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# Appraisal of Gully Erosion in Owerri South Eastern Nigeria Using Remote Sensing Data

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***Abstract***

*The identification of priority areas for the establishment of control measures is one of the major objectives of conservation plans at regional level. A methodology, based on the analysis of multi spectral remote sensed data (Landsat TM), has been proposed and applied for the identification of areas with high gully activity. This work identifies and studies gully erosion in the study area, Owerri and its environs in Imo State, South Eastern Nigeria which is located between latitude 5.18° – 5.39° N and longitude 6.51°- 7.08° E. The remote sensing data analysis the land sat enhancement thematic mapper (land sat ETM) data obtained was subjected to various image enhancement and transformation. For image enhancement 3 band RGB colour composites were created using ILWIS 8.0 ILWIS ACADEMIA AND ERDAS. These software's have the capacities of carrying various data enhancement techniques such as linear enhancement, statistical analysis, principal component analysis. The process was employed to enhance the spectral quality of the images. An extensive data processing was carried out on land sat which resulted to generation of the following maps: digital elevation model (DEM) map, lineament and lineament density map, normalized difference vegetation index map (NDVI), and the rose diagram. This paper defines remote sensing technique, discusses applications of remote sensing in geology and discusses gully erosion, causes of gully erosion, impacts of gully erosion, modes, types and mechanism of gully erosion. It discusses solution to gully erosion in Nigeria. Solutions that have been proffered include public awareness campaign, improved farming techniques, cultural method of gully control, enactment of laws against any activities that favour gully growth, and thorough implementation of suggested solutions.*

***Keywords:*** *remote sensing, land sat, gully erosion, control, data.*

## INTRODUCTION

The task of managing natural resources of the earth is daily growing in complexities. This is due partly to increasing uncertainties in the natural-physical systems, as well as increasing interference of man with these systems. Natural resources development and management is of tremendous concern to mankind. The utility derivable from resource use and the deleterious effects and consequences of resource abuse are important for continued existence of man and survival of the natural ecosystems. Degradation sets in when the capacity of a natural ecosystem to renew itself is constrained by frequent disturbance and/or perturbations and this is a big threat to human survival and livelihood. Maps and measurements of degraded land can be derived directly from remotely sensed data by a variety of analytical procedures, including statistical methods and human interpretation. Conventional maps are categorical, dividing land into categories of land use and land cover (thematic mapping; land classification), while recent techniques allow the mapping of land degradation and other properties of land as continuous variables or as fraction of the land by different land use- land cover categories, such as tree canopy, herbaceous vegetation, and barren (continuous fields mapping). These types of datasets may be compared between time periods using Geographic Information Systems (GIS) to map and measure their extent and change at local, regional, and global scales. South eastern Nigeria is a typical erosion region in the country. The presence of gully sites is one of the hazardous features that characterize Imo State and several other eastern states adjoining it (Okereke, Onu, Akaolisa, Ikoro, Ibeneme, Ubechu, and Amadikwa 2012)

## REMOTE SENSING

Remote Sensing is the acquisition and recording of information about an object without being in direct contact with the object (Paul and Clave, 2000). Remote sensing can be defined as the process of measuring the physical properties of distant objects using reflected or emitted energy (Moore, 1979). Remote Sensing (RS) refers to the science of identification of earth surface features and estimation of their geo-biophysical properties using electromagnetic radiation as a medium of interaction. Spectral, spatial, temporal and polarization signatures are major characteristics of the sensor/target, which facilitate target discrimination. Earth surface data as seen by the sensors in different wavelengths (reflected, scattered and/or emitted) is radiometrically and geometrically corrected before extraction of spectral information (Roy and Behera, 2000) (Roy and Tomar, 2000).

Remote sensing in geology is remote sensing used in the geological sciences as a data acquisition method complementary to field observation, because it allows mapping of geological characteristics of regions without physical contact with the areas being explored (Rees, 2013). About one-fourth of the Earth's total surface area is exposed land where information is ready to be extracted from detailed earth observation via remote sensing (Kuehn, King, Hoerig, Peters, Newcomb, Toms, 2000). Remote sensing is conducted via detection of electromagnetic radiation by sensors.( Rees, 2013). The radiation can be naturally sourced (passive remote sensing), or produced by machines (active remote sensing) and reflected off of the Earth surface (Rees, 2013). The electromagnetic radiation acts as an information carrier for two main variables. First, the intensities of reflectance at different wavelengths are detected, and plotted on a spectral reflectance curve.( Rees,2013). This spectral fingerprint is governed by the physio-chemical properties of the surface of the target object and therefore helps mineral identification and hence geological mapping, for example by hyperspectral imaging.( Rees,2013). Second, the two-way travel time of radiation from and back to the sensor can calculate the distance in active remote sensing systems, for example, Interferometric synthetic-aperture radar. This helps geomorphological studies of ground motion, and thus can illuminate deformations associated with landslides, earthquakes, etc ( Gupta 1991, Ray, 2020).

Remote Sensing data, with its ability for a synoptic view, repetitive coverage with calibrated sensors to detect changes, observations at different resolutions, provides a better alternative for natural resources management as compared to traditional methods (Kasturirangan, 1985) (Rao, 1991). Remote sensing of earth has come a long way from nineteenth century aerial photography (Madry, 2013), to latest UAV remote sensing. In general sense, remote sensing at present means satellite remote sensing and it started with the launch of Landsat-1 in 1972 for civilian applications (Simonettin, Simonetti, Preatoni, 2014). In 1979, Seasat-1 became the first RADAR imaging satellite (Ouchi 2013) and started a new domain of remote sensing. Over the following years, the field of satellite remote sensing has seen many exciting new developments such as new higher spatial resolution optical and radar systems, hyperspectral sensors, important by-products such as digital elevation model (DEM), furthermore development of new processing techniques using machine learning) (Ali, Greifeneder, Stamenkovic,Neumann, Notarnicola 2015).

## APPLICATIONS OF REMOTE SENSING

Remote sensing makes it possible to collect data on dangerous or inaccessible areas. In most cases remote sensing techniques have been applied simply to identify the characteristics (or the absence) of the vegetation cover, largely because of limited visibility of the soil surface in humid and sub-humid environments. Other studies have demonstrated the usefulness of remote sensing techniques in determining temporal and spatial erosion patterns. Calculation of the percentage of bare ground has also been used to estimate erosion risk. Other methodologies applied to inventories and monitoring of erosion processes include band ratios vegetation indices, combinations of reflective and microwave data, and combinations of remote sensing data and other ancillary data (Vrieling, 2006).

Remote sensing data can help studies involving geological mapping, geological hazards and economic geology (i.e., exploration for minerals, petroleum, etc.( Gupta 1991). These geological studies commonly employ a multitude of tools classified according to short to long wavelengths of the electromagnetic radiation which various instruments are sensitive to. Shorter wavelengths are generally useful for site characterization up to mineralogical scale, while longer wavelengths reveal larger scale surface information, e.g. regional thermal anomalies, surface roughness, etc. Such techniques are particularly beneficial for exploration of inaccessible areas, and planets other than Earth. Remote sensing of proxies for geology, such as soils and vegetation that preferentially grows above different types of rocks, can also help infer the underlying geological patterns. Remote sensing data is often visualized using Geographical Information System (GIS) tools. (Gupta, 1991, Ray, 2020). Such tools permit a range of quantitative analyses, such as using different wavelengths of collected data sets in various Red-Green-Blue configurations to produce false color imagery to reveal key features. Thus, image processing is an important step to decipher parameters from the collected image and to extract information.

Remote sensing has been used for geologic interpretations with remarkable success. Remote sensing techniques are used because of their cost effectiveness, their ability to access areas that are difficult to access and because the data can be collected frequently and rapidly on a large scale. Remote sensing also replaces costly and slow data collection on the ground, ensuring in the processes that areas or objects are not disturbed. These data sets allow earth-based phenomena such as land use and land cover characteristics to be rapidly mapped, if needed repetitively and at relatively low costs. With increasing capacity to rapidly generate maps of large areas, planners in the rural and urban areas are getting more empowered to address issues associated with land use analysis.( Uja, Equere, Popoola, 2019)

Geological mapping: Remote sensing can aid surficial geological mapping and landform characterization.

**Spectral features**

The visible and near infrared (VNIR) and thermal infrared (TIR) are sensitive to intra-atomic electronic transitions and inter-atomic bond strength respectively can help mineral and rock identifications. The instrument in use is called spectroradiometer in lab and imaging spectrometer or multi-/ hyper-spectral scanner as imaging remote sensors.(Gupta,1991). Provided that the land is not obscured by dense vegetation, some characteristics of superficial soil (the unconsolidated sedimentary materials covering the land as surficial deposits from weathering and erosion of bedrock) may be measured with a penetration depth into air-soil interface of about half of wavelength used (e.g. green light (~0.55 micro-meters) gives depth of penetration into ~0.275 micro-meters).( Mulder, et al., 2011). Hence most remote sensing systems using the VNIR wavelength region give characteristics of surface soil, or sometimes exposed rock (Jensen,2007).

**Mineral and rock**

To identify mineral, available spectral reflectance libraries, for instance the USGS Spectral Library, summarize diagnostic absorption bands for many materials not limited to rocks and minerals. This helps create a mineral map to identify the type of mineral sharing similar spectra, with minimal in situ field work.(Gupta, 1991).

The mineralogy is identified by matching collected sample with spectral libraries by statistical method, such as partial least squares regression. In addition to high signal-to-noise ratio (>40:1), a fine spatial resolution, which limits the number of elements inside one single pixel, also promotes decision accuracy, ( Mulder, De bruin, Schnaepman, Mayr, 2011). There are also digital subpixel spectral unmixing tools available. The USGS Tetracorder which applies multiple algorithms to one spectral data with respect to the spectral library is sensitive and give promising results.(Clark,2003). The different approaches are summarized and classified in literature but unfortunately there is no universal recipe for mineral identification.

**Soil**

Surficial soil is a good proxy to the geology underneath. Some of the properties of soil, alongside lithology mentioned above, are retrievable in remote sensing data, for instance Landsat ETM+, to develop the soil horizon and therefore aid its classification. ( Jensen, 2007) (Mulder, et al., 2011).

**Soil texture and moisture content**

The amount of moisture within soil particles is governed by the particle size and soil texture as the interstitial space may be filled with air for dry soil and water for saturated soil. Essentially, the finer the grain size, the higher capability to hold moisture. As mentioned above, wetter soil is brighter than dry soil in radar image. For short wavelength VNIR region, in the same theory, clayey surface with smaller grain size promoting more backscattering should give higher spectral response. However, the higher soil moisture and organic contents makes clay darker in images, compared to silty and sandy soil cover after precipitation.( Jensen,2007). With regard to VNIR region, as the moisture content increases, more prominent absorption (at 1.4, 1.9, 2.7 micrometers, and sometimes at 1.7 for hydroxyl absorption band) take place. On the other hand, radar is sensitive to one more factor: dielectric constant. Since water has a high dielectric constant, it has high reflectivity and hence more backscattering takes place, i.e. appears brighter in radar images (Rees,2013). Index Therefore, soil appears brighter with higher soil moisture content (with the presence of capillary water) but appears dark for flooded soil (specular reflection). Quantitatively, while soil texture is determined by statistical means of regression with calibration, scientists also developed a Soil Water index (SWI) ( Wagner, Pathe, Sabel, Bartsch, Kunze, Scipal, 2007).

**Geomorphology**

3-dimensional geomorphological features arising from regional tectonics and formation mechanisms could also be understood from a perspective of small scale images showing a large area acquired in elevation. The topography of an area is often characterized by volcanic activity or orogenesis. These mountain building processes are determined by the stress-strain relation in accordance with rock types (Gupta, 1991). They behave as elastic/ plastic/ fracturing deformations, in response to different kinetics. Remote sensing techniques provide evidence such as observed lineament, global scale mountain distribution, seismicity and volcanic activities to support crustal scale tectonics and geodynamics studies.(Burgmann and Thatcher 2013). Additional spectral information also helps. For example, the grain size differentiates snow and ice (Vincent,1997). Aside from a planar geological map with cross-sections, sometimes 3-dimensional view from stereo-photos or representation in Digital Elevation Model (DEM) could aid the visualization. In theory, LiDAR gives the best resolution up to cm grade while radar gives 10m grade because of its high sensitivity to small scale roughness (Mulder, et al., 2011). Oblique images could greatly enhance the third-dimension, but users should bear in mind the shadowing and distortions (Ray, 2020).

**Inaccessible areas**

Although field mapping is the most primary and preferable way to acquire ground truth, the method does not work when areas become inaccessible, for example the conditions are too dangerous or extreme. Sometimes political concerns bar scientists' entering. Remote sensing, on the other hand, provides information of the area of interest sending neither a man nor a sensor to the site ( Ray,2020).

**Geological hazards**

Geological hazards cause casualties and serious damage to properties. While it is almost impossible to prevent naturally occurring disasters, their impact could be reduced and minimized with proper prior risk assessment and planning (Joyce et al., 2009).

**Mineral and petroleum exploration**

The occurrence of nature reserves that are exploitable is in close association with the surrounding geology. Feasible resources explorations should be backed up by accurate geological models to locate prospect ore and petroleum deposits from a preliminary regional overview ( Gupta 1991). Remote sensing can provide scalable investigation as the exploration program progress at a reasonable expenditure. One example is to monitor the surface deformation in a mine using InSAR time series ( Paradella et al., 2015). Another example is using short wavelength region in VNIR to estimate the petroleum reservoir because VNIR can provide both accurate distance measurement by lidar and spectral data from spectral scanning ( Hodgetts 2013). One point to bear in mind is the inherit limitation, that remote sensing is for surface detection while natural resources are concentrated in depth, therefore its use is somewhat limited.

## GULLY EROSION

*Gully erosion* is defined as the erosion process whereby runoff water accumulates and often recurs in narrow channels and, over short periods, removes the soil from this narrow area to considerable depths ( Poesen *et al.*, 2003). *Permanent gullies* are often defined for agricultural land in terms of channels too deep to easily ameliorate with ordinary farm tillage equipment, typically ranging from 0.5 to as much as 25–30 m depth (Soil Science Society of America, 2001).

Erosion is one of the surface processes that sculpture the earth's landscape and constitutes one of the global environmental problems. Soil erosion is perhaps the most serious mechanism of land degradation in the tropics. However, gully is visually the most impressive of all types of erosion . Gully erosion is a well-defined water worn channel. It is a recently extended drainage channel that transmits ephemeral flow, steep side, steeply sloping or vertical head scarf with a width greater than 0.3 m and a depth greater than 0.6 m. It is a V or U-shaped trench in unconsolidated materials with a minor channel in the bottom, but not necessarily linked to a major stream.

Gully erosion, the most impressive and striking erosion type, has been recognized as one of the major global environmental problems. Many States in Nigeria are currently under threats of this phenomenal process, south-eastern part of the country being the most affected. It has numerous causes; and these causes can be both naturally and artificially-induced, but the underlying geology and the severity of accompany surface processes play a key role. Observations have shown clearly that gully erosion is more prevalent in sedimentary terrain than in the basement complex of Nigeria. This erosion activity at various scales has resulted in the loss of lives and properties almost on a yearly basis. Solutions that have been proffered include public awareness campaign, improved farming techniques, cultural method of gully control, enactment of laws against any activities that favour gully growth, and thorough implementation of suggested solutions.

**Causes of Erosion**

Because of more prevalence of gully erosion in the southeastern part of the country as earlier noted, the region has attracted more attention of a number of researchers to unravel the causes of gully erosion. Therefore, the works from this area are overwhelming in the literature.

Gully erosion can be caused in a number of ways, having different mechanisms, modes and conditions of formation; some of which are directly related to the underlying geology and the severity of the surface processes operating on the surface geology and soil cover. (Ezechi and Okagbue 1989) summarized the types of gully erosion with respect to their modes and conditions of formation, and common advance mechanism (Table 1). Their study indicated that the nature of the underlying bed (or geology) has a bearing on the initiation and propagation of gullies. Observations have also shown that gully erosion, in Nigeria, is more predominant in the sedimentary terrains and perhaps in the basement/sediment contact areas. This accounts for why its occurrences is more skewed to the south-eastern Nigeria where most of the gullies take the advantage of the loosely consolidated and sometimes friable rocks such as the Ajali Sandstone in Auchi area of Edo State of Nigeria . The causes of gully erosion with respect to the geologic settings as suggested by the earlier studies are numerous. Some of the identified natural causes include tectonism and uplift, climatic factors, geotechnical properties of soil, among others. Anthropogenic causes include farming and uncontrolled grazing practices, deforestation, and mining activities. (Abdulfatai, Okunlola, Akande, Momoh, Ibrahim 2014).

**Table 1.** Gully types, modes and conditions of formation and common advance mechanism (Ezechi and Okagbue, 1989)

| Gully Type | Modes and Condition of Formation | Common Advance Mechanism |
|---|---|---|
| Base level | Groundwater flow | Slope undermine, sliding and slumping |
| Scarp | Runoff and slope change | Slope undermining, sliding/slumping, toppling |
| Fracture | Runoff and shrinkage fracture | Collapsing, also block failure |
| Incidental | Runoff concentration and vulnerable soil exposure by man | Common sliding/slumping. |

## Impacts of Erosion

The impacts of gully erosion in Nigeria are enormous and similar to that obtainable elsewhere in the world and they include:

i) Loss of Farmland: A vast area of farmlands has been lost due to the menace of gully erosion while others are at their various stages of destruction leading to drastic decrease in agricultural productivity and ultimately food shortage that can lead to famine. ( Abdulfatai, *et al.*, 2014).

ii) Treat to Vegetation: The gully erosion in Nigeria has resulted in loss of vegetation as its continuous expansion encroaches into areas that are hitherto forest leading to falling of trees and exposure of more surface areas to gully activities. The phenomenon if allowed to continue and remains unchecked may ultimately lead to climatic changes locally or globally.( Abdulfatai, *et al.*, 2014)

iii) Effect on Properties: Several properties whose value cannot be quantified accurately here have been destroyed and others are under treat by this menace especially houses and other properties located on the floodplain. About 10 houses have been lost in a single event of gully erosion in Auchi area of Edo State. Besides, it was reported recently that over 450 buildings are lost in Edo State of Nigeria as a result of erosion (NTA News, Sunday 6th July 2013). On a separate note, Committee on Erosion and Ecological matter recently discovered 15 gully sites in Bida, Niger State of Nigeria (NTA Minna News, Wednesday 17th July 2013). Apart from untimely evacuation from these gully sites, infrastructural facilities such as pipelines, utility cables, roads and houses also suffer from these hazardous events. .( Abdulfatai, *et al.*, 2014)

iv) Effect on Life: Many lives have been lost as a result of the problem of gully erosion. Some either fell into these gullies and sustained various degrees of injury or died. Some instances have also been reported where people are drowned in some of the gully sites. About 23 people have been reported in the past few years to have lost their lives in a single event of gullying activities in Ibori, Ugbalo, Ewu-Eguare, Idogalo and Oludide communities of Edo State, Nigeria. Millions of people have been displaced and evacuated their homes following the gully incidences. The gully erosion in Oko community in Anambra State has created a deep gully and wide crater, threatening to sweep away the homes of about 826 families as this channel is continuously expanding at an alarming rate. .( Abdulfatai, *et al.*, 2014)

v) Isolation of Villages and Towns: Gully erosion has resulted in the separation of adjacent villages and towns as it may involve collapse of the bridges linking them together. This has had negative impacts on such areas since some facilities such as schools, hospitals and water supplies shared by the affected neighbouring communities may become inaccessible. Transportation of farm produce has also been affected and this also often leads to loss of agricultural products especially the perishable ones. Traders who also go to these areas for their trade are also cut off from their normal day-to-day business. .( Abdulfatai, *et al.*, 2014)

Bad Land: Gully erosion has given rise to infertile and barren land that may need to be reclaimed. This usually brings untold hardship to the inhabitants if the land is still inhibitable but has been severely affected. Anambra State lost over 30% of her land, and over 40% of the total area of land and homes are being threatened by the menace according to the Anambra State Ministry of environment (Abdulfatai, *et al.*, 2014)

## MATERIALS AND METHOD

### The study area

The Study Area (Imo State, Nigeria) is located in the South eastern section of Nigeria and is one of the 36 States of the Nigerian Federation, with Owerri as its capital and largest city. It lies between latitude 4°45'N and 5°50'N, longitude 6°35'E and 7°30'E. It occupies an area of about

5,329.17 sq. km with a Population of 2,938,708 . The State derives its name from Imo River, which takes its course from the Okigwe/Awka upland. Imo State is located between the lower River Niger and the upper and middle Imo River. The Area experiences the humid, semi-hot equatorial climate. The rainfall is heavy, with an average annual rainfall of 2000-2400 mm and an average number of 152 rainy days particularly during the rainy season (April–October). Rainfall distribution is bimodal, with peaks in July and September and a two weeks break in August. The rainy season begins in March and lasts till October or early November.

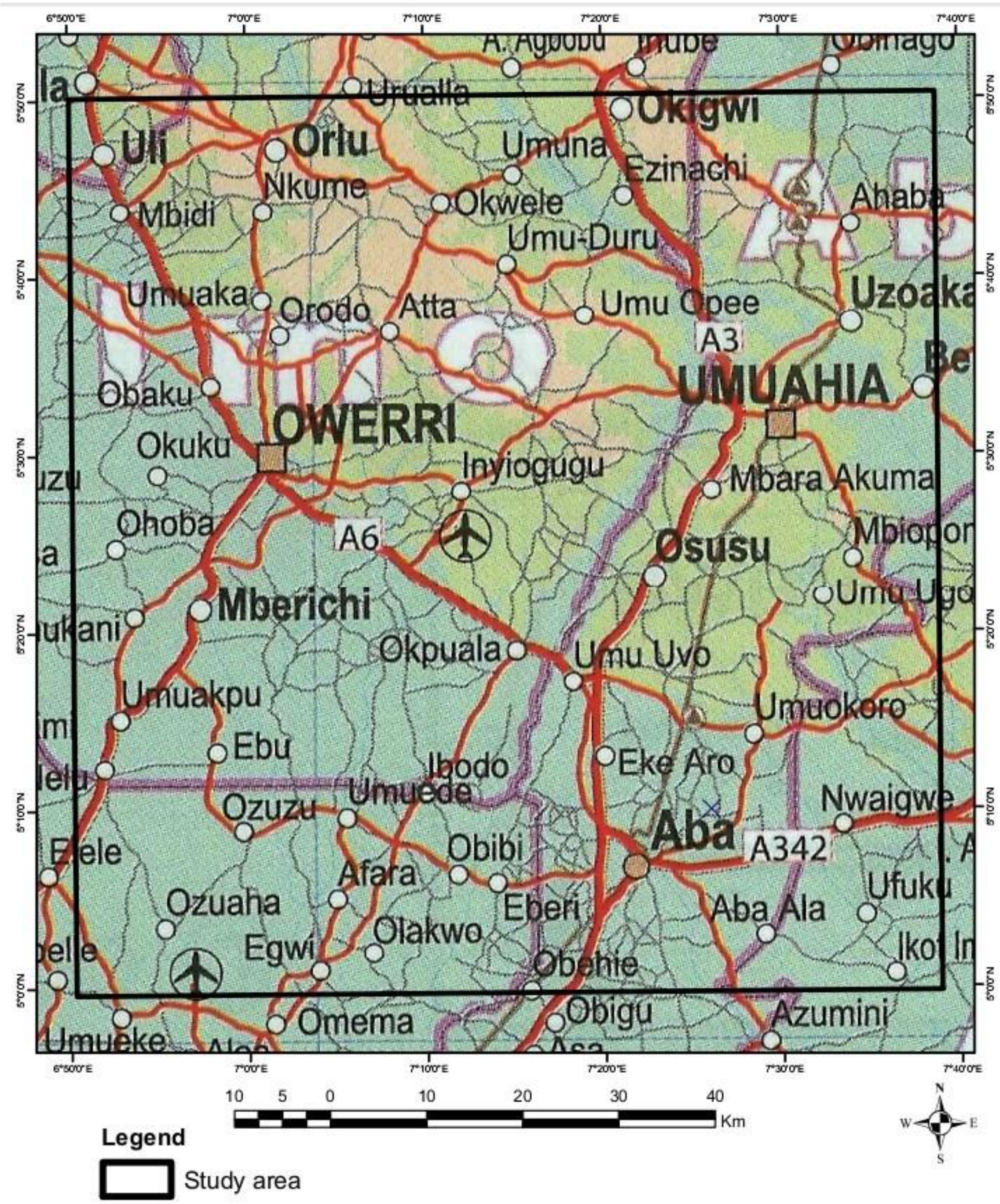


**Fig 1 location Map of the study area owerri above**

## GEOLOGY OF THE STUDY AREA

Geologically, Imo State is underlain by the sedimentary sequences of the Benin Formation (Miocene to recent), and the Bende-Ameki Formation (Eocene). The Benin Formation is made up of friable sands with minor intercalations of clay. The sand units are mostly coarse-grained, pebbly, poorly sorted, and contain lenses of fine grained sands. In some areas like Okigwe, impermeable layers of clay occur near the surface, while in other areas, the soil consists of lateritic material under a superficial layer of fine grained sand. Imo State is characterized by three main landform regions: a highland region of elevation of 340m in the northern sections covering Orlu, Ideato, Okigwe and Ihitte Uboma local government areas. The main stream - Orashi (Ulasi) River, rises near Dikenafai in Imo State, flows northward to Ozubulu in Anambra State and then turns round in a wide loop and heads for the Atlantic Ocean. The second main landform region is midway between the north and the southern section of the State and is of a moderate elevation of between 175m - 240m above msl. They provide elevated, well drained topography with few isolated undulating topography and valleys. The third landform region is the lowland/plains lie South of the high and moderately elevated highlands; the Orashi River plain, south of Oguta, and the inter-basin area between Oguta and Egbema. The main rivers draining the State are Imo, Otamiri, Njaba, Orashi, Nwaorie, Oraminiukwa and a couple of other smaller streams all of which have very few tributaries. These rivers constitute the five sub basins in the ImoAnambra River Basin draining an average area of about 3,777.76km2 of Imo State. Imo River flows through the area underlain by the Imo Shales, other rivers rise within the coastal plain sands. The width and depth of majority of these rivers ranged between 10m to 350m and 0.5m to 2.8m respectively. The Drainage Density is medium texture with a Dd of 0.21, Stream frequency is 0.02 and the drainage intensity is 2.00. Oguta Lake and Lake Abadaba also constitute significant water body in the State.

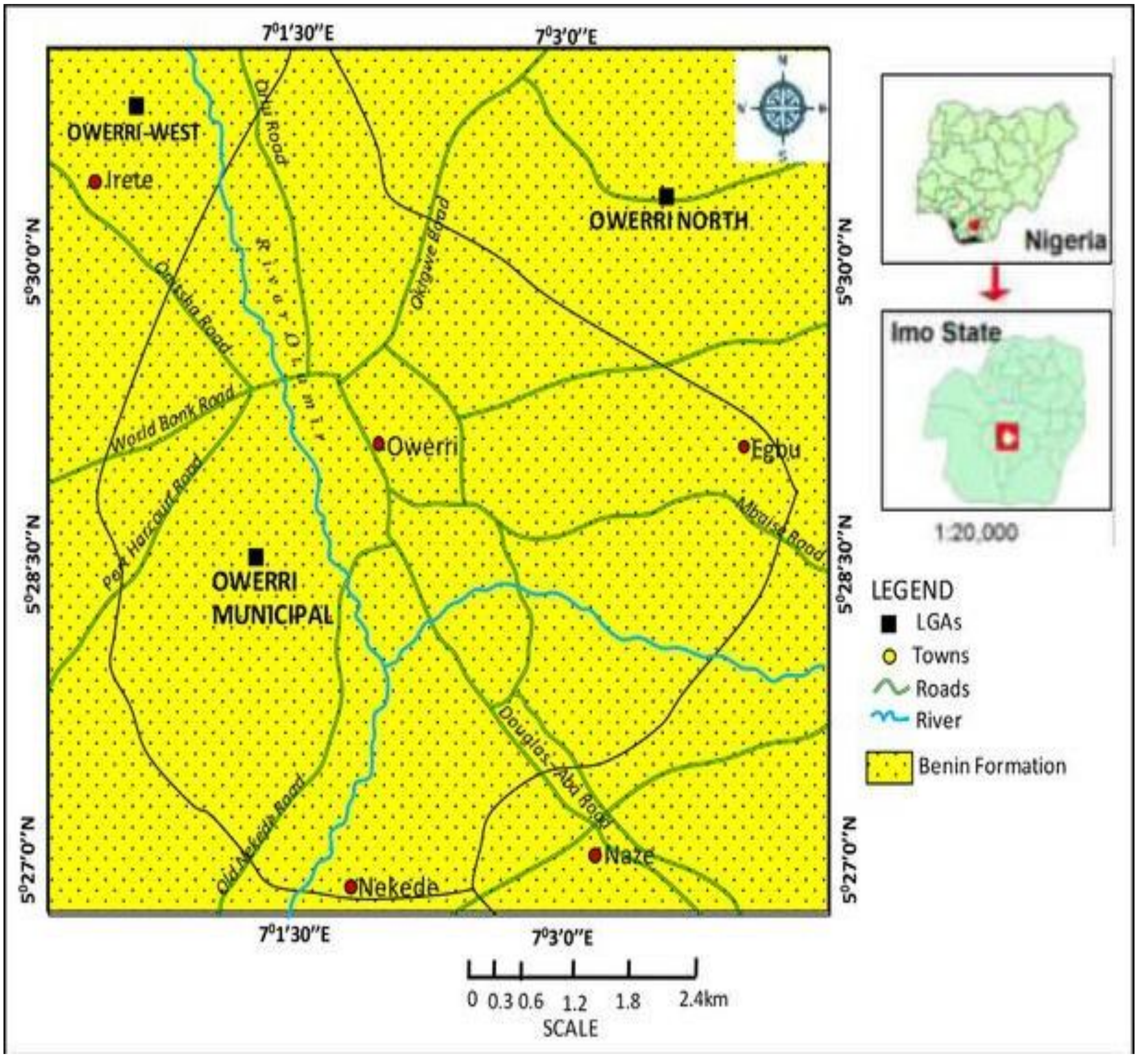


**Fig. 2: Geological map of the study area**

## METHODOLOGY

### RECONNAISSANCE SURVEY

First a reconnaissance survey was carried out in different, selected gully erosion sites within owerri environs. Various stop where made at gully sites. The locations where studied visually and analised. The positions (latitude, longitude and elevation) of the gully sites measured using a global positioning system (GPS) are listed below:

**AKACHI JUNCTION OWERRI**

LONGITUDE: N 05 28.111secs

LATITUDE: E 007 02.458 secs

Elevation 235ft

**OLD NEKEDE ROAD OWERRI**

LONGITUDE: N 05 27.649Secs

LATITUDE: E 007 01.705Secs

Elevation 209ft

**INLAND ROAD OWERRI**

LONGITUDE: N 05 28.189Secs

LATITUDE: E 007 01.889Secs

Elevation 168ft

**Fig 3 Gully Site At Inland Road Owerri Above**


**Fig 4 Gully Site At Old Nekede Road Owerri Above**


**Fig 5 Gully Site At Akachi Junction Owerri Above**

## REMOTE SENSING DATA ANALYSIS

The land sat enhancement thematic mapper (land sat ETM) data obtained was subjected to various image enhancement and transformation. For image enhancement 3 band RGB colour composites were created using ILWIS 8.0. the process was employed to enhance the spectral quality of the images. Lineament or curvilinear surface feature can be described as a broad non genetic term used to include any visible linear trend commonly, but not always, of regional extent (masursky *et al.*, 1978). It refers to any linear-trending feature observed in aerial or remote sensing imagery, including fault zones, ditches, fractures, ridges, and escarpment. On earth (O'Leary *et al.*,1976) defined lineaments as a mappable simple or composite linear feature whose parts align in a straight or slightly curving relationship and that differs distinctly from the patterns of adjacent features.

Presumably a lineament expresses a subsurface phenomenon. The surface features making up a lineament may be geomorphic ( caused by relief)

**RESULTS AND DISCUSSION**

Remote sensing data interpretation and explanation is directed towards qualitative interpretation of both environmental and geological explanation. To explain the causes of the anomalies. An extensive data processing was carried out on land sat which resulted to generation of the following maps: digital elevation model (DEM) map, lineament and lineament density map, normalized difference vegetation index map (NDVI), and the rose diagram.

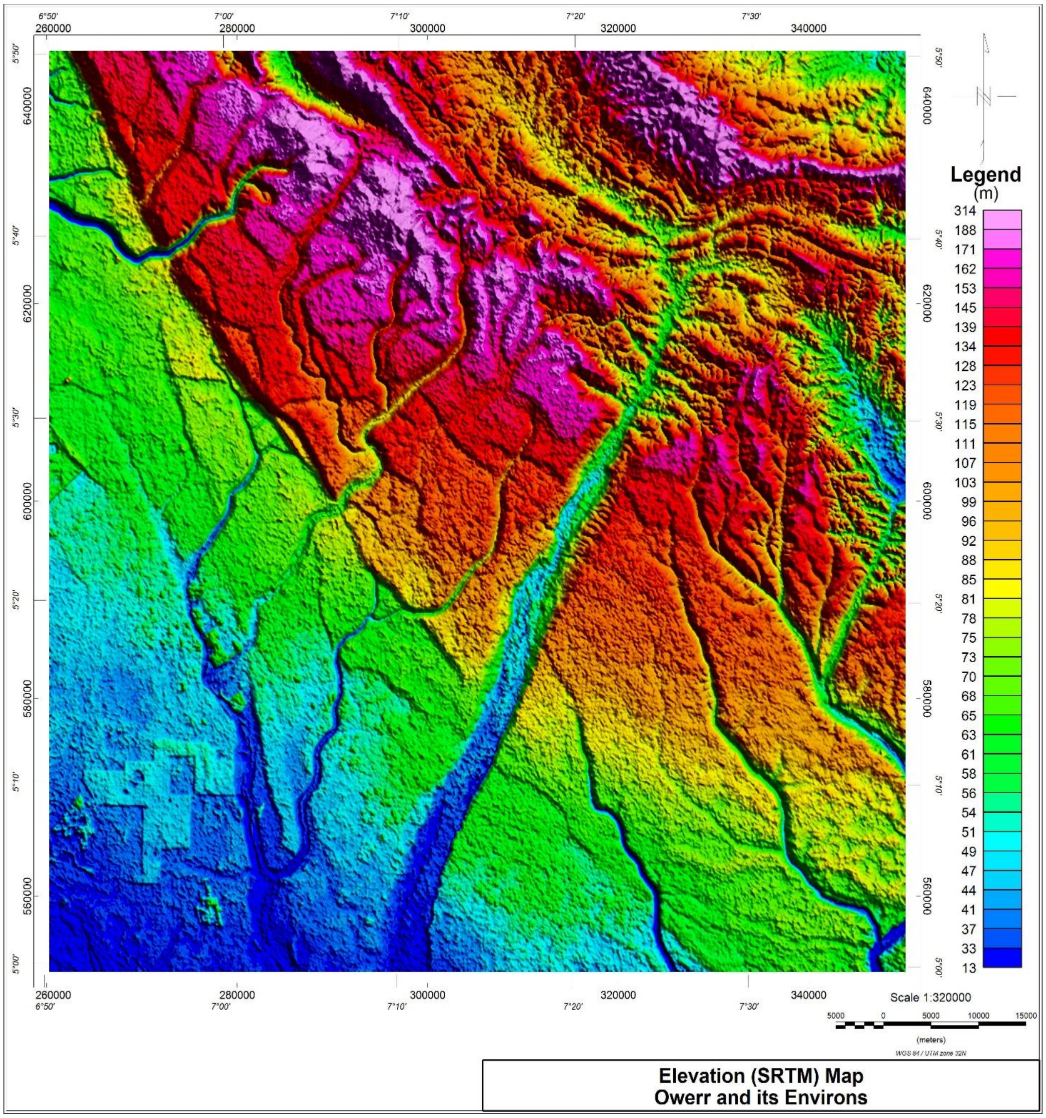


**Fig 6: Digital elevation model of owerri above.**

The elevation map above shows the different heights, and it would possibly shows how water moves from point of high elevation to lower elevation. As rain is falling we have a place of high source where the rain causes gully erosion due to rain moving from high elevation to lower elevation.

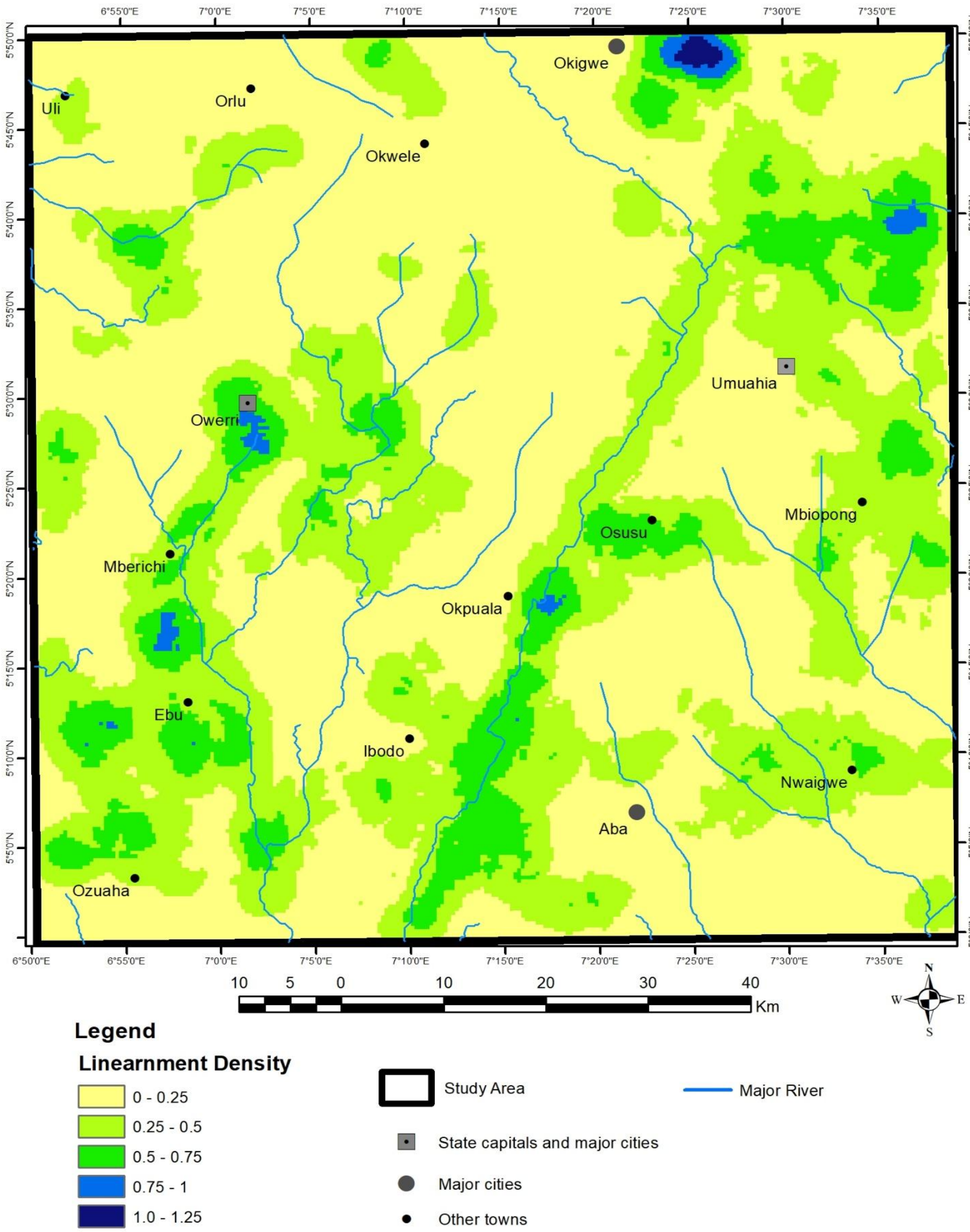


Fig 7: Lineament Density with Drainages

There are increased lineaments density in Owerri.

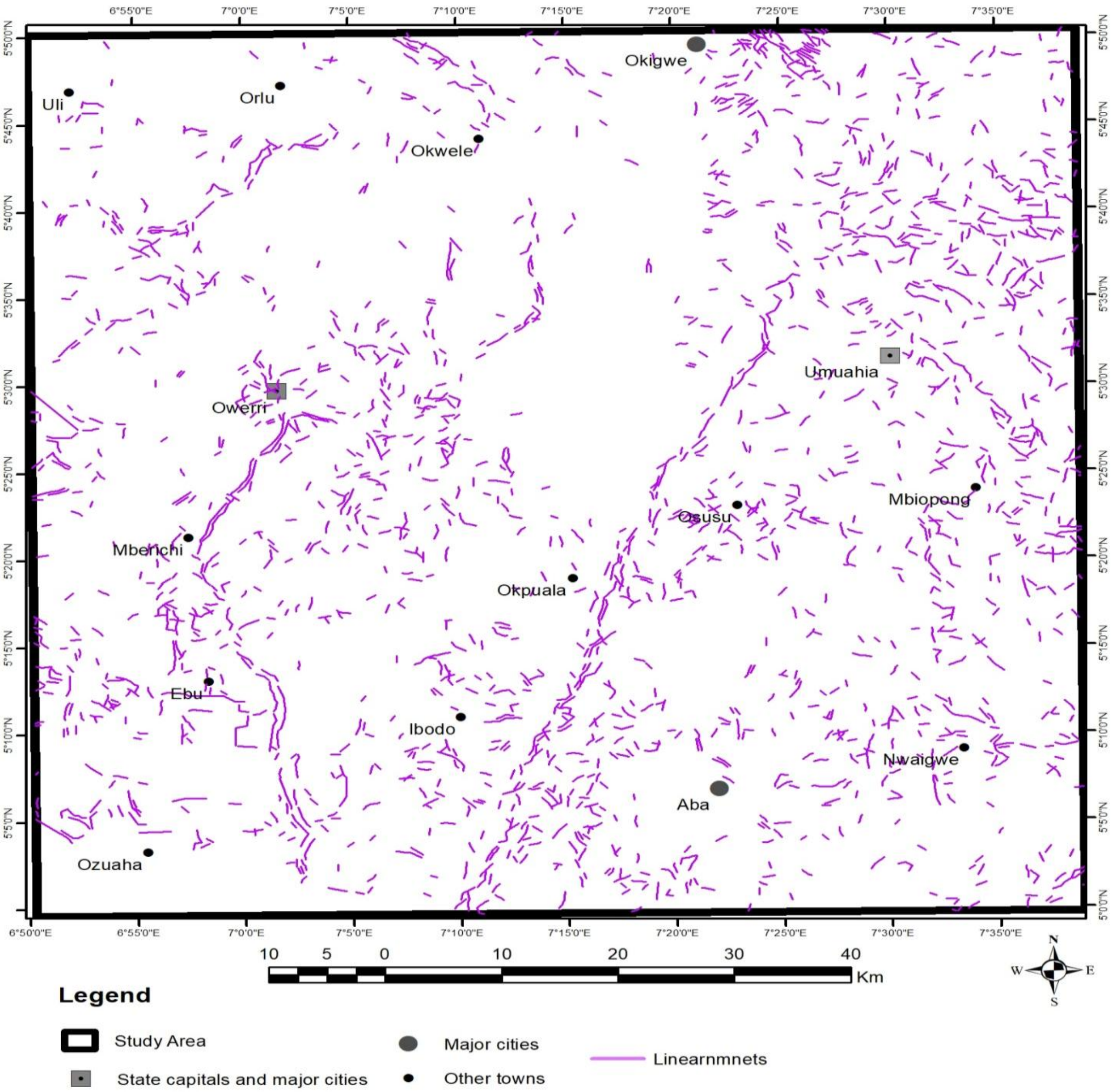


**Fig 8 lineament map above**

It shows clusters of underground structures in Owerri.

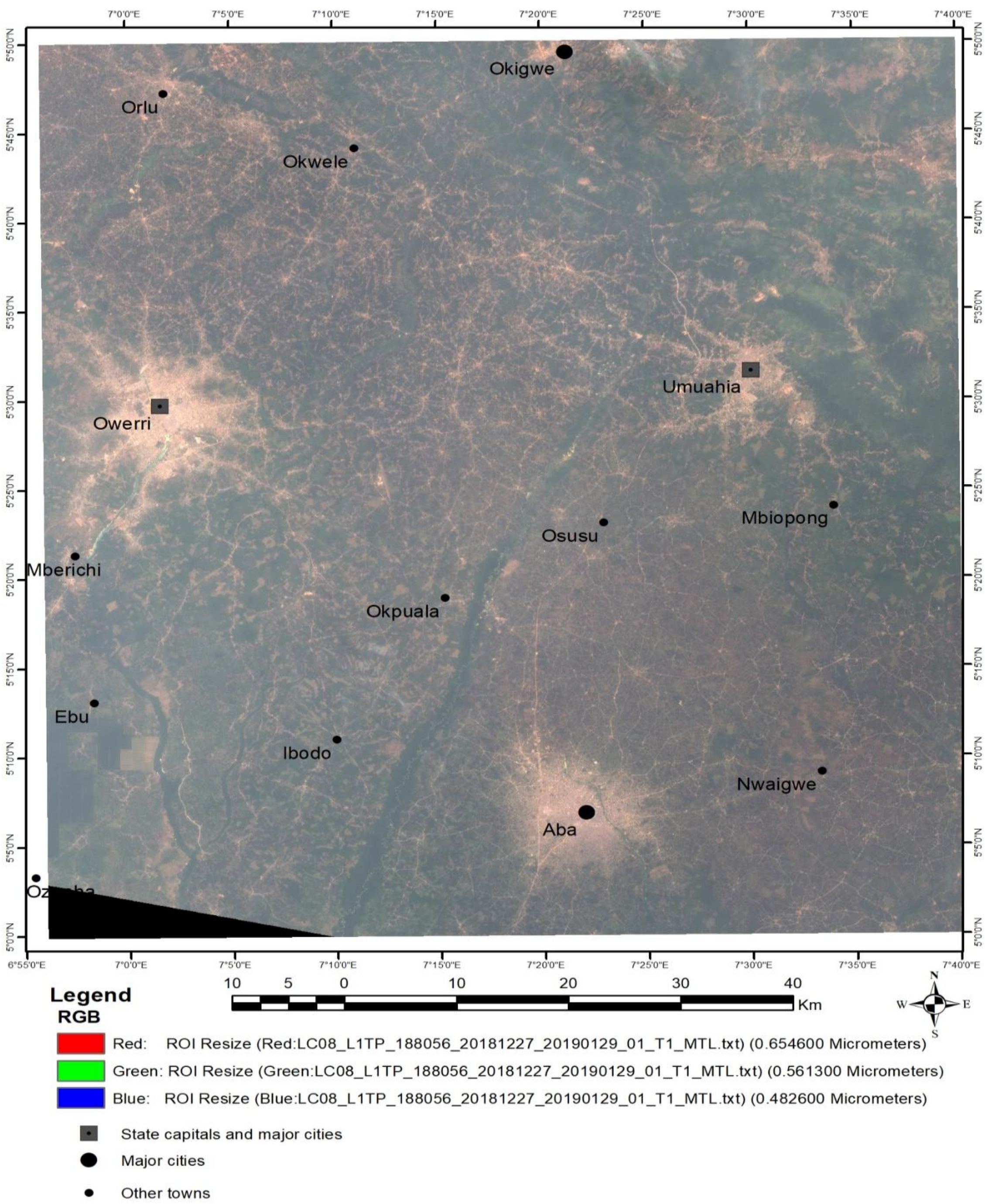


**Fig 9 above shows land sat map.** The above map shows built up areas in peach color, vegetation in grey, river in blue, black shows out crop.

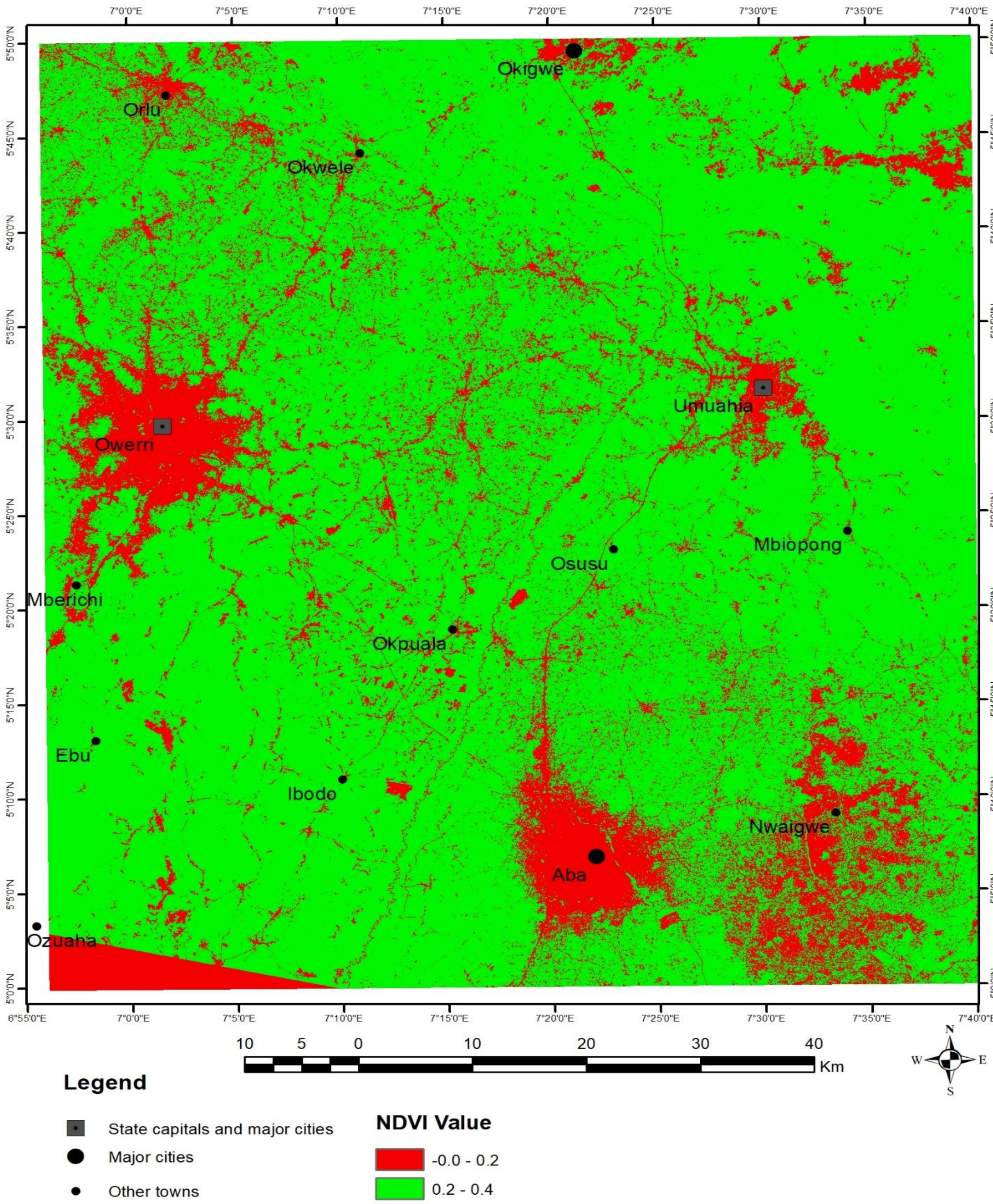


**Fig 10 Normalised Difference Vegetation index map above**. The NDVI above shows red as major cities, green as vegetation, green as minor towns, red as roads.

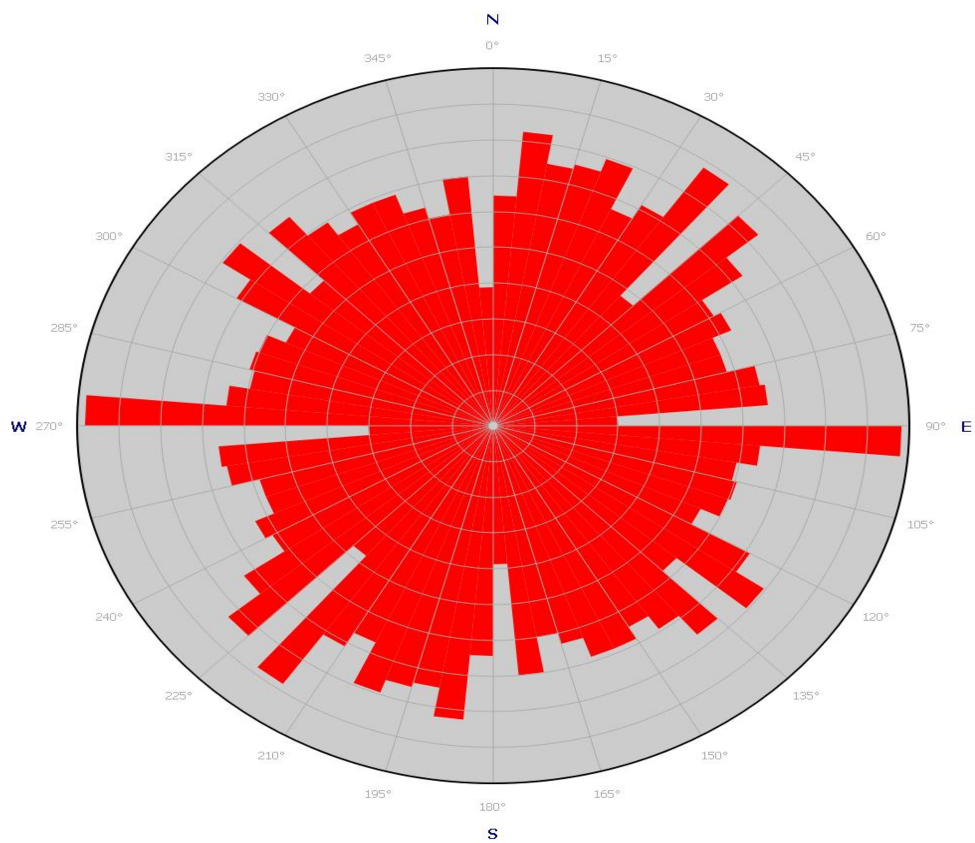


**Fig 11: Lineament rose diagram**. The above map shows the dominant lineament trends, NE,SW

## PROPOSED SOLUTIONS TO GULLY EROSION IN NIGERIA

Prevention is better than cure, they say. Thus, prevention of the processes or mechanisms that result into or advance to gully erosion should be of paramount importance to all the stakeholders in environmental management in the country. Control measures to stem gully erosion that are incipient are most effective when erosion is still at an early stage (Obidimma and Olorunfemi, 2011). Organic carbon, chemical properties, textural characteristics and moisture content of the soil have been suggested as the most useful factors to be considered in a detailed survey and control of gully (Osadebe and Enuvie, 2008). Thus, these factors and others should be carefully examined in the erosion-prone regions of the country in a bid to better design preventive measures. Other measures that could be used to curb the menace of gully erosion are suggested as follows:

i) As earlier mentioned, poor farming techniques were found to be a contributing factor to the growth of gully erosion. Improved farming practices that reduce the gully erosion processes to the barest minimum therefore should be encouraged.

ii) Refuse dump along the river courses impede the flow of water leading to flooding especially during heavy rainfall. Therefore, dumping of refuse on the river channels and floodplains should be prohibited. Government at all levels should enact and enforce laws to deter such activities.

iii) Cultural method (also called vegetative techniques by Simpson, 2010) of erosion control has been found to be a cheap and effective method. Cultivation along contours. Treesand crop planting. Sand bagging/ speed breakers. Control of animal grazing. Back filling. Construction of channels. Planting of plantain and banana on the floodplains have also been found to be effective in controlling erosion. Grasses species such as *Eulaliopsiss binata* (Babiyo), *Neyraudia reynaudiana* (Dhonde), *Cymbopogon microtheca* (Khar), *Saccharum pontaneum* (Kans) and *Thysanolaena maxima* (Amliso), *Arunduella nepalesis* (Phurke) and *Themeda species* have been suggested by Ojha and Shrestha (Ojha and Shrestha, 2007) as suitable especially for slope stability.

iv) Inadequate awareness of effects of human activities on both floodplain and river channels contribute to misuse of these areas. Therefore, there should be general enlightenment campaign on the dangers posed by gully erosion and human activities that promote them.

v) Efforts should also be made by relevant authorities to enact a law against location of engineering structures on waterways.

**i.** The government at all levels in Nigeria should take it as matter of urgency to yield to addressing issues relating to erosion especially gully erosion at an early stage so as to avoid loss of lives of Nigerian people and their properties preventing gully erosion

In most cases gullies can be prevented by good land management practices aimed at maintaining even infiltration rates and a good plant cover.

Strategies for preventing gully erosion include:

i. maintaining remnant vegetation along drainage lines and eliminating grazing from these areas
ii. increasing water usage by planting deep-rooted perennial pastures, trees, or an appropriate mixture of both thus maintaining healthy, vigorous levels of vegetation
iii. identifying drainage lines as a separate land class in which vegetation needs to be protected
iv. immediate stabilisation of sheet or rill erosion
v. vermin control
vi. ensuring runoff from tracks is evenly distributed across paddocks ton dissipate its energy
vii. maintaining high levels of organic matter in the soil
viii. avoiding excessive cultivation (fence and manage the land according to its capability)

Control measures for gully erosion

To be effective, gully control needs to be tackled in two ways:

i. fixing the problems in the catchment
ii. stabilizing the gully itself.

**Catchment works**

The objective of catchment works is to reduce and divert the flow of water into stable drainage lines. This can be achieved by:

i. increasing infiltration rates and water uptake by plants
ii. by diverting and storing water.

A practical way to begin is to subdivide the catchment into appropriate land classes and then apply grazing and cropping practices most suited to each class. The development of a land management or whole farm plan is an ideal way of identifying these issues.

Strategies for stabilizing the catchment include:

i. cooperatively tackling the problem by the formation of a land care group — this could be the most effective method where the source of the problem is spread over several properties
ii. diversion of water away from erosion prone gullies (for example, with diversion banks) — this disperses the erosive power of the water over well-vegetated areas
iii. contour cultivation where possible to slow down runoff and spread the water over a wide area

iv. maintaining farm tracks and culverts so that drainage is evenly dissipated and prevented from concentrating along any section
v. using trees and deep-rooted perennial pastures to assist in both utilising excess water and reducing runoff.

**Stabilising gullies**

The objective is to divert and modify the flow of water moving into and through the gully so that scouring is reduced, sediment accumulates and revegetation can proceed. Stabilising the gully head is important to prevent damaging water flow and headward erosion.

A variety of options can be used to get the water safely from the natural level to the gully floor, such as:

i. grass chutes
ii. pipe structures
iii. rock chutes
iv. drop structures.

Structures might also be required along gully floors since some grades can be quite steep and allow water to rush down under peak flows, ripping away soil and vegetation. These may take the form of rock barrages, wire netting or logs across gullies.

Sediments held in the water will then be deposited along the flatter grades as a result of slower water flow, allowing vegetation to re-establish.

If erosion control and revegetation work is undertaken, then damaged areas should be fenced off from stock, until restoration is complete.

Dams can also be constructed to slow the flow of water into the gully head, but special care needs to be taken to get the overflow water back into the gully floor safely.

Don't fill gullies with solid objects

Don't fill eroded gullies with solid objects such as old drums, car bodies or concrete. This only creates further erosion by directing water around such objects and removing more soil.

**Conclusion**

Nigeria and elsewhere in the world suffer from the havocs of gully erosion. The causes of gully erosion in Nigeria include both natural and anthropogenic sources. The impacts include loss of human and animal lives, loss of properties and land resources. Some of the solutions that are proffered include improved farming techniques, cultural method of gully control, and enactment of laws against any activities that favour gully growth. The government at all levels in Nigeria and the stakeholders in environmental management such as State Ministry of Environment and Federal Ministry of Environment should also sensitize Nigerians on the causes, impacts and problems of gully erosion. However, poor or lack of implementation of research findings and recommendations seem to hinder complete evaluation of proposed solutions. For instance, in some cases where an effort is made, poor quality of work usually leads to even greater erosion, as in the case of road construction probably due to poor supervision, poor funding and corruption.

Though we have little or no control on the natural causes of gully erosion especially those related to the underlying geology, the individuals and relevant stakeholders should discourage all practices that are capable of initiating or speeding the phenomenon in Nigeria. If all the suggested solutions are carefully looked into, it is believed that the incidence of gully erosion in Nigeria would be drastically reduced and the security of the lives of Nigerians and their properties will be guaranteed.

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