was at Apt_1 with a range of 71% to 87% and mean of 78%. Apt_2 has a range of 74% to 87% and a mean value of 79% (Table 22).

4. 6.1.7 Fine Sand

The percentage fraction of fine sand as was recorded in table 13 did not follow a particular trend throughout the horizons in all the profit pits of both formations. In Mamu formation, the highest percentage value of fine sand was obtained at Mpt_2 with a range of

72% to 76% and a mean value of 75%. The least value was obtained at Mpt_1 with a range of 15% to 19% and a mean of 18%. Mpt_3 has a range from 41% to 61% and a mean value of 55% (Table 21).

In Ajali formation, highest value was obtained at Apt_1 with a range of 17% to 30% and a mean value of 44%. The lowest was obtained at Apt_3 with a range of 7% to 20% and a mean value of 15%. On the other hand, Apt_2 has a range of 11% to 22% and a mean value of 17% (Table 22).

4. 6.1.8 Coarse Sand

Like other fractions, coarse sand values had no definite pattern along the horizons in all the profile pits of both formations. Highest value in Mamu formation obtained at Mpt_1 (range = 59% to 70%, mean = 65%) followed by Mpt_3 (ranges = 8% to 47%, mean = 25%) while the least value (range = 9% to 13%, mean = 12%) was obtained at Mpt_2 (Table 21).

In the Ajali formation, highest value was recorded at Apt_3 (range = 68% to 78%, mean = 71%) followed by Apt_2 (range = 57% to 63%, mean = 62%), while the least value (range = 54% to 57%, mean = 55%) was recorded at Apt_1 (Table 22).

Table 21 Summary of the particle size distribution of the soils of Mamu Formation

Mapping Units /Horizons (cm)	Clay	Silt	FS	CS	TC
MPt_1					
AO 0-25	11.0	0.4	19.0	66.0	LS
AB 25-50	10.0	5.0	15	70	LS
Bt1 50-90	12.0	3.0	19	66.0	LS
Bt1 90-170	12.0	10.0	19	59.0	SL
Range	10-12	3-10	15-19	59-70	
Mean	11	6	18	65	
MPt_2					
AO 0-22	18.0	4.0	76	12.0	SL
AB 22-46	2.0	10.0	75.0	13.0	S
Bt1 46-100	4.0	15.0	72.0	9.0	LS
Bt2 100-180	4.0	7.0	76.0	13.0	S
Range	2-8	4-15	72-76	9-13	
Mean	5	9	75	12	
MPt_3					
AO 0-20	3.0	9.0	41	47.0	S
AB 20-46	1.0	10.0	56.0	33.0	S
Bt1 46-80	13.0	14.0	60	13.0	LS
Bt2 80-150	19.0	12.0	61.0	8.0	LS
Range	1-19	9-14	41-61	8-47	
Mean	9	11	55	25	
Over all Average	**11**	**10**	**79**		

SL = Sandy Loam, LS= Loamy sand, S = Sand Soil, Apt_1 = Iheaka Soil, Apt_2 = Ede-Oballa Soil, Apt_3 = Aku Soil, FS = fine sand, CS = coarse sand.

Table 22 Summary of the particle size distribution of the soils of Ajali Formation

Mapping Units /Horizons (cm)	Clay	Silt	FS	CS	TC
APt1					
AO 0-35	10.0	3.0	30.0	57.0	LS
AB 35-56	22.0	7.0	17	54.	SL
Bt1 56-100	20.0	6.0	19.0	55.0	SL
Bt2 100-180	16.0	5.0	250	540	LS
Range	8-22	5-7	17-30	54-57	
Mean	17	6	23	55	
APt2					
AO 0-21	10.0	3.0	22.0	65	LS
AB 21-46	14.0	7.0	18.0	61.0	LS
Bt1 46-80	10.0	16.0	11.0	63.0	LS
Bt2 80-180	20.0	5.0	18.0	57.0	SL
Range	10-18	3-16	11-22	57-63	
Mean	14	8	17	62	
APt3					
AO 0-30	10.0	2.0	20.0	68.0	SL
AB 30-53	11.0	4.0	7.0	78.0	LS
Bt1 53-100	11.0	2.0	19.0	69.0	LS
Bt2 100-180	12.0	4.0	15.0	69.0	LS
Range	10-12	2-4	7-20	68-78	
Mean	11	3	15	71	
Over all Average	**14**	**5**		**81**	

SL = Sandy Loam, LS= Loamy sand, Apt_1 = Iheaka Soil, Apt_2 = Ede-Oballa Soil, Apt_3 = Aku Soil, FS = fine sand, CS = coarse sand.

4. 6.1.9 Silt/Clay Ratio

In Mamu formation, the highest was silt/clay ratio was obtained at Mpt_3 with a range of 0.67 to 7.14 and mean ratio of 3.1. The least ratio was at Mpt_1 with a range of 0.3 to 0.8 and a mean value of 0.45. Mpt_2 ranges from 0.84 to 4.17 and a mean ratio of 3 (Table 23).

In Ajali formation, the highest ratio was obtained at Apt_2 with a range of 0.22 to 1.44 and a mean of 0.58. The least was obtained at Apt_3 with a range of 0.12 to 0.33 and a mean ratio of 0.21. Apt_1 ranges from 0.22 to 0.52 and a mean ratio of 0.33 (Table 24).

4. 6.1.10 Silt/ Silt + Clay Ratio

Mamu formation had the highest ratio at Mpt_2 with a range of 0.46 to 0.81 and mean ratio of 0.7. The least ratio was obtained at Mpt_1 at with a range of 0.23 to 0.45 and mean ratio of 0.3. Mpt_3 ranges from 0.4 to 0.88 and a mean ratio of 0.65 (Table 23).

In the Ajali formation, the highest ratio was obtained at Apt_2 with a range of 0.18 to 0.62 and mean ratio of 0.33. The least ratio was obtained at Apt_3 with a range of 0.11 to 0.22 and a mean ratio of 0.17. Apt_1 ranges from 0.18 to 0.34 with a ratio of 0.24 (Table 24).

4. 6.1.11 Fine Sand/Coarse sand Ratio

At Mamu formation, a maximum fine sand/coarse sand ratio was obtained at Mpt_2 with a range of 5.85 to 8.00 with a mean of 6.61. The least ratio was at Mpt_1 with a range of 0.21 to 0.32 and mean of 0.28. Mpt_3 ranges from 0.87 to 7.63 with a ratio of 3.71 (Table 23).

In Ajali formation, the highest ratio was obtained at Apt_1 with a range of 0.31 to 0.53 and mean ratio of 0.41. Least mean ratio was at Apt_3 with a range of 0.09 to 0.29 and mean ratio of 0.22. Apt_2 ranges from 0.18 to 34 with a mean ratio of 0.29 (Table 24).

4. 6.1.12 Water/Calgon Dispersion Ratio (DR)

The highest water/calgon dispersion which ranges from 0.84 to 0.9 at Mamu formation was obtained at Mpt_2 with a mean ratio of 0.86. The least ratio which ranges from 0.52 to 0.82 and mean ratio of 0.72 was recorded at Mpt_3. Mpt_1 ranges from 0.7 to 0.84 and has a mean of 0.79 (Table 23).

In the Ajali formation, the highest ratio was at Apt_3 with a range of 0.66 to 0.88 and mean value of 0.80. Least ratio was obtained at Apt_2 with a range of 0.61 to 0.88 and a mean ratio of 0.76. Apt_1 ranges from 0.55 to 0.88 with a mean ratio of 0.78 (Table 24).

Table 23 Summary of the ratios of the particle size distribution of the soils of Mamu Formation.

Mapping Units /Horizons (cm)	DR	Silt/Clay	Silt/Silt + Clay	Fine Sand/Coarse Sand
MPt_1 AO 0-25	0.70	0.30	0.23	0.29
AB 25-50	0.80	0.38	0.28	0.21
Bt1 50-90	0.84	0.30	0.23	0.29
Bt1 90-170	0.82	0.81	0.45	0.32
Range	0.7-0.84	0.3-0.81	0.23-0.45	0.21-0.32
Mean	0.79	0.45	0.30	0.28
MPt_2 AO 0-22	0.90	0.84	0.46	6.33
AB 22-46	0.84	4.17	0.81	6.25
Bt1 46-100	0.84	3.41	0.77	8.00
Bt2 100-180	0.84	3.17	0.76	5.85
Range	0.84-0.90	0.84-4.17	0.46-0.81	5.85-8.00
Mean	0.86	3.00	0.70	6.61
MPt_3 AO 0-20	0.52	3.36	0.77	0.87
AB 20-46	0.74	7.14	0.88	1.70
Bt1 46-80	0.78	1.20	0.55	4.62
Bt2 80-150	0.82	0.67	0.40	7.63
Range	0.52-0.82	0.67-7.14	0.40-0.88	0.87-7.63
Mean	0.72	3.10	0.65	3.71
Over all Average	**0.79**	**2.15**	**0.55**	**3.53**

Mpt_1 = Ada Soil, Mpt_2 = Agu Orba Soil, Mpt_3 = Agu-Ekwegbe Soil, DR = Water/Calgon dispersion ratio

Table 24 Summary of the ratios of the particle size distribution of the soils of Ajali Formation.

Mapping Units /Horizons (cm)	DR	Silt/Clay	Silt/Silt+Clay	Fine Sand/Coarse Sand
APt1 AO 0-35	0.88	0.52	0.34	0.53
AB 35-56	0.81	0.29	0.22	0.31
Bt1 56-100	0.88	0.22	0.18	0.35
Bt2 100-180	0.55	0.27	0.21	0.46
Range	0.55-0.88	0.22-0.52	0.18-0.34	0.31-0.53
Mean	0.78	0.33	0.24	0.41
APt2 AO 0-21	0.66	0.23	0.19	0.34
AB 21-46	0.88	0.44	0.31	0.30
Bt1 46-80	0.84	1.44	0.62	0.18
Bt2 80-180	0.66	0.22	0.18	0.32
Range	0.66-0.88	0.22-1.44	0.18-0.62	0.18-0.34
Mean	0.76	0.58	0.33	0.29
APt3 AO 0-30	0.88	0.13	0.12	0.29
AB 30-53	0.84	0.30	0.22	0.09
Bt1 53-100	0.66	0.12	0.11	0.28
Bt2 100-180	0.81	0.27	0.22	0.22
Range	0.66-0.88	0.12-0.30	0.11-0.22	0.09-0.29
Mean	0.80	0.21	0.17	0.22
Over all Average	**0.78**	**0.37**	**0.24**	**0.31**

Apt_1 = Iheaka Soil, Apt_2 = Ede-Oballa Soil, Apt_3 = Aku Soil, DR = Water/Calgon dispersion ratio

4.6.2 Chemical Properties.

4.6.2.1 Soil Reaction.

The pH (H_2O) values obtained in the soils of Mamu formation are generally higher than in the soils of Ajali formation as can be seen in Table 25.

Values obtained at Mpt_1 ranged from 4.7 - 4.9 and mean values of 4.8. The least was obtained at Mpt_2 with a range of 4.7 to 5.2 and mean values of 5.0. Soil of Mpt_3 has an intermediate value with a range of 4.7-5.1 and mean values of 4.9.

The pH (H_2O) value of the soil of Ajali formation varied along the profiles as shown in Table 26. Highest pH values were observed in the soils of Mpt_2 (range = 4.8-5.1, mean = 4.9) followed by Apt_1 (ranges = 4.9 to 5.1, mean = 5.0 while the least value was obtained at Mpt_3 range = 4.7-5.3, mean = 5.1).

4. 6.2.2 Aluminum (cmol kg^{-1}).

In all the soils of both Mamu and Ajali Formations, Aluminum was obtained only at Apt_1 with a value of 0.4. Every others soil had no Aluminum and the acidity property can be attributed to Hydrogen alone. The TEA range was highest at Apt_1 and ranged from 2.2 to 4.0value with a mean of 3.0. The least was at Apt_3 with a range of 9.6 to 22.0 and mean of 1.8. Apt_2 had a range of 1.6 to 3.6 and mean of 2.7 (Table26).

4. 6.2.3 Hydrogen and Total Exchangeable Acidity (cmol kg^{-1}).

There was no defined pattern in the values of hydrogen and total exchangeable acidity along the profiles of the soils of the Mamu formations as shown in Table 25 Mpt_1 had the highest concentration of H^+ and TEA (range = 2.0 to 3.6, mean = 2.6) followed by Mpt_2 (range = 1.6 to 2.6, mean = 2.15), while the least value was obtained atMpt_3 (range = 1.0 to 2.8, mean value = 2.05)

In Ajali formation, the highest acidity concentration was obtained at Apt_1 (range =2.2 to 4.0, mean value = 2.9 followed by Apt_2 (range = 1.6 to 3. 6, mean value = 2.7, while the least value (range = 1.6 to 2.0, mean value =1.8) was obtained at Apt_3 (Table 26).

Table 25 Summary of acidic properties in Mamu Formation profiles

Mapping Units /Horizons (cm)	pH (H_2O)	AL^{3+} (cmol kg^{-1})	H^+ (cmol kg^{-1})	TEA (cmol kg^{-1})
Mpt_1 AO 0-25	4.9	-	2.0	2.0
AB 25-50	4.7	-	2.4	2.4
Bt1 50-90	4.7	-	3.6	3.6
Bt1 90-170	4.9	-	2.4	2.4
Range	4.7 – 4.9	-	2.0-3.6	2.0-3.6
Mean	4.8	-	2.6	2.6
Mpt_2 AO 0-22	5.0	-	2.6	2.6
AB 22-46	4.7	-	2.4	2.4
Bt1 46-100	5.2	-	2.0	2.0
Bt2 100-180	5.1	-	1.6	1.6
Range	4.7 – 5.2	-	1.6-2.6	1.6-2.6
Mean	5.0	-	2.15	2.15
Mpt_3 AO 0-20	5.1	-	1.6	1.6
AB 20-46	5.0	-	1.0	1.0
Bt1 46-80	4.8	-	2.8	2.8
Bt2 80-150	4.7	-	2.8	2.8
Range	4.7 – 5.1	-	1.0-2.8	1.0-2.8
Mean	4.9	-	2.05	2.05
Over all Average		**-**	**1.75**	**1.75**

Mpt_1 = Ada Soil, Mpt_2 = Agu Orba Soil, Mpt_3 = Agu-Ekwegbe Soil, Apt_1 = Iheaka Soil, Apt_2 = Ede-Oballa Soil, Apt_3 = Aku Soil, pH H_2O = pH in water, AL $^{3+}$ = Aluminum, H^+ = Hydrogen, TEA = total exchangeable acidity
.

Table 26 Summary of acidic properties in Ajali Formation profiles

Mapping Units /Horizons (cm)	pH (H_2O)	AL^{3+} (cmol kg^{-1})	H^+ (cmol kg^{-1})	TEA (cmol kg^{-1})
Apt1 AO 0-35	5.0	0.4	2.6	3.0
AB 35-56	4.9	-	4.0	4.0
Bt1 56-100	5.0	-	2.6	2.6
Bt2 100-180	5.1	-	2.2	2.2
Range	4.9 – 5.1	-	2.2-4.0	2.2-4.0
Mean	5.0	-	2.9	3.0
Apt2 AO 0-21	5.1	-	1.6	1.6
AB 21-46	4.8	-	3.6	3.6
Bt1 46-80	4.5	-	3.6	3.6
Bt2 80-180	5.0	-	2.0	2.0
Range	4.8 – 5.1	-	1.6-3.6	1.6-3.6
Mean	4.9	-	2.7	2.7
Apt3 AO 0-30	5.1	-	1.6	1.6
AB 30-53	5.2	-	1.8	1.8
Bt1 53-100	4.7	-	2.0	2.0
Bt2 100-180	5.3	-	2.0	2.0
Range	4.7 – 5.3	-	1.6-2.0	1.6-2.0
Mean	5.1	-	1.8	1.8
Over all Average		**-**	**2.46**	**2.5**

Mpt_1 = Ada Soil, Mpt_2 = Agu Orba Soil, Mpt_3 = Agu-Ekwegbe Soil, Apt_1 = Iheaka Soil, Apt_2 = Ede-Oballa Soil, Apt_3 = Aku Soil, pH H_2O = pH in water, AL^{3+} = Aluminum, H^+ = Hydrogen, TEA = total exchangeable acidity

4.6.2.4 Sodium (Na^+ cmol kg^{-1}).

Highest value was obtained at Mpt_2 with a range of 0.19 to 0.25 and mean of 0.22, while the lowest value was at Mpt_1 and $Mpt_{3.}$ While Mpt_1 ranges from 0.12 to a 0.23 with a mean of 0.18, Mpt_3 ranges from 0.08 to 0.23 with a mean of 0.18 (Table 27).

The soil of Ajali formation, ranked highest at Apt_1 with a range of 0.06 to 0.21 and a mean value of 0.15. Apt_2 was the least ranging from 0.14 to 0.23 with a mean value of 0.19 Apt_3 had an intermediate value of 0.26 and ranges from 0.17 - 0.33 (Table 28).

4. 6.2.5 Potassium (K^+ cmol kg^{-1}).

Potassium values fluctuated along the horizons in all the profile pits. Highest value of potassium was obtained at both soils of Mpt_1 and Mpt_3. While Mpt_1 range from 0.08 to 0.28, Mpt_3 ranges from 0.10 to 0.33; both have a mean value of 0.20. The lowest value was obtained at Mpt_2 with a range of 0.1 to 0.2 and mean value of 0.16 (Table 27).

The soils of Ajali formation also fluctuated in potassium concentration along the horizons in all the profile pits. Meanwhile, Apt_3 scored highest and ranged from 0.06 to 0.42 with a mean value of 0.22. Least value obtained at Apt_1 ranged from 0.16 to 0.21 with mean of 0.19. Apt_2 ranged from 0.11 to 0.23 with a mean value of 0.21. Auger samples ranged from 0.07 (Table 28).

4. 6.2.6 Calcium (Ca^{2+} cmol kg^{-1}).

The soils of Mamu formation had the same fluctuation along the horizons in calcium Ca^{2+} concentration in all the profile pits. Moreover, highest value was obtained at Mpt_3 (range = 0.4 to 1.2, mean value = 0.75. followed by Mpt_2 (range = 0.4 to 1.2, mean value = 0.65) while the least value (ranges = 0.4 to 0.8, mean value = 0.55) was obtained at Mpt_1 (Table 27).

The soils of Ajali formation had the highest value obtained at Apt_1 (ranged = 0.4 to 0.8, mean value = 0.7) followed by Apt_2 (ranged = 0.4 to 0.8, mean = 0.65) while the least value (range = 0.4 to 0.6, mean = 0.5 was obtained at Apt_3 (Table 28).

4. 6.2.7 Magnesium (Mg^{2+} cmol kg^{-1}).

Soils of Mamu formation had a fluctuating concentration of magnesium along the horizons. Higher value was obtained at Mpt_2 with a range of 0.2 to 2.0 and mean value of

0.9. Least value was recorded at Mpt_3 with a range of 0.2 to 0.8 with a mean of 0.45. Mpt_1 ranged from 0.4 to 1.2 with a mean value of 0.75 (Table 27).

In the soils of Ajali formation, magnesium concentration also fluctuated along the profiles. Highest value was obtained at Apt_2 with a range of 0.4 to 1. 6 and mean value of 0.9. The least value was at Apt_3 with a range of 0.4 to 0.8 and mean of 0.65. Apt_1 ranges from 0.4 to 1.6 with a mean value of 0.8 (Table 28).

4. 6.2.8 Total Exchangeable Base (TEB cmol kg^{-1}).

The values of TEB also fluctuated along the horizons in of the soils of both Mamu and Ajali formations. In Manu formation, highest value was observed at Mpt_2 with a range of 1.22 to 3.25 and mean of 1.98. Least value was at Mpt_3 with a range of 0.99 to 0.29 and mean value of 1.58. Mpt_1 had an intermediate value that ranges from 1.22 to 2.37 with mean of 1.68 (Table 27).

In the soils of Ajali formation, highest TEB value was obtained at Apt_2 with a range of 1.54 to 2.82 and mean of 1.94. Least value was observed at Apt_3 with a range of 1.14 to 2.11 with mean of 1.63. Apt_1 had an intermediate value that ranges from 1.44 to 2.3 with mean value of 1.8 (Table 28).

Table 27 Summary of exchangeable bases of Mamu Formation

Mapping Units /Horizons (cm)	Total Exchangeable Bases (cmol kg^{-1}).					ECEC (cmol kg^{-1}).	B.S (%)
	Na^+	K^+	Ca^{2+}	Mg^{2+}	TEB		
Mpt_1 AO 0-25	0.23	0.19	0.4	0.4	1.22	3.22	37.9
AB 25-50	0.14	0.28	0.4	0.6	1.42	3.82	37.2
Bt1 50-90	0.12	0.25	0.8	1.2	2.37	5.97	41.6
Bt1 90-170	0.23	0.08	0.6	0.8	1.71	4.11	41.6
Range	0.12-0.23	0.08-0.28	0.4-0.8	0.4-1.2	1.22-2.37	3.22-5.97	37.2-41.6
Mean	0.18	0.20	0.55	0.75	1.68	4.28	39.6
Mpt_2 AO 0-22	0.25	0.20	0.6	2.0	3.25	5.85	55.6
AB 22-46	0.19	0.14	0.6	0.8	1.73	4.13	41.9
Bt1 46-100	0.21	0.10	0.8	0.6	1.71	3.71	46.1
Bt2 100-180	0.23	0.19	0.6	0.2	1.22	2.82	43.3
Range	0.19-0.25	0.1-0.2	0.6-0.8	0.2-2.0	1.22-3.25	2.82-5.85	41.9-55.6
Mean	0.22	0.16	0.65	0.9	1.98	4.13	46.7
Mpt_3 AO 0-20	0.21	0.33	0.8	0.6	1.94	3.54	54.8
AB 20-46	0.19	0.10	1.2	0.8	2.29	3.29	69.6
Bt1 46-80	0.23	0.26	0.4	0.2	1.09	3.89	28.0
Bt2 80-150	0.08	0.11	0.6	0.2	0.99	3.79	26.1
Range	0.08-0.23	0.10-0.33	0.4-1.2	0.2-0.8	0.99-2.29	3.29-3.89	26.1-69.6
Mean	0.18	0.2	0.75	0.45	1.58	3.63	44.6
Over all Average	**0.19**	**0.19**	**0.65**	**0.70**	**1.75**	**4.01**	**43.64**

Mpt_1 = Ada Soil, Mpt_2 = Agu Orba Soil, Mpt_3 = Agu-Ekwegbe Soil, Na^+ = Sodium, K^+ = Potassium, Ca^{2+} = calcium, Mg^{2+} magnesium, TEB = total exchangeable acidity, ECEC = effective cat ion exchange capacity, B.S = base saturation.

Table 28 Summary of exchangeable bases of Ajali Formation

Mapping Units /Horizons (cm)	Total Exchangeable Bases (cmol kg^{-1}).					ECEC (cmol kg^{-1}).	B.S (%)
	Na^+	K^+	Ca^{2+}	Mg^{2+}	TEB		
Apt_1 AO 0-35	0.06	0.18	0.8	0.4	1.44	4.44	32.4
AB 35-56	0.14	0.16	0.4	1.6	2.3	6.3	36.5
Bt1 56-100	0.21	0.19	0.8	0.8	2.0	4.6	43.5
Bt2 100-180	0.17	0.21	0.8	0.4	1.58	2.78	56.8
Range	0.06-0.21	0.16-0.21	0.4-0.8	0.4-1.6	1.44-2.3	2.78-6.3	32.4-56.8
Mean	0.15	0.19	0.7	0.8	1.8	4.5	42.3
Apt_2 AO 0-21	0.19	0.23	0.8	0.4	1.62	3.22	50.3
AB 21-46	0.23	0.11	0.6	0.6	1.54	5.14	30.0
Bt1 46-80	0.14	0.25	0.4	1.0	1.79	3.39	33.2
Bt2 80-180	0.19	0.23	0.8	1.6	2.82	4.82	58.5
Range	0.14-0.23	0.11-0.23	0.4-0.8	0.4-1.6	1.54-2.82	3.22-5.14	30-50.3
Mean	0.19	0.21	0.65	0.9	1.94	4.14	43
Apt_3 AO 0-30	0.29	0.42	0.6	0.8	2.11	3.71	56.9
AB 30-53	0.17	0.17	0.4	0.4	1.14	2.94	38.8
Bt1 53-100	0.33	0.06	0.4	0.6	1.39	3.39	41.0
Bt2 100-180	0.25	0.23	0.6	0.8	1.88	3.88	48.5
Range	0.17-0.33	0.06-0.42	0.4-0.6	0.4-0.8	1.14-2.11	2.94-3.88	38.8-56.9
Mean	0.26	0.22	0.5	0.65	1.63	3.48	46.3
Over all Average	**0.20**	**0.20**	**0.62**	**0.78**	**1.80**	**4.05**	**43.87**

Apt1 = Iheaka Soil, Apt_2 = Ede-Oballa Soil, Apt_3 = Aku Soil, Na^+ = Sodium, K^+ = Potassium, Ca^{2+} = calcium, Mg^{2+} magnesium, TEB = total exchangeable acidity, ECEC = effective cat ion exchange capacity, B.S = base saturation.

4.6.2.9 Soil Organic Matter (g/kg).)

In the soils of Mamu formation, there was no defined pattern along the profile. Organic matter had highest value at Mpt_3 (range = 3.8 to 5.3, mean value = 4.5) followed by Mpt_2 (ranges = 2.3-8.3, mean = 4.4), while the least value (range = 0.38 to 4.5, mean = 4.2) was obtained at Mpt_1 (Table 29).

In the soils of Ajali formation, maximum value was obtained at both Apt_1 and Apt_2. Apt_1 ranges from 1.5 to 12.1, while Apt_2 ranges from 2.3 to 9.8 and both have mean value of 6.8. The least value was obtained at Apt_3 with a range of 0.8 to 5.3 with mean of 3.6 (Table 30).

4. 6.2.10 Available Phosphorus (mg/kg)

The available phosphorous in part per million (mg/kg) had no defined pattern along the profile of the soils of both Mamu and Ajali formations. In Mamu formation, highest value was obtained at Mpt_1 with a range of 5.6 to 8.39 and mean of 7.0. Least value was obtained at Mpt_2 with a range of 4.66 to 7.46 and mean of 6.06. Mpt_3 ranged from 5.6 to 7.46 with mean value of 6.76 (Table 29).

In the soils of Ajali formation, the highest value was obtained at Apt_3 with a range of 6.53 to 7.46 and mean of 9.09. Least value was obtained at Apt_2 with a range of 3.73 to 8.39 and mean of 5.6. Apt_1 ranges from 6.54 to 8.39 with a mean value of 7.46 (Table 30).

4. 6.2.11 Total Nitrogen (g/kg)

The values of total Nitrogen had a defined pattern along the profiles of the soils of both formations. In Mamu formation, highest percentage value was obtained at Mpt_1 with a range of 0.06 to 0.5 and mean of 0.15. Least percentage value was obtained at Mpt_3 with a range of 0.06 to 0.08 and mean of 0.07. Mpt_2 ranges from 0.06 to 0.1 with mean of 0.09 (Table 29).

In the soils of Ajali formation, maximum value was obtained at Apt_2 with a range of 0.08 to 0.1 and mean value of 0.09. Least value was recorded at Apt_1 and Apt_3 with a range of 0.06 to 0.1 and mean of 0.07 in both (Table 30).

Table 29 Summary of chemical properties in Mamu Formation profiles

Mapping Units /Horizons (cm)	SOC (g/kg)	S0M (g/kg)	Available Phosphorus (mg/kg)	Total N (g/kg)
Mpt_1 AO 0-25	2.2	3.8	7.46	0.1
AB 25-50	2.6	4.5	6.53	0.06
Bt1 50-90	3.5	3.8	5.60	0.06
Bt1 90-170	2.6	4.5	8.39	0.06
Range	2.2 – 3.5	3.8 – 4.5	5.6 – 8.39	0.06 – 0.1
Mean	2.7	4.2	7.0	0.07
Mpt_2 AO 0-22	4.8	8.3	4.66	0.1
AB 22-46	2.6	4.5	7.46	0.08
Bt1 46-100	1.3	2.3	5.60	0.08
Bt2 100-180	1.3	2.3	6.53	0.08
Range	1.3 – 4.8	2.3 – 8.3	04.66 – 7.46	0.08 – 0.1
Mean	2.5	4.4	6.06	0.05
Mpt_3 AO 0-20	3.1	5.3	5.60	0.06
AB 20-46	2.2	3.8	6.53	0.11
Bt1 46-80	2.6	4.5	7.46	0.06
Bt2 80-150	2.6	4.5	7.46	0.06
Range	2.2 – 3.1	3.8 – 5.3	5.6 – 7.46	0.06 – 0.11
Mean	2.6	4.5	6.76	0.07
Average Values	**2.62**	**4.34**	**6.61**	**0.08**

Mpt_1 = Ada Soil, Mpt_2 = Agu Orba Soil, Mpt_3 = Agu-Ekwegbe Soil, SOC = soil organic carbon, SOM = soil organic matter, N = nitrogen.

Table 30 Summary of chemical properties in Ajali Formation profiles

Mapping Units /Horizons (cm)	SOC (g/kg)	S0M (g/kg)	Available Phosphorus (mg/kg)	Total N (g/kg)
APt1 AO 0-35	7.0	12.1	7.46	0.14
AB 35-56	3.5	6.1	6.54	0.3
Bt1 56-100	4.4	7.6	7.46	0.08
Bt2 100-180	0.9	1.6	8.39	0.06
Range	0.9 – 7.0	1.6 – 12.1	6.54 – 8.39	0.06 – 0.3
Mean	4.0	6.8	7.46	0.15
APt2 AO 0-21	5.3	9.1	5.60	0.06
AB 21-46	5.7	9.8	4.66	0.1
Bt1 46-80	3.5	6.1	3.73	0.1
Bt2 80-180	1.3	2.3	8.39	0.08
Range	1.3 – 5.7	2.3 – 9.8	3.73 – 8.39	0.06 – 0.01
Mean	4.0	6.8	5.60	0.09
APt3 AO 0-30	2.6	4.5	6.53	0.06
AB 30-53	3.1	5.3	7.46	0.08
Bt1 53-100	0.4	0.8	7.46	0.08
Bt2 100-180	2.2	3.8	7.46	0.06
Range	0.4 – 3.1	0.8 – 5.3	6.53 – 7.46	0.06 – 0.08
Mean	2.1	3.6	9.09	0.07
Average Values	**2.62**	**4.34**	**6.61**	**0.10**

APt1 = Iheaka Soil, APt_2 = Ede-Oballa Soil, APt_3 = Aku Soil, SOC = soil organic carbon, SOM = soil organic matter, N = nitrogen.

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4.7 Correlation Co-Efficient between some Soil Properties

In Ajali formation, the Mean Weight Diameter (MWD) has a positive correlation with Soil Organic Matter SOM (r = 0.480), Water/Calgon Dispersion Ratio (DR) (r = 0.154), Percentage Aggregate Stability PAS (r = 0.982) and Percentage State of Aggregation PSA (r = 0.982) but a negative correlation with the percentage Clay (r = -0.601). Percentage Clay has a positive correlation with the Effective Cat ion Exchange Capacity ECEC (r = 0.673) but a strong negative correlation with both Percentage Aggregate Stability (PAS) r = -0.605 and Percentage State of Aggregation PSA (r = -0.568) The Percentage Fine Sand plus Silt PFSS has a positive correlation with SOM (r = 0.182) but a negative correlation with exchngeable sodium percentage Na^+ (r = 0.420 The Water/Calgon Dispersion Ratio DR has a positive correlation with ECEC (r = 0.380) (Table 31)

In Mamu formation, the Mean Weight Diameter MWD has a strong positive correlation with the Percentage State of Aggregation PSA (r = 0.940) and Percentage Aggregate Stability PAS (r = 0.971), but a negative correlation with percentage Clay (r = 022), the Percentage Fine Sand plus Silt PFSS (r = -0.678), Water/Calgon Dispersion Ratio DR (r = -0.766). The percentage Clay has a positive correlation with ECEC r = 0.512, SOM (r = 0.515) and DR (r = 0.372). The Percentage Fine Sand plus Silt PFSS has a strong negative correlation with the Percentage State of Aggregation PSA r = -0.547 and Percentage Aggregate Stability PAS (r = -0.686). The Water/Calgon Dispersion ratio has a positive correlation with ECEC (r = 0.441) (Table 32)

Table 31 Main Correlation Mamu Formation

	MWD	Clay	SOM	PFSS	DR	Na^+	ECEC	PSA	PAS
MWD	-								
Clay	-.022	-							
SOM	.069	.515	-						
PFSS	-.678*	-.198	.009	-					
DR	-.766**	.372	.023	.300	-				
Na+	.023	-.248	.156	.221	-.102	-			
ECEC	-.068	.512	.589*	-.129	.441	-.159	-		
PSA	.940**	.062	.172	-.547	-.767**	-.112	-.062	-	
PAS	.971**	.072	.113	-.686*	-.717**	-.140	-.016	.979**	-

* Correlation is significant at the 0.05 level (2-tailed).

** Correlation is significant at the 0.01 level (2-tailed).

MWD = Mean Weight Diameter, SOM = Soil Organic Matter, PFSS = Percentage Fine Sand plus Silt, DR = Water/Calgon Dispersion Ratio, Na^+ = Exchangeable Sodium, ECEC = Effective Cat ion Exchange Capacity, PSA = Percentage State of Aggregation, PAS = Percentage Aggregate Stability

Table 32 Main Correlation Ajali Formation

	MWD	Clay	SOM	PFSS	DR	Na^+	ECEC	PSA	
MWD	-								
Clay	-.601*	-							
SOM	.480	-.176	-						
PFSS	-.251	.128	.180	-					
DR	.154	-.137	.598*	-.319	-				
Na^+	.029	-.129	-.550	-.420	-.143	-			
ECEC	-.300	.673*	.326	.023	.384	-.200	-		
PSA	.982**	-.568	.588*	-.244	.305	-.029	-.166	-	
PAS	.982**	-.605*	.480	-.330	.290	.064	-.244	.989**	-

*Correlation is significant at the 0.05 level (2-tailed).

**Correlation is significant at the 0.01 level (2-tailed).

MWD = Mean Weight Diameter, SOM = Soil Organic Matter, PFSS = Percentage Fine Sand plus Silt, DR = Water/Calgon Dispersion Ratio, Na^+ = Exchangeable Sodium, ECEC = Effective Cat ion Exchange Capacity, PSA = Percentage State of Aggregation, PAS = Percentage Aggregate Stability

CHAPTER FIVE

DISCUSSION

The disparity between the numbers of erosion sites in the two geological formations is two wide. This is not a factor of land mass but a factor of soil type, land cover, and topography. Taking a look at the eastern aspect of the Udi-Nsukka table land, the inter-phase between the two geological formations studied was under heavy degradation due to the variation in geological topography and altitude which gave rise to a steep slope inter-phase. According to Abegunde *et al* (2006) the steeper the slope of a field, the greater the amount of soil loss from erosion by water.

Due to this variation, the run off from the top of the table land moves with tremendous speed down the slope resulting in land crip, gully erosions and colluvial deposits. Pimentel, (2006) stressed that in the developing countries, soil erosion is particularly severe on small farms that are often located on marginal lands where the soil quality is poor and the topography is frequently steep. The worst is that the colluvium was only sand deposits while the clay and silt were moved down slowly to the next geology (Nkporo Formation).

The gully affected areas which constitute parts of Ukehe, Ekwegbe, Umunko, Opi, Akira, Ezimo, Orba, Obollo and Imilike were under heavy deforestation. People carelessly cut down trees for timber and fire woods. Within the Ajali formation, erosion sites were mainly due to anthropogenic factors while Mamu formation can be attributed to topography and impact from run off from Ajali formation. On their own view, Brady and Weil (1999) pointed out that the environmental and economic damages suffered by sites on which the eroded soil materials are deposited may be as great as or greater than that incurred on the sites from which the soil material was removed. Considering Ajali as the site from which the eroded materials are collected while Mamu is the site which the sand fractions are deposited, the poor soil condition in both Mamu and Ajali formations had left a high percentage of the area with poor vegetation. This had made the area more vulnerable to soil erosion.

5.1 Erosional features

The difference in the slope of both formations can be pointed out as one of the factors responsible for the erodibility of the soil. This fact was supported by Pimentel (2006) who pointed out that the impact of soil erosion is intensified on sloping land, where often, more than half of the surface soil is carried away as the water splashes downhill into valleys and water ways. The widths of the gullies in the soils of both formations were statistically the same at 95% confidence interval.

Increase on the width of erosion is a factor of soil shear strength, clay type and amount and the deepness of the profile. The two formations had very deep bed-rock as revealed by the deep gullies at Agu-Ukehe, Ezimo, Agu-Ekwegbe, Imilike-Agu, Agu-Opi and Agu-Orba. The above fact joined with the values of the average percentage aggregate stability of the two formations; 42.78 for Mamu formation and 36.24 for Ajali formation (table 17) agreed with Huddec *et al.,* (2006) who commented that landslides and related phenomena contribute to gully enlargement in southeastern Nigeria, while floods commonly occur at lower elevations, where river channels are choked with the sand from gullies in the adjacent uplands. The high erodibility of the soils of the two formations is obvious considering the low clay fraction; 13% (average clay fraction in Ajali formation) and 9% (average clay fraction in Mamu Formation).

Factors that determine the length, depth and width of gully erosion can be attributed to the soil erodibility which is a factor of soil physical characteristics (Abegunde *et al*, 2006). The depth and length were statistically different using **t-test** analysis. Sand, sandy loam and loam-textured soils tend to be less erodible than silt, very fine sand, and certain clay textured soils (Olori, 2006). Soils of the study area were made of sandy loam, loamy sand and sand, but the case was increased by the long, steep slope at the inter-phase of the two geological formations. The run off as it moves with builders would be scraping the soil and more dept would be created. The increase in depth and length as it concerns the Ajali formation can be attributed solely to the sloppy nature of the inter-phase, and the steepness of the slope. Run-off along this slope would continue to deepen until a hard rock is met, and if not, the depth would continue year after year.

The action of this deepening can also be viewed as a way nature is leveling the earth surface. Brady and Wail (1999) called it a natural leveling process. The after effect of some of these great gullies led to the inception of river heads. One of the field discoveries in this project includes that majority of the river in eastern Nigeria has their sources at Udi-Nsukka table land with higher percentage at the Nsukka Area which incidentally is the study area.

The positive correlation between erosional features in Mamu Formation indicates that increase in length has a corresponding increase in both width and Depth in Mamu formation but not to a significant level. This may be due to the soil type which is more of sandy loam with high infiltration rate. The positive and significant correlation between the width and depth in Mamu formation can be suggested as a factor of poor soil structure. The soil structure which the aggregate stability revealed to be low can easily slide and slide as the depth increase. This means that as the soil deepens the rate of widening also increases correspondingly.

In Ajali formation, the case differs since all the features have a positive and significant correlation. This can be suggested to be as a result of the soil type long steep slope, and high slope gradient especially at the eastern escarpment. As water flows down hill, the soil which has weak structure and low clay and silt, and SOM would be carried away by the heavy flood with a high velocity. The long and steep slope would help to promote the flow and then result in land slide and deepening as the length increases.

5.2 Effects on the Soil Physical Properties

The susceptibility of soil to water erosion depends on the aggregate break down while particle detachment depends on aggregate stability and particle size distribution characteristics (Gabriel, 1993). The results of the soil water stable aggregate (WSA) at macro level > 0.5mm was low in both soils. There was no significant difference between the Mean Weight Diameter (MWD), percentage state of aggregation and percentage Aggregate Stability. The MWD having a low value 1.1mm in the soils of Mamu formation and 1.2mm in the soil of Ajali formation is an indication that the soil is highly susceptible to erosion. Igbokwe *et al.,* (2008) documented that in south-eastern Nigerian, the soil is mostly loose and very porous. The soil particles are not consolidated and therefore detach easily when impacted by water flow. On this note, the soils of the study area which was predominantly loamy sand and sandy loam (Tables 21 and 22) have been heavily degraded by soil erosion.

Ramezanpour *et al.,* (2010) recorded that increase in silt and fine sand particles increase the susceptibility of the soil to erosion. Both soils of the studied area have low silt content (8% in the soil of Ajali and 5% in the soil of Mamu) but the fine sand was on average medium (18% Ajali and 49% In Mamu). These might be one of the factors promoting the soil erodibility. Increase in sand fraction decreases the soil erodibility, (Ramezanpour *et al.,* 2010) but the result of this study is in contrast following the fact that the soil aggregate stability is very weak, and the soils are on a sloppy land. Ramezanpour *et al.,* (2010) agued that the above statement was due to infiltration which leads to reduced run off but in contrast, south-eastern Nigeria experiences heavy downpour to the point that the soil would saturate and run off starts with rill, interril and finally dangerous gullies. This fact was supported by the work of Bobe (2004) who stated that run off occurs when rainfall intensity exceeds infiltration rate. At micro level, the water/calgon dispassion ratios (DR) were more than 0.50 which is the least value for structurally strong aggregates. Salako, (2003) pointed out that if the ratio is higher than 50% (0.50) which could be up to 87% for the coarse textured Alfisols of south-western Nigeria, the soils are structurally weak. The soils of the studied area had an average value of water/calgon dispersion ratio (0.78) which indicates weak structure.

5.3 Effects on Soil Nutrition

The t-test analysis for all the chemical nutrients revealed no significant difference in all. The study area had suffered severe wash down by water causing gully erosion. Gully erosion affected both Mamu and Ajali formations and led to loses to all the soil nutrients.

In the study area, low soil pH affected the soil structure and promoted erodibility. This can be attributed to heavy rainfall, the acidic nature of the underlying geology (false bedded sand stones and coal measures) and acidic precipitation. The annual rainfall around the study area is about 1750mm (Akamigbo *et al.,* (1987)) which extends up to seven months (from April to October) in a year. This was reported sufficient for leaching and colloid transportation via run off (Fasina, 2007).

The organic matter content of the soils was generally low averaging 5.8g/kg in the soils of Ajali Formation and 4.3g/kg in those of Mamu Formation. These values are less than the critical value for plant nutrient which is 20g/kg (Fasina, 2007). The AO horison had the highest values which decreased down the profile in all the profile pits. Ramezanpour *et al.,* (2010) maintained that organic carbon is one of the most important factors in aggregate stability because it protects the soil structure against raindrop impact or run off. Since the value is very low, it then means that the soils of the studied area are highly susceptible to erosion. Fasina (2007) observed that low organic matter may be due to high temperature and relative humidity which promotes rapid mineralization of organic matter. Pimentel (2006) commented that once the organic matter layer is depleted, the productivity of our ecosystem, as measured by plant biomass, declines both because of the degraded soil structure and the depletion of nutrition contained in the organic matter.

There was a low nitrogen content averaging 0.1g/kg in the soil of Ajali and 0.07g/kg on the soils of Mamu formation. When compared with the critical value 0.20g/ kg for most tropical soils (Fasina, 2007), the values are generally low.

The soil effective cat ion exchange capacity (ECEC) values were very low in both geological formations. These values indicate that the soils have low potentials for retaining plant nutrients. These low values when coupled with low pH, low organic carbon and nitrogen signifies low soil fertility as a result of severe land wash by soil erosion.

The result revealed medium values of calcium and magnesium in both soils (0.65 cmol kg^{-1} and 0.70 cmol kg^{-1} in the soil of Mamu and 0.62 cmol kg^{-1} and 0.80cmol kg^{-1} on the soil of Ajali formation. compared with critical values 0.15 cmol kg^{-1} and 0.2 cmol kg^{-1} respectively (Fasina, 2007). This can suggest that the soil parent material contains these elements

Soil phosphorus was generally low (6.6mg/kg in the soils of Mamu and 6.7mg/kg in the soils of Ajali formation) when compared with the critical value (8-15m/kg) (Fasina, 2007). These values indicate that severe wash due to erosion has grossly affected the studied area.

In general, the soil water erosion in the soils of both Ajali and Manu formations has left the area impoverished and from year to year the situation is getting worse due to increasing anthropogenic effects on the soil cover (deforestation and poor tillage cultivation) and soil disruption due to sand and stone excavation.

CHAPTER SIX

CONCLUSION

The study was on identification and characterization of soil Gully erosion in two Geological formations in eastern Nigeria using the Global Positioning System (GPS) and Aerial Photograph.

Results revealed a general presence of gully erosion on both formations. The gully erosion features had an average length of 1606.5 meters, an average width of 64.2 meters and an average depth of 8.6 meters in Ajali formation. On the other hand, an average length of 484.2 meters, average width of 6.5 meters and an average depth of 3.7 meters were obtained in Mamu Formation. In the soils of both formations, poor soil structure and aggregate stability had left the soil prone to erosion. The natural resource miners also contributed in devastating the studied area in effort to harvest wood and timbers and excavate sand and stones.

Both geologic formations are very deep which promoted deep, long and wide gullies. The sandy nature of the soil can be suggested to have promoted the menace while the positive correlation among length, width and depth are all in support that the two geological formations promote soil erosion. The soils of both Mamu and Ajali formations have high level of fine sand which may be contributing to the sliding of the soil. The soil when detached would be carried away and if saturated with water due to the poor aggregate stability would slide as a result of poor soil structure

There was no significant difference in all the soil chemical properties between the soils of the two geological formations even though both were badly affected nutritionally. The soil organic matter (SOM), nitrogen (N), the effective cat ion exchange capacity (ECEC), soil acidic level, and Phosphorus (P) were generally low, while only magnesium and calcium are of medium availability.

The global positioning system (GPS), the satellite photo and the geographic information system (GIS) all made the study easy. Gully erosion inception, development, and hazardous effects can be monitored easily using the GPS and GIS. The GPS helps in real-time investigation and monitoring.

6.1 Preventive and control measures

Soil erosion by water occurs when bare-sloped soil surface is exposed to rainfall, and the rainfall intensity exceeds the rate of soil intake, or infiltration rate, leading to soil-surface runoff. Since soil erosion can occur in two stages: (1) detachment of soil particles by raindrop impact, splash, or flowing water; and (2) transport of detached particles by splash or flowing water. It means that it is a physical process requiring energy, and its control requires certain measures to dissipate this energy.

The most effective way to control erosion is to maintain a permanent surface cover on the soil surface, such as pasture or cover crops. Therefore, areas that is highly susceptible to erosion need to be considered for soil conservation programs. Conservation tillage which helps to protect the soil cover is recommended. Erosion caused by tillage damages soil immensely. The most desirable form of tillage is conservative tillage which leaves a protective blanket of leaves. To this, effort should be intensified by the local vigilante groups to preserve their concerned areas while we wait for the governments to intervene in the soil and land preservation programs. This is because the soil, stone and wood harvesters care less for the implications of their action. The sand, stone and fire wood harvesters have their separate adverse contributions.

The planting of cover crops and ornamental trees along the roads to schools, market areas and governmental establishments is recommended. A soil conservation measure such as planting of Vertiver grass at the water sediment lodge is also recommended. As it concerns deforestation, incessant felling of trees is condemned and artificial forestry encouraged. Those living around the erosion vulnerable areas should implement aforestation .This should be spear-headed by town leaders and local Government town planning authorities.

Proper waste management remains a sector under less consideration in Nigeria. Therefore, waste recycling is recommended to correct the water clogging of canals. The use of organic wastes and manure from livestock can help improve the soil texture and quality. This will go a long way to increase the soil nutritional quality, soil viability and food security.

In other words, individual efforts is of major important to checkmate the way people drink and throw away water sachets, milk sachets, fruit juice cans and other non-biodegradable materials. These promote the clogging of water ways and over-spill from the drainage canals which in turn result into gullies in the urban areas.

The use of vegetative barrier to create natural terraces is recommended. This involves the use of grasses or shrubs planted at contours to slow down run-off, trap sediments and eventually built terraces.

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Appendix

Appendix I. Aggregate Stability values of the two Formations

Mapping Units /Horizons	MWD	Stat of Aggregation (%)	Aggregate Stability (%)
MP AO	2.75336	61.88	84.12
AB	1.064468	34.8	47.77
Bt1	1.7102	40.64	59.76
Bt1	0.804812	8.64	15.67
MP AO	0.643632	23.04	23.37
AB	0.15666	.44	0.45
Bt1	0.380168	9.6	9.75
Bt2	0.262298	5.16	5.28
MP AO	2.452488	65.6	77.03
AB	1.388412	42.72	47.30
Bt1	0.961976	33.00	34.48
Bt2	0.633938	28.6	29.90
AP AO	1.519488	43.48	53.95
AB	0.65817	20.08	24.78
Bt1	0.668384	18.28	23.34
Bt2	0.517734	7.76	10.18
AP AO	2.841536	66.80	91.61
AB	1.500504	43.00	56.17
Bt1	0.748376	19.88	27.86
Bt2	0.57742	13.72	18.19
AP AO	1.99524	52.64	80.59
AB	1.91906	47.72	72.83
Bt1	0.911492	20.20	31.58
Bt2	0.710634	15.08	22.27
MAU 1	2.688862	43.40	81.76
MAU 2	2.123172	67.6	77.20
MAU 3	3.272198	78.4	89.29
MAU 4	1.99634	52.44	69.88
MAU 5	2.756344	67.8	86.52
AAU 1	2.558426	52.52	83.52
AAU 2	2.45426	65.48	80.01
AAU 3	2.414884	63.16	78.25
AAU 4	2.999012	70.68	92.51
AAU 5	1.441066	39.04	50.05

Appendix II. Particle Size Distribution

Mapping Units	Clay	Silt	Sand	Textural Class
Mp 11	11.0	0.4	85.0	Loamy sand
12	10.0	5.0	85.0	Loamy sand
13	12.0	3.0	85.0	Loamy sand
14	12.0	10.0	78.0	Sand loam
21	18.0	4.0	88.0	Sandy loam
22	2.0	10.0	88.0	Sand
23	4.0	15.0	81.0	Loamy sand
24	4.0	7.0	89.0	Sand
31	3.0	9.0	88.0	Sand
32	1.0	10.0	89.0	Sand
33	13.0	14.0	73.0	Loamy sand
34	19.0	12.0	69.0	Sandy loam
AP11	10.0	3.0	87.0	Loamy Sand
12	22.0	7.0	71.0	Sandy loam
13	20.0	6.0	74.0	Sandy loam
14	16.0	5.0	79.0	Loamy sand
21	10.0	3.0	87.0	Loamy sand
22	14.0	7.0	78.0	Loamy sand
23	10.0	16.0	74.0	Sandy loam
24	20.0	5.0	75.0	Sandy loam
31	10.0	2.0	88.0	Sandy loam
32	11.0	4.0	84.0	Loamy sand
33	11.0	2.0	88.0	Loamy sand
34	12.0	4.0	84.0	Loamy sand
MAU_1	3.0	22.0	75.0	Loamy sand
MAU_2	3.0	10.0	87.0	Loamy sand
MAU_3	30.4	24.0	46.0	Clay loam
MAU4	32.0	18.0	50.0	Clay loam
MAU_5	2.0	2.0	96.0	Sand
AAU_1	2.0	2.0	96.0	Sand
AAU_2	0.1	4.0	95.0	Sand
AAU_3	0.3	4.0	93.0	Sand
AAU_4	1.0	2.0	97.0	Sand
AAU5	6.0	3.0	91.0	Sand

Appendix III
Some Ratios of the Particle Size Distribution

Mapping Units	Dispersion Ratio	Fine Sand	Coarse Sand	Silt/Clay	Silt/Silt+C lay	Fine Sand/ Coarse Sand
Mp 11	0.70	19.0	66.0	0.30	0.23	0.29
12	0.80	15	70	0.38	0.28	0.21
13	0.84	19	66.0	0.30	0.23	0.29
14	0.82	19	59.0	0.81	0.45	0.32
21	0.90	76	12.0	0.84	0.46	6.33
22	0.84	75.0	13.0	4.17	0.81	6.25
23	0.84	72.0	9.0	3.41	0.77	8.00
24	0.84	76.0	13.0	3.17	0.76	5.85
31	0.52	41	47.0	3.36	0.77	0.87
32	0.74	56.0	33.0	7.14	0.88	1.70
33	0.78	60	13.0	1.20	0.55	4.62
34	0.82	61.0	8.0	0.67	0.40	7.63
AP11	0.88	30.0	57.0	0.52	0.34	0.53
12	0.81	17	54.	0.29	0.22	0.31
13	0.88	19.0	55.0	0.22	0.18	0.35
14	0.55	250	540	0.27	0.21	0.46
21	0.66	22.0	65	0.23	0.19	0.34
22	0.88	18.0	61.0	0.44	0.31	0.30
23	0.84	11.0	63.0	1.44	0.62	0.18
24	0.66	18.0	57.0	0.22	0.18	0.32
31	0.88	20.0	68.0	0.13	0.12	0.29
32	0.84	7.0	78.0	0.30	0.22	0.09
33	0.66	19.0	69.0	0.12	0.11	0.28
34	0.81	15.0	69.0	0.27	0.22	0.22
MAU_1	0.90	69.0	6.0	9.33	0.90	11.50
MAU_2	0.66	26.0	61.0	4.33	0.81	0.43
MAU_3	0.95	43.0	3.00	0.67	0.40	14.30
MAU4	0.92	46.0	4.0	0.58	0.37	11.50
MAU_5	0.63	34.0	62.0	0.58	0.37	0.50
AAU_1	0.63	28.0	68.0	0.58	0.37	0.41
AAU_2	0.29	16.0	79.0	11.00	0.92	0.20
AAU_3	0.51	16.0	77.0	2.00	0.69	0.21
AAU_4	0.85	31	66.0	1.00	0.5	0.47
AAU5	0.73	85.0	0.6	0.38	0.27	14.2

Appendix IV

Laboratory Calculation Procedure
Soil Analysis

i) Particle size Analysis
This was done according to Bouyoucos (1936) hydrometer method using NaOH in place of sodium hexametaphosphate (Calgon) as the dispersing agent and soaking for 24 hours. The textural classes were determined using the textural triangle and the percentage of clay, silt and total sand.

ii) **Chemical Analysis**
The electrometric method outlined in the laboratory manual by Enwezor (1980) was used to determine the soil pH. This was done in duplicate for water and 0.1 N KCL solutions with soil liquid ratio of 1: 2.5. The soil liquid content was stirred for 30 minutes and the pH determined using the pH meter.

Organic carbon was determined using Walkley and Black (1934) method. The percentage organic matter was calculated by multiplying the percentage carbon by 1. 724.

The total nitrogen was determined by micro kjedahl distillation method of Jackson (1962).

The available phosphorus was determined using Bray II method after Bray and Kurtz (1945).

The exchangeable bases of Na^{+}, K^{+}, Ca^{2+} and Mg^{2+} were determined using Jackson (1962) method Na^{2+} and K^{+} were determined by flame photometer.

The effective cat ion exchange capacity (ECEC) was calculated by summing up the total exchangeable bases and total exchangeable acidity.

The base saturation was determined by summing up the exchangeable bases and dividing the sum total by the effective cat ion exchange capacity (ECEC) and then multiplying by 100 to gate the percentage value.

$$B.S\ (\%) = \frac{TEB}{ECEC} \times \frac{100}{1}$$

(1) $$C.E.C = T \times N \times \frac{1}{A} \times \frac{100}{X} \quad \text{in meq/100g soil}$$

Where T = titre value.
N = Normality of titrant.
I = quantity of leachate collected (100g)
X = Quantity of soil leached 5gram
A = aliquat of leachate used 50mls

(2) $$\text{Base saturation } (\%) = \frac{S}{E} \times \frac{100}{1}$$

Where S=Total exchangeable base
E=Effective cation exchange capacity

(3) **Percentage Soil Fractions**
% Clay = $H^{1}R/WS \times 100$
% Silt = $(H^{0}R-H^{1}R)/WS \times 100$

% Total Sand =100 – (Clay + Silt)
% Coarse sand = Wc/Ws X 100
% Fine Sand = Total sand - coarse sand
Where H^0R = Hydrometer reading at 4 seconds.
H^1R = Hydrometer readings at 2 hrs.
Ws = Weight of Sample of Soil
Wc =Weight of Coarse Sand after sieving with 0.25 mesh sieve.

3) Organic Matter:

$$\% \text{ Carbon} = T \times N \times 0.003 \times \frac{100}{X} \times 1.33$$

Where N = Normality of $K_2Cr_2O_7$ = 1.1
T = Titre difference (i.e blank – titre with soil)
X = Weight of soil sample taken
NB 1 ml $K_2Cr_2O_7$ = 3mg C.

Percentage organic matter was simply obtained by multiplying %carbon by 1.724.

4) Percentage Nitrogen:

$$\% \text{ Total N} = T \times N \times \frac{AN}{100} \times \frac{100}{X}$$

Where T = Titre
N = Normality of HCL = 0.01
AN = Atomic wt of Nitrogen = 14
X = Wt of soil sample = 5g.

5) Calcium Meq/100g soil $= \frac{T}{A} \times \frac{L}{5} \times \frac{100}{X}$

Where T = Titer
L = Volume of leachate Collected (100ml)
A = Volume of aliquot used 50 ml
N = Normality of EDTA (0.011)
X = Wt of soil sample = 5g.

7) Magnesium – same as in Calcium.

8) Exchangeable acidity Meg/100g soil $= T \times \frac{L \times N}{A} \quad \frac{100}{X}$

Where T = Titre using 0.05 NaoH
C = leachate collected (100mls)
N = Aliquot used
A = Normality of NaOH (0.05N).
X = Wt of soil sample = 5g.

Al^{3+}. The same formular as above. The value of H+was gotten by subtracting Al^{3+} from TEA to gate the value of H^+ in meg/100, soil.

Appendix V
Results of statistical analysis of some chemical and physical parameters

1 *** Summary of Base Saturation ***

Sample	Size	Mean	Variance	Standard deviation	Standard error of mean
A_BS	17	47.53	141.7	11.90	2.887
M_BS	17	49.88	264.8	16.27	3.947

Standard error for difference of means 4.890
95% confidence interval for difference in means: (-12.31, 7.608)
*** Test of null hypothesis that mean of A_BS is equal to mean of M_BS ***
Test statistic t = -0.48 on 32 d.f.
Probability = 0.634

2 *** Summary o soil Organic Matter***

Sample	Size	Mean	Variance	Standard deviation	Standard error of mean
A_SOM	17	0.3665	0.03819	0.1954	0.04739
M_SOM	17	0.4588	0.1914	0.4375	0.1061

Standard error for difference of means 0.1162
95% confidence interval for difference in means: (-0.3333, 0.1486)
*** Test of null hypothesis that mean of A_SOM is equal to mean of M_SOM ***
Test statistic t = -0.79 on approximately 22.14 d.f.
Probability = 0.435

3 *** Summary of Total Exchangeable Acidity ***

Sample	Size	Mean	Variance	Standard deviation	Standard error of mean
A_TEA	17	2.306	0.8056	0.8975	0.2177
M_TEA	17	2.082	0.5753	0.7585	0.1840

Standard error for difference of means 0.2850
95% confidence interval for difference in means: (-0.3570, 0.8041)
*** Test of null hypothesis that mean of A_TEA is equal to mean of M_TEA ***
Test statistic t = 0.78 on 32 d.f.
Probability = 0.439

4 *** Summary of Total Exchangeable Base***

Sample	Size	Mean	Variance	Standard deviation	Standard error of mean
A_TEB	17	1.980	0.3506	0.5921	0.1436
M_TEB	17	2.146	1.223	1.106	0.2682

Standard error for difference of means 0.3043
95% confidence interval for difference in means: (-0.7932, 0.4615)
*** Test of null hypothesis that mean of A_TEB is equal to mean of M_TEB ***
Test statistic t = -0.55 on approximately 24.48 d.f.
Probability = 0.591

5 *** Summary of Total Nitrogen***

Sample	Size	Mean	Variance	Standard deviation	Standard error of mean
A_Total N	17	0.01035	0.00003762	0.006133	0.001488
M_Total N	17	0.01241	0.00009926	0.009963	0.002416

Standard error for difference of means 0.002838
95% confidence interval for difference in means: (-0.007839, 0.003721)
*** Test of null hypothesis that mean of A_To_N is equal to mean of M_To_N ***
Test statistic t = -0.73 on 32 d.f.
Probability = 0.473

6 *** Summary of Available Phosphorus ***

Sample	Size	Mean	Variance	Standard deviation	Standard error of mean
A_VV_P	17	6.639	2.269	1.506	0.3654
M_AVV_P	17	7.736	21.28	4.613	1.119

Standard error for difference of means 1.177
95% confidence interval for difference in means: (-3.557, 1.363)
*** Test of null hypothesis that mean of A_VV_P is equal to mean of M_AVV_P ***
Test statistic t = -0.93 on approximately 19.37 d.f.
Probability = 0.363

7 *** Summaryof soil PH ***

Sample	Size	Mean	Variance	Standard deviation	Standard error of mean
A_pH	17	5.018	0.1578	0.3972	0.09634
M_pH	17	5.059	0.1188	0.3447	0.08360

Standard error for difference of means 0.1276
95% confidence interval for difference in means: (-0.3010, 0.2187)
*** Test of null hypothesis that mean of A_pH is equal to mean of M_pH ***

Test statistic t = -0.32 on 32 d.f., Probability = 0.749

8 *** Summary of Effective Cat ion Exchange Capacity***

Sample	Size	Mean	Variance	Standard deviation	Standard error of mean
A_ECEC	17	4.139	1.108	1.053	0.2553
M_ECEC	17	4.206	1.226	1.107	0.2685

Standard error for difference of means 0.3705
95% confidence interval for difference in means: (-0.8212, 0.6883)
*** Test of null hypothesis that mean of A_ECEC is equal to mean of M_ECEC ***
Test statistic t = -0.18 on 32 d.f.
Probability = 0.859

9 *** Summary of Aggregate Stability ***

Sample	Size	Mean	Variance	Standard deviation	Standard error of mean
AGG_S_A	17	52.18	799.9	28.28	6.860
AGG_S_M	17	49.38	976.5	31.25	7.579

Standard error for difference of means 10.22
95% confidence interval for difference in means: (-18.02, 23.62)
*** Test of null hypothesis that mean of AGG_S_A is equal to mean of AGG_S_M ***
Test statistic t = 0.27 on 32 d.f.
Probability = 0.786

10 ***** Two-sample T-test *****
Variates: AGG_S_A, AGG_S_M.
Probability (under null hypothesis of equal variances) = 0.69
*** Summary ***

Sample	Size	Mean	Variance	Standard deviation	Standard error of mean
AGG_S_A	17	52.18	799.9	28.28	6.860
AGG_S_M	17	49.38	976.5	31.25	7.579

Standard error for difference of means 10.22
95% confidence interval for difference in means: (-18.02, 23.62)
*** Test of null hypothesis that mean of AGG_S_A is equal to mean of AGG_S_M ***
Test statistic t = 0.27 on 32 d.f.
Probability = 0.786

11 ***** Two-sample T-test *****
Variates: MWD_A, MWD_M.
*** Test for equality of sample variances ***
Test statistic F = 1.36 on 16 and 16 d.f.
Probability (under null hypothesis of equal variances) = 0.55
*** Summary ***

Sample	Size	Mean	Variance	Standard deviation	Standard error of mean
MWD_A	17	1.555	0.7524	0.8674	0.2104
MWD_M	17	1.532	1.020	1.010	0.2450

Standard error for difference of means 0.3229
95% confidence interval for difference in means: (-0.6350, 0.6804)
*** Test of null hypothesis that mean of MWD_A is equal to mean of MWD_M ***
Test statistic t = 0.07 on 32 d.f.
Probability = 0.944
***** Two-sample T-test *****

12 Variates: SAGG_A, S_AGG_M.
*** Test for equality of sample variances ***
Test statistic F = 1.31 on 16 and 16 d.f.
Probability (under null hypothesis of equal variances) = 0.59
*** Summary ***

Sample	Size	Mean	Variance	Standard deviation	Standard error of mean
SAGG_A	17	38.80	452.2	21.26	5.157
S_AGG_M	17	39.04	592.6	24.34	5.904

Standard error for difference of means 7.840
95% confidence interval for difference in means: (-16.22, 15.72)
*** Test of null hypothesis that mean of SAGG_A is equal to mean of S_AGG_M ***
Test statistic t = -0.03 on 32 d.f.
Probability = 0.975

13 ***** Two-sample T-test *****
Variates: A_BS, M_BS.
*** Test for equality of sample variances ***
Test statistic F = 1.87 on 16 and 16 d.f.
Probability (under null hypothesis of equal variances) = 0.22
*** Summary ***

Sample	Size	Mean	Variance	Standard deviation	Standard error of mean
A_BS	17	47.53	141.7	11.90	2.887
M_BS	17	49.88	264.8	16.27	3.947

Standard error for difference of means 4.890
95% confidence interval for difference in means: (-12.31, 7.608)
*** Test of null hypothesis that mean of A_BS is equal to mean of M_BS ***
Test statistic t = -0.48 on 32 d.f.
Probability = 0.634

Appendix VI

Glossary of GPS Terms

2D Operating Mode: A two-dimensional GPS position fix that includes only horizontal coordinates (no GPS elevation). It requires a minimum of three visible satellites.

3D Operating Mode: A three-dimensional GPS position fix that includes horizontal coordinates, plus elevation. It requires a minimum of four visible satellites.

Accuracy: A measure of how close an estimate of a GPS position is to the true location.

Acquisition Time: The time it takes a GPS receiver to acquire satellite signals and determine the initial position.

Active Antenna: An antenna that amplifies the GPS signal before sending it to the receiver.

Active Leg: The segment of a route currently being traveled. A "segment" is that portion of a route between any two waypoints in the route.

Almanac Data: Information transmitted by each satellite on the orbits and state (health) of every satellite in the GPS constellation. Almanac data allows the GPS receiver to rapidly acquire satellites shortly after it is turned on.

Altimeter: An instrument for determining elevation, especially an aneroid barometer used in aircraft that senses pressure changes accompanying changes in altitude. The Garmin® eTrex® Vista and Summit models contain a basic GPS with a built-in barometric altimeter.

Analog Signal: The principal feature of analog signals is that they are continuous. In contrast, digital signals consist of values measured at discrete intervals.

Anti-Spoofing: Encryption of the P-code to protect the P-signals from being "spoofed" through the transmission of false GPS signals by an adversary.

Atomic Clock: A very precise clock that operates using the elements cesium or rubidium. A cesium clock has an error of one second per million years. GPS satellites contain multiple cesium and rubidium clocks.

AutoLocate®: This is a proprietary feature of Garmin GPS receivers. A Garmin unit displays the "AutoLocate" status when it is looking for and collecting data from satellites that were visible at its last known or initialized position (almanac data), but it has not collected enough data to calculate a position fix.

Azimuth: The horizontal direction from one point on the earth to another, measured clockwise in degrees (0-360) from a north or south reference line. An azimuth is also called a bearing.

Basemap: Garmin mapping units come with permanently built-in basemaps, which typically include coverage of oceans, rivers, and lakes; principal cities, smaller cities, and towns; interstates, highways, and local thoroughfares; and railroads, airports, and political boundaries. Basemaps are available in a variety of global coverage areas, depending on the user's needs.

Beacon: Stationary transmitter that emits signals in all directions (also called a non-directional beacon). In DGPS, the beacon transmitter also broadcasts pseudorange correction data to nearby GPS receivers for greater accuracy.

Bearing: The compass direction from a position to a destination, measured to the nearest degree (also call an azimuth). In a GPS receiver, bearing usually refers to the direction to a waypoint.

C/A Code: See Coarse/Acquisition Code.

Carrier Frequency: The frequency of an unmodulated output of a radio transmitter. The GPS L1 carrier frequency is 1575.42 MHz. ****

Cartography: The art or technique of making maps or charts. Many GPS receivers have detailed mapping—or cartography—capabilities.

CDI: See Course Deviation Indicator.
CDMA: See Code Division Multiple Access.
Code Division Multiple Access (CDMA): A method whereby many radios use the same frequency, but each one has a unique code. GPS uses CDMA techniques with codes for their unique cross-correlation properties.
Clock Bias: The difference between the indicated clock time in the GPS receiver and true universal time (or GPS satellite time).
Clock Offset: A constant difference in the time reading between two clocks, normally used to indicate a difference between two time zones.
CMG: See Course Made Good.
Coarse/Acquisition Code (C/A Code) : The standard positioning signal the GPS satellite transmits to the civilian user. It contains the information the GPS receiver uses to fix its position and time, and is accurate to 100 meters or better.
COG: See Course Over Ground.
Cold Start: The power-on sequence where the GPS receiver downloads almanac data before establishing a position fix.
Control Segment: A worldwide chain of monitoring and control stations that control and manage the GPS satellite constellation.
Coordinates: A set of numbers that describes your location on or above the earth. Coordinates are typically based on latitude/longitude lines of reference or a global/regional grid projection (e.g., UTM, MGRS, Maidenhead).
Coordinated Universal Time (UTC) : Replaced Greenwich Mean Time (GMT) as the world standard for time in 1986. UTC uses atomic clock measurements to add or omit leap seconds each year to compensate for changes in the rotation of the earth.
Course: The direction from the beginning landmark of a course to its destination (measured in degrees, radians, or mils), or the direction from a route waypoint to the next waypoint in the route segment.
Course Deviation Indicator (CDI): A technique for displaying the amount and direction of crosstrack error (XTE).

Course Made Good (CMG): The bearing from the 'active from' position (your starting point) to your present position.
Course Over Ground (COG): Your direction of movement relative to a ground position.
Course To Steer: The heading you need to maintain in order to reach a destination.
Course Up Orientation: Fixes the GPS receiver's map display so the direction of navigation is always "up."
Crosstrack Error (XTE/XTK): The distance you are off the desired course in either direction.
Datum: A math model which depicts a part of the surface of the earth. Latitude and longitude lines on a paper map are referenced to a specific map datum. The map datum selected on a GPS receiver needs to match the datum listed on the corresponding paper map in order for position readings to match.
DCG®: See Depth Controlled Gain.
Depth Controlled Gain (DCG): A Garmin proprietary technology that automatically adjusts fishfinder sensitivity according to depth, not echo intensity. The result is a much more detailed and accurate picture of bottom structure.
Desired Track (DTK): The compass course between the "from" and "to" waypoints.
DGPS: See Differential GPS.

Differential GPS (DGPS): An extension of the GPS system that uses land-based radio beacons to transmit position corrections to GPS receivers. DGPS reduces the effect of selective availability, propagation delay, etc. and can improve position accuracy to better than 10 meters.
Dilution Of Precision (DOP): A measure of the GPS receiver/satellite geometry. A low DOP value indicates better relative geometry and higher corresponding accuracy. The DOP indicators are GDOP (geometric DOP), PDOP (position DOP), HDOP (horizontal DOP), VDOP (vertical DOP), and TDOP (time clock offset).
Distance: The length (in feet, meters, miles, etc.) between two waypoints or from your current position to a destination waypoint. This length can be measured in straight-line (rhumb line) or great-circle (over the earth) terms. GPS normally uses great circle calculations for distance and desired track.
DOD: The United States Department of Defense. The DOD manages and controls the Global Positioning System.
DOP: See Dilution Of Precision.
Downlink: A transmission path for the communication of signals and data from a communications satellite or other space vehicle to the earth.
DTK: See Desired Track.
Elevation: The distance above or below mean sea level.
Ellipsoid: A geometric surface, all of whose plane sections are either ellipses or circles.

Ephemeris Data: Current satellite position and timing information transmitted as part of the satellite data message. A set of ephemeris data is valid for several hours.
EPE: See Estimated Position Error.
Estimated Position Error (EPE): A measurement of horizontal position error in feet or meters based upon a variety of factors including DOP and satellite signal quality.
Estimated Time Enroute (ETE): The time it will take to reach your destination (in hours/minutes or minutes/seconds) based upon your present position, speed, and course.
Estimated Time Of Arrival (ETA): The estimated time you will arrive at a destination.
ETA: See Estimated Time Of Arrival.
ETE: See Estimated Time Enroute.
Frequency: The number of repetitions per unit time of a complete waveform, as of a radio wave (see L1 and L2 frequencies in this glossary).
Geocaching: A high-tech version of hide-and-seek. Geocachers seek out hidden treasures utilizing GPS coordinates posted on the Internet by those hiding the cache.
Geodetic Datum: A math model representing the size and shape of the earth (or a portion of it).
Geographic Information System (GIS): A computer system or software capable of assembling, storing, manipulating, and displaying geographically referenced information (i.e., data identified according to their location). In practical use, GIS often refers to the computer system, software, and the data collection equipment, personnel, and actual data.
Geosynchronous Orbit: A specific orbit around where a satellite rotates around the earth at the same rotational speed as the earth. A satellite rotating in geosynchronous orbit appears to remain stationary when viewed from a point on or near the equator. It is also referred to as a geostationary orbit.
GIS: See Geographic Information System.
Global Positioning System (GPS): A global navigation system based on 24 or more satellites orbiting the earth at an altitude of 12,000 statue miles and providing very precise,

worldwide positioning and navigation information 24 hours a day, in any weather. Also called the NAVSTAR system. For more information, see About GPS.

Glonass: The Global Orbiting Navigational Satellite System; the Russian counterpart to the United States' GPS system.

GMT: See Greenwich Mean Time.

GoTo: A route consisting of one leg, with your present position being the start of the route and a single defined waypoint as the destination.

GPS: See Global Positioning System.

Greenwich Mean Time (GMT): The mean solar time for Greenwich, England, which is located on the Prime Meridian (zero longitude). Based on the rotation of the earth, GMT is used as the basis for calculating standard time throughout most of the world.

Grid: A pattern of regularly spaced horizontal and vertical lines forming square zones on a map used as a reference for establishing points. Grid examples are UTM, MGRS, and Maidenhead.

Heading: The direction in which a vehicle is moving. For air and sea operations, this may differ from actual Course Over Ground (COG) due to winds, currents, etc.

Healthy: A term used when an orbiting GPS satellite is suitable for use. "State" is also used to refer to satellite health.

Input/Output (I/O); The two-way transfer of GPS information with another device, such as a nav plotter, autopilot, or another GPS unit.

Initialization: The first time a GPS receiver orients itself to its current location and collects almanac data. After initialization has occurred, the receiver remembers its location and acquires a position more quickly because it knows which satellites to look for.

Ionosphere: A region of the earth's atmosphere where ionization caused by incoming solar radiation affects the transmission of GPS radio waves. It extends from a height of 50 kilometers (30 miles) to 400 kilometers (250 miles) above the surface.

Invert Route: To display and navigate a route from end to beginning for purposes of returning to the route's starting point.

L1 Frequency: One of the two radio frequencies transmitted by the GPS satellites. This frequency carries the Coarse Acquisition Code (C/A code), P-Code, and the nav message, and is transmitted on a frequency of 1575.42 MHz.

L2 Frequency: One of the two radio frequencies transmitted by the GPS satellites. This frequency carries only the P-Code, and is transmitted on a frequency of 1227.6 MHz.

L Band: The radio frequencies that extend from 390 MHz to 1550 MHz. The GPS carrier frequencies are in the L band (1227.6 MHz and 1575.42 MHz).

LAAS: See Local Area Augmentation System.

Latitude: A position's distance north or south of the equator, measured by degrees from zero to 90. One minute of latitude equals one nautical mile.

LCD: See Liquid Crystal Display.

Leg (Route): A portion of a route consisting of a starting (from) waypoint and a destination (to) waypoint. A route that is comprised of waypoints A, B, C, and D would contain three legs. The route legs would be from A to B, from B to C, and from C to D.

Lithium Battery: A soft, silvery, highly reactive metallic element that is used in batteries where weight and cold weather conditions are concerns.

Line Of Sight (LOS) Propagation: Of an electromagnetic wave, propagation in which the direct transmission path from the transmitter to the receiver is unobstructed. The need for LOS propagation is most critical at GPS frequencies.

Liquid Crystal Display (LCD): A display circuit characterized by a liquid crystal element sandwiched between two glass panels. Characters are produced by applying an electric field to liquid crystal molecules and arranging them to act as light filters.
Local Area Augmentation System (LAAS): The implementation of ground-based DGPS to support aircraft landings in a local area (20-mile range).
Longitude: The distance east or west of the prime meridian (measured in degrees). The prime meridian runs from the north to south pole through Greenwich, England.
LORAN: Loran, which stands for LOng RAnge Navigation, is a grid of radio waves in many areas of the globe that allows accurate position plotting. Loran transmitting stations around the globe continually transmit 100 kHz radio signals. Special shipboard Loran receivers interpret these signals and provide readings that correspond to a grid overprinted on nautical charts. By comparing signals from two different stations, the mariner uses the grid to determine the position of the vessel.
Magnetic North: Represents the direction of the north magnetic pole from the observer's position. The direction a compass points.
Magnetic Variation: In navigation, at a given place and time, the horizontal angle (or difference) between true north and magnetic north. Magnetic variation is measured east or west of true north.
Map Display: A graphic representation of a geographic area and its features.
Mean Sea Level: The average level of the ocean's surface, as measured by the level halfway between mean high and low tide. Used as a standard in determining land elevation or sea depths.
Multipath Error: An error caused when a satellite signal reaches the GPS receiver antenna by more than one path. Usually caused by one or more paths being bounced or reflected. The TV equivalent of multipath is "ghosting."
Multiplexing Receiver: A GPS receiver that switches at a very rapid rate between satellites being tracked. Typically, multiplexing receivers require more time for satellite acquisition and are not as accurate as parallel channel receivers. Multiplexing receivers are also more prone to lose a satellite fix in dense woods than parallel channel GPS receivers.
Nautical Mile: A unit of length used in sea and air navigation, based on the length of one minute of arc of a great circle, especially an international and U.S. unit equal to 1,852 meters (about 6,076 feet).
Navigation: The act of determining the course or heading of movement. This movement could be for a plane, ship, automobile, person on foot, or any other similar means.
Navigation Message: The message transmitted by each GPS satellite containing system time, clock correction parameters, ionospheric delay model parameters, and the satellite's ephemeris data and health. The information is used to process GPS signals to give the user time, position, and velocity. Also known as the data message.
NAVSTAR: The official U.S. Government name given to the GPS satellite system. NAVSTAR is an acronym for NAVigation Satellite Timing and Ranging.
NMEA (National Marine Electronics Association): A U.S. standards committee that defines data message structure, contents, and protocols to allow the GPS receiver to communicate with other pieces of electronic equipment aboard ships.
NMEA Standard: ANMEA standard defines an electrical interface and data protocol for communications between marine instrumentation.
North Up Orientation: Fixes the GPS receiver's map display so north is always fixed at the top of the screen.

PanTrack™: A Garmin-proprietary feature that allows the user to move the pointer and pan a track in either direction, then select a location along the track to start a TracBack® or GoTo, or to mark a waypoint.
Parallel Channel Receiver: A continuous tracking receiver using multiple receiver circuits to track more than one satellite simultaneously.
P-Code: The precise code of the GPS signal typically used only by the U.S. military. It is encrypted and reset every seven days to prevent use from unauthorized persons.
Pixel: A single display element on an LCD screen. The more pixels, the higher the resolution and definition.
Position: An exact, unique location based on a geographic coordinate system.
Position Fix: The GPS receiver's computed position coordinates.
Position Format: The way in which the GPS receiver's position will be displayed on the screen. Commonly displayed as latitude/longitude in degrees and minutes, with options for degrees, minutes and seconds, degrees only, or one of several grid formats.
Prime Meridian: The zero meridian, used as a reference line from which longitude east and west is measured. It passes through Greenwich, England.
Pseudo-Random Code: The identifying signature signal transmitted by each GPS satellite and mirrored by the GPS receiver in order to separate and retrieve the signal from background noise.
Pseudorange: The measured distance between the GPS receiver and the GPS satellite using uncorrected time comparisons from satellite-transmitted code and the local receiver's reference code.
Quadrifilar Helix Antenna: A type of GPS antenna in which four spiraling elements form the receiving surface of the antenna. For GPS use, quadrifilar antennas are typically half-wavelength or quarter-wavelength size and encased in a plastic cylinder for durability.
RS-232: A serial input/output standard that allows for compatibility between data communication equipment made by various manufacturers.
Radio Technical Commission For Maritime Services (RTCM) Special Committee 104: A committee created for the purposes of establishing standards and guidance for interfacing between radio beacon-based data links and GPS receivers, and to provide standards for ground-based differential GPS stations.
RAIM: Receiver Autonomous Integrity Monitoring; A GPS receiver system that would allow the receiver to detect incorrect signals being transmitted by the satellites by comparing solutions with different sets of satellites.
Route: A group of waypoints entered into the GPS receiver in the sequence you desire to navigate them.
SA: See Selective Availability.
Search The Sky: A message shown when a GPS receiver is gathering satellite almanac data. This data tells the GPS receiver where to look for each GPS satellite.
Serial Communication: The sequential transmission of the signal elements of a group representing a character or other entity of data. The characters are transmitted in a sequence over a single line, rather than simultaneously over two or more lines, as in parallel transmission. The sequential elements may be transmitted with or without interruption.
See-Thru® Technology: A Garmin exclusive technology which allows the various Garmin fishfinders to hear both weak and strong signals simultaneously so as to identify fish returns under the toughest conditions: suspended in thermoclines or even hiding near structures.
Selective Availability (SA): The random error, which the government can intentionally add to GPS signals, so that their accuracy for civilian use is degraded. SA is not currently in use.
SOG: See Speed Over Ground.

SONAR: A system using transmitted and reflected underwater sound waves to detect and locate submerged objects or measure the distance to the floor of a body of water. This technology is used in Garmin fishfinders and sounder products.
Space Segment: The satellite portion of the complete GPS system.
Speed Over Ground (SOG): The actual speed the GPS unit is moving over the ground. This may differ from airspeed or nautical speed due to such things as head winds or sea conditions. For example, a plane that is going 120 knots into a 10-knot head wind will have a SOG of 110 knots.
Spread Spectrum: The received GPS signal is wide bandwidth and low power. The L-band signal is modulated with a pseudo-random noise code to spread the signal energy over a much wider bandwidth than the signal information bandwidth. This provides the ability to receive all satellites unambiguously and to give some resistance to noise and multipath.
Statute Mile: A unit of length equal to 5,280 feet or 1,760 yards (1,609 meters) used in the U.S. and some other English-speaking countries.
Straight-Line Navigation: The act of going from one waypoint to another in the most direct line and with no turns.
Time To First Fix (TTFF): If you have not used your GPS unit for several months, the almanac data for the satellites may be out of date. The unit is capable of recollecting this information on its own, but the process can take several minutes. Time to First Fix (TTFF) is the time it takes a GPS receiver to find satellites after the user first turns it on (when the GPS receiver has lost memory or has been moved over 300 miles from its last location).
TracBack: The proprietary Garmin feature which takes your current track log and converts it into a route to guide you back to a starting position.
Track Up Orientation: Fixes the GPS receiver's map display so the current track heading is at the top of the screen.
Track (TRK): Your current direction of travel relative to a ground position (same as Course Over Ground).
Transducer: A device, much like a microphone, that converts input energy of one form into output energy of another. Fishfinders separate and enhance the information received from a transducer to show underwater objects.

Triangulation: A method of determining the location of an unknown point, as in GPS navigation, by using the laws of plane trigonometry.
TRK: See Track.
TRN: See Turn.
Troposphere: The lowest region of the atmosphere between the surface of the earth and the tropopause, characterized by decreasing temperature with increasing altitude. GPS signals travel through the troposphere (and other atmospheric layers).
True North: The direction of the north pole from your current position. Magnetic compasses indicate north differently due to the variation between true north and magnetic north. A GPS receiver can display headings referenced to true north or magnetic north.
TTFF: See Time To First Fix.
Turn (TRN): The degrees which must be added to or subtracted from the current heading to reach the course to the intended waypoint.
Universal Transverse Mercator (UTM) : A nearly worldwide coordinate projection system using north and east distance measurements from reference point(s). UTM is the primary coordinate system used on U.S. Geological Survey topographic maps.
Uplink: A transmission path by which radio or other signals are sent from the ground to an aircraft or a communications satellite.

User Interface: The way in which information is exchanged between the GPS receiver and the user. This takes place through the screen display and buttons on the unit.
User Segment: The segment of the complete GPS system that includes the GPS receiver and operator.
UTC: See Coordinated Universal Time.
UTM: See Universal Transverse Mercator.
Velocity Made Good (VMG) : The rate of closure to a destination based upon your current speed and course.
WAAS: See Wide Area Augmentation System.
Waterproof: Most Garmin GPS units are waterproof in accordance with IEC 529 IPX7. IEC 529 is a European system of test specification standards for classifying the degrees of protection provided by the enclosures of electrical equipment. An IPX7 designation means the GPS case can withstand accidental immersion in one meter of water for up to 30 minutes. An IPX8 designation is for continuous underwater use.
Wavelength: The distance between points of corresponding phase of two consecutive cycles of a wave.
Waypoints: Waypoints are locations or landmarks worth recording and storing in your GPS. These are locations you may later want to return to. They may be check points on a route or significant ground features. (e.g., camp, the truck, a fork in a trail, or a favorite fishing spot). Waypoints may be defined and stored in the unit manually by taking coordinates for the waypoint from a map or other reference. This can be done before ever leaving home. Or more usually, waypoints may be entered directly by taking a reading with the unit at the location itself, giving it a name, and then saving the point. Waypoints may also be put into the unit by referencing another waypoint already stored, giving the reference waypoint, and entering the distance and compass bearing to the new waypoint.
Wide Area Augmentation System (WAAS): A system of satellites and ground stations that provide GPS signal corrections for better position accuracy. A WAAS-capable receiver can give you a position accuracy of better than three meters, 95 percent of the time. (At this time, the system is still in the development stage and is not fully operational.) WAAS consists of approximately 25 ground reference stations positioned across the United States that monitor GPS satellite data. Two master stations, located on either coast, collect data from the reference stations and create a GPS correction message. For more information, see What is WAAS?, or visit the FAA's website.
WGS-84 : World Geodetic System, 1984. The primary map datum used by GPS. Secondary datums are computed as differences from the WGS 84 standard.
Y-Code: The encrypted P-Code.
XTE/XTK: See Crosstrack Error.