MAPPING AND MONITORING OF THE IMPACT OF GULLY EROSION IN SOUTHEASTERN NIGERIA WITH SATELLITE REMOTE SENSING AND GEOGRAPHIC INFORMATION SYSTEM

J. I. Igbokwe[a*], J. O. Akinyede[b], B. Dang[c], T. Alaga[c], M. N. Ono[a], V. C. Nnodu[d], L. O. Anike[e]

[a]Department of Surveying and Geoinformatics, Nnamdi Azikiwe University, Awka, Nigeria-(joel_igbokwe)@yahoo.com.
[b]Director of Space Applications, National Space Research and Development Agency, Abuja, Nigeria-(joakinyede)@yahoo.com
[c]National Centre for Remote Sensing, Jos, Nigeria.
[d]Department of Environmental Management, Nnamdi Azikiwe University, Awka, Nigeria.
[e]Department of Geological Sciences, Nnamdi Azikiwe University, Awka, Nigeria.

Commission VIII, WG VIII/2

KEY WORDS: Land Degradation, Landcover, Landuse, Topography, Soil Erosion, Settlements, Gullies, Vegetation.

ABSTRACT:

Gully Erosion, in part, explains soil erosion. Soil erosion is described as an accelerated process under which soil is bodily displaced and transported away faster than it can be formed. The agents of soil erosion are principally running water, glaciers, waves and wind. These are natural agents of erosion. Anthropogenic factors also contribute to soil erosion, particularly in this zone. Erosion usually transports rocky materials or soil particles after the processes of weathering have broken them down into smaller pieces which are moveable. Soil erosion starts with the delayed type of rainfall droplets, dislodging particles of soils, removing them and eventually depositing them at new location different from the original site. When the surface of soil is not protected by plant covers or any other materials, it erodes or washes away easily. An area is subject to erosion when certain factors are considered. These include geology, landuse practices, geomorphology, climate, soil texture, nature and biodiversity, land conservation practices and environmental management. Soil erosion constitutes the major ecological problems in Southeastern Nigeria. Three types of soil erosion occur in the area, namely sheet, rill and gully erosion. Gully erosion is however the most prominent feature in the landscape of Southeastern Nigeria. The topography, geology, nature and texture of soil, vegetation as well as activities of man contribute to the speedy development and expansion of gullies in the area. The focus of this research project is therefore on gully erosion and its impact in Southeastern states of Anambra, Abia, Enugu, Imo and Ebonyi. Gully erosion in this area is a causative action of nature and man (anthropogenic factors). Man, in most cases remain nonchalant, unconcerned to the consequences of his actions and inactions to the environment. The natural causes of gully erosion are also indirect actions of man which in some cases are even orchestrated for political reasons. In the cause of this study we identified such activities as laterite excavations, bad farming practices, unplanned road construction and urbanization, wood harvesting for fuel and bush burning to clear lands for farming, among others. These activities, coupled with annual flooding from rain water are causing havoc and untold hardship as gullies continue to develop and expand rapidly in the area. Utilizing the opportunities offered by Remote Sensing and Geographic Information System (GIS), this research project came up with vital spatial datasets on the spatial distribution, development and impact of gully erosion in Southeastern Nigeria. This paper therefore presents the results of this study, which include

i. Comprehensive landcover and landuse mapping of the 5 states of the area with a view to depicting the spatial distribution of gully sites in the area.
ii. Comprehensive study of the impact of gully sites on their immediate surroundings, determine the impact on settlements, agricultural farmlands, vegetation and topography.
iii. Development of 3D – Digital Terrain Models (DTM) of critical areas in the States for the purpose of studying topography, characteristics and patterns of gully sites.
iv. Integration of the DTMs with processed satellite images to generate data for slope analysis and other spatial attributes of gullying.
v. Soil loss analyses for the critical areas using Universal Soil loss models to determine the volume of annual soil loss in erosion in the areas.

The project was carried out with NigeriaSat-1, Landsat ETM+, SPOT 5, Quick Bird and SRTM image data.[*]

[*] Corresponding Author.

1. INTRODUCTION

1.1 Gully Erosion Problem In Southeastern Nigeria

Southeastern Nigeria is a typical gully erosion region in Nigeria. The presence of gully sites is one of the hazard features that characterize this zone as well as other States that adjoin them (Ofomata, 1985). Asiabaka and Boers (1988) had estimated that over 1,970 gully sites occur in Imo and Abia States. A conservative assessment shows the distribution of known gully sites, in different stages of development as follows; Abia (300), Anambra (700), Ebonyi (250), Enugu (600), Imo (450) (Igbokwe et al (2003), Egboka (2004)) These statistics are not exhaustive (See Table 1) as small size sites were not included and new ones keep on developing during each rainy season due to flooding and torrential rainfall.

S/N	STATE	NO. OF GULLY SITES	STATE	CONTROL MEASURES
1	Anambra	700	Mostly active	Not successful
2	Abia	300	Some active/some dormant	"
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 (2003), Egboka (2004)

Table 1: Distribution of Gully Sites in Southeastern Nigeria (in Different Stages of Development).

Of these five states, Anambra has the highest concentration of active gully sites. In fact, every community in the state has tells of woes as a result of expanding gullies. Imo, Abia and Enugu States also have stressed areas where gully sites predominate. Our field experiences revealed that the causative factors of gully erosion in the area are natural and anthropogenic. With the highest rainfall average of 1952 mm from March to November, erosion results from impacts of rain drops on the topographic surface. Similarly cases of exacerbation of gully erosion by human activities abound in parts of the area. Good examples are those of the Ajali water scheme at Owa, the Enugu-Onitsha highway, the ever expanding Umuchiana gullies at Ekwulobia, the gullies along the Umuchu – Umunze Road, and the famous Agulu – Nanka gullies. Urbanization involving road constructions, building developments, etc. contribute immensely to gully sites development in the zone. One of the booming businesses in the south – east of Nigeria is sand excavation. Excavations are being carried out by individuals on the existing road sides. In the areas around Agu Awka in Anambra State, Awomamma in Isu-Njaba L.G.A. of Imo State, people have illegally acquired the permission to excavate sands in these places. Their activities are greatly contributing to gully sites development. In Ebonyi State, due to the geology of the area, there is a sequence of marine and sand shale. There is also evidence of volcanic activity and minor igneous intrusions and sedimentations of brown and grey limestone which encourage quarrying and mining activities. Some of these mining pits have been abandoned and over the years have developed into gully sites. The active / major gully sites are spatially distributed in the region. The figures 2 to 5 show some of those gully sites and their impact on the immediate environment.

1.2 The Study Area

This region is located between latitudes 04° 30'N and 07° 30'N and longitudes 06° 45'E and 08°45'E. The area comprises the geographical location of the following states: Abia, Anambra, Ebonyi, Enugu, and Imo. The relative location is; in the north west by Kogi and Benue States in the northeast by Cross River State, in the South by Akwa Ibom and Rivers States and finally in the West by Delta State, as shown on figure 1 below.
The area is well drained. The notable rivers and streams that are found in this zone include Niger, Imo, Nike Lake, Anambra, Idemili, Njaba, Oguta Lake, Nkisi, Ezu, Oji etc.

Geologic formations such as hills that elongate in the north east to south westernly directions include Missions hill and Abakaliki hill. The hills are generally of volcanic rocks and sandstones. It is found that from these hills that a number of streams that recharge the rivers that drain the area originated. In Ebonyi, the out-crops of folded cretaceous limestone and shale are found in so many places. The natural flow patterns of the rivers and their tributaries form dendritic kind of drainage pattern in the area.

The study area lies within the tropical region. We have early rainfall usually in January/February with full commencement of rainy season in March and stopping in November of each year. The dry season lasts between four to five months. The highest rainfall is recorded from July to October with little break in August. The average highest annual rainfall is about 1952 mm. The temperature pattern has mean daily and annual temperatures as 28°C and 27°C respectively.

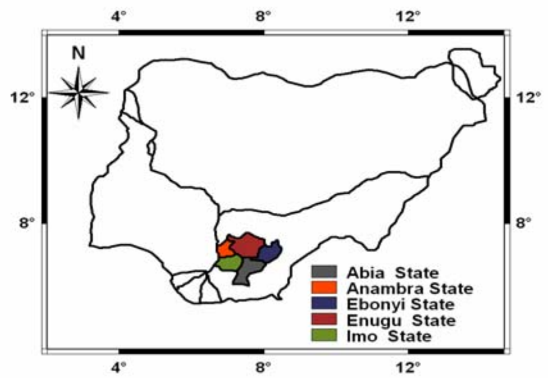


Fig. 1. Map of Nigeria Showing the Study Area

Figure.2 A Gully Site in Abiriba, Abia State

Figure.3. A Gully Site in Nachi-Agbalaenyi Enugu State

2. METHODOLOGY

Utilizing the opportunities offered by Remote Sensing and Geographic Information System (GIS), we came up with vital spatial datasets on the spatial distribution, development and impact of gully erosion in Southeastern Nigeria. The procedure we adopted involved

- Landcover and landuse mapping of the five States in the Region, to depict the spatial distribution of gully sites
- Development of 3D-Digital Terrain Models of areas where gully sites predominate
- Integration of the DTMs with processed satellite images to generate data for slope and soil analysis and other spatial attributes of gullies and
- Soil Loss analysis using modified Universal Soil Loss Models.

To carry through the above , the following satellite images were used.

- NigeriaSat-1 images of 2005
- Landsat ETM+ Images of 2001
- SRTM Image Data of 2004
- SPOT 5 image Data of 2005
- Quick Bird Image Data -2005

Figure. 4. A Gully Site in Umuchu, Anambra State

Figure.5. A Gully Site in Umuchiana, Aguata, Anambra State

For image analysis, the following software were used

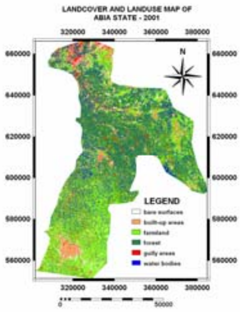
- ArcGIS 9.0
- Erdas Imaging 8.6
- ILWIS 3.3
- Golden SURFER 8.0.

2.1 Landcover and Landuse Mapping

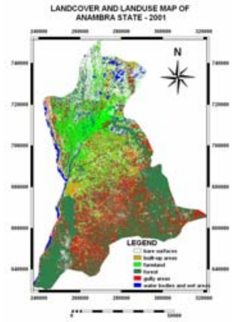
A comprehensive landcover and landuse mapping of the states in this zone – Abia, Anambra, Ebonyi, Enugu and Imo State was done, state by state. The particular emphasis here was to highlight the spatial spread of gully erosion and its impact in the territories of the state (see figure 6 below).

Multi-spectral landcover and landuse classification was done for each state using both NigeriaSat – 1 image data (2005) and Landsat ETM data (2001). A comparative analysis of the results of classifications was done to determine the landcover and landuse patterns in the two data dates, as a result of the development and spread of gullies. Furthermore the classified images from 2001 and 2005 were merged in order to identify areas mildly, moderately and severely gullied in each State.

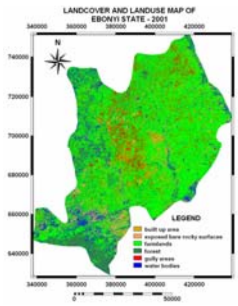
Prior to the classification, the spatial as well as the spectral resolution of the images were improved by image fusion technique using both Landsat ETM Panchromatic band, SPOT 5 and Quick bird image data where appropriate (Igbokwe, 2004, 2005).



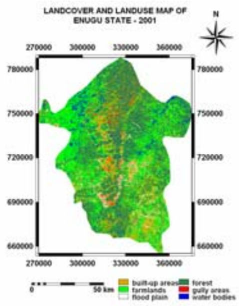
(a) Abia State



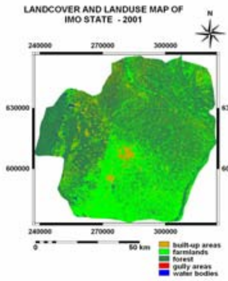
(b) Anambra State



(c) Ebonyi State



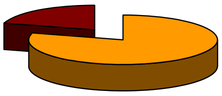
(d) Enugu State



(e) Imo State

Figure. 6 (a-e). Landcover and Landuse data of the Five Statesof Southeastern Nigeria.

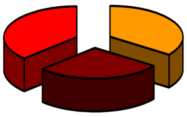
figure 7 shows the classification of the states in terms of mildly gullied areas, moderately gullied areas and severely gullied areas. In **Abia State**, 3322.61 km^2 of the territory or about 79.4 % are mildly gullied, while 864.45 km^2 of the territory or about 20.6 % are moderately gullied. In **Anambra State,** The picture shows that 1661.38 km^2 or 35.1 % of the territory are mildly gullied, 1316.58 km^2 or 27.8 % of the territory are moderately gullied, while 1758 km^2 or 37.1% of the territory are severely gullied. In **Ebonyi State,** 2447 km^2 or 47.4 % of the territory are mildly gullied, while 2712.06 km^2 or 52.6 % of the territory are moderately gullied. In **Enugu State,** 6252.08 km^2 or 80.8 % of the territory are mildly gullied, 1481.41 km^2 or 19.2 % of the territory suffer moderate gully impacts. In **Imo State,** 4694.67 km^2 or 88.1% of the territory are under the impact of mild gullies, while 634.50 km^2 or 11.9 % of the territory are impacted by moderate gully actions.



Mildly Gullied Areas - 79.4%

Moderately Gullied Areas - 20.6%

(a) Abia State

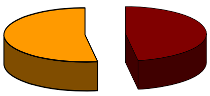


Mildly Gullied Areas – 35.1%

Moderately Gullied Areas – 27.8%

Severely Gullied Areas – 37.1%

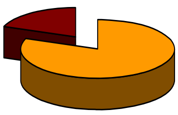
(b) Anambra State



Mildly Gullied Areas - 47.4%

Moderately Gullied Areas - 52.6%

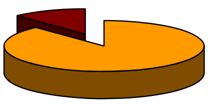
(c) Ebonyi State



Mildly Gullied Areas - 80.8%

Moderately Gullied Areas - 19.2%

(d) Enugu State



Mildly Gullied Areas - 88.1%

Moderately Gullied Areas - 11.9%

(e) Imo State

Figure. 7 (a – e) Severity of Gully Sites in Pie Charts.

Figure 8 shows the classification map according to severity of gullies in two of the States –Abia and Anambra States.

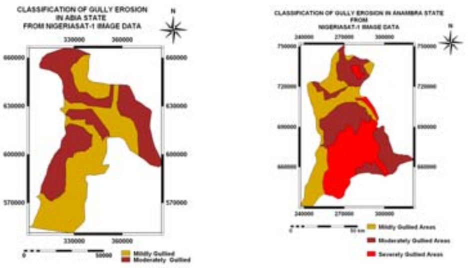


Figure.8. Classification Map according to severity of Gullies.

2.2 Development of 3D-Digital Terrain Models of areas where gully sites predominate

The SRTM image data and the topographic sheets were used to generate contour data at about 10m interval. From the contour data, point files with the coordinates and elevations were generated and imported into Surfer 8 software, where the DEMs (Digital Elevation Models) were generated. The enhanced image window for each of the concerned State was furthermore draped over the corresponding DEM to generate the 3D – Digital Terrain Model with much more enhanced surface information. Although the scale of generation was medium, due to the resolution of the satellite images used, the results display very well various geomorphologic characteristics that facilitate the development and formation of gullies.

2.3 Soil Loss Analysis Using the Universal Soil Loss Equation

The data used for soil loss analysis comprise the following:

- Landsat – ETM, NigeriaSat-1 and SPOT 5 data over the critical areas of Southeastern Nigeria, where the impact of gully erosion is most severe, as remotely sensed data.
- Soil attribute data (detachability, moisture content, Bulk density, root depth) acquired mostly from digital analysis of the SRTM data of the areas and some field data.
- Rainfall data from the states concerned
- Landcover data of the areas concerned
- Topographic data of the areas concerned

The soil attribute data were obtained from field work and from the existing Nigeria soil map. Rainfall data were collected from each of the state's offices with meteorological data. Landcover data were generated from the landcover / landuse map of each of the states concerned.

The topographic data (slope gradient) were generated from the DTM and DSM produced for each state from the SRTM image data and the topographic map sheets (1:50,000) over the study areas.

2.3. 1 Data Analysis and Soil Maps Generation: Soil erosion modelling, used here, is based on the methods explained by Morgan (1986); Morgan and Finney (1984) and reported by Shrestha (2006) in ILWIS Applications Guide. The model tries to encompass some of the recent advances in understanding of erosion processes. The model considers soil erosion to result from the detachment of soil particles by raindrop impact and the transport of those particles by overland flow. The procedure adopted to actualize the erosion modelling is as follows (See Chapter 24, Soil erosion modeling in ILWIS Application Guide)

i. Use of the Generated DTMs

The generated Digital Terrain Models (DTMs) were used to generate slope maps for each of the States. It is also possible to generate slope exposition from a Digital Terrain Model. Terrain slope plays quite an important role not only on its influence in soil formation and development but also on degradation of land, caused by soil erosion. Having other erosion parameters being constant, we can assume that the higher the slope gradient the larger the risk of soil erosion. Thus it is very important to compute slope gradient. Terrain slope gradient is one of the most important parameters in soil erosion modelling in GIS. It is also essential in many land use planning exercises. The slope gradients were thus computed for each of the States.

ii. Computation of Height Difference Maps

Once you have a digital elevation map you can compute slope gradients. For this purpose height differences need to be computed in X and Y directions since overall slope gradient is a function of height differences over horizontal distances in both X and Y directions. The filtering operation in ILWIS 3.3 with the filter dfdx was used to compute height differences in west east direction where the positive value in the resulting map indicates the increase of height, the negative value indicates the decrease of height and a zero indicates no difference. The resultant map was recorded as **Dx**. Similarly, a filtering in north-south direction with the same filter resulted in a map called **Dy**.

iii. Generation of Rainfall Maps Based on DTMs

In an area with known variations of annual rainfall, caused by elevation differences a DTM can be used to generate a rainfall map. Assuming that no rain shadow area exists in the watershed, a regression analysis of annual rainfalls with different elevations can be performed and if the correlation coefficient is found to be high enough an equation can be derived to compute a rainfall map from elevation data. This was adopted to generate rainfall maps for the critical areas of the States. Thus

Rainfall map **(R)** =1384.2 0.329 + Elevation

The rainfall data generated compares very well with the rainfall data collected on site in each of the States.

iv. Generation of Rainfall Energy and the Rate of Soil Detachment by Raindrop Impact

a) Generation of Rainfall Energy Maps

Kinetic energy of rainfall **(E)** in J/m^2 is dependent on the amount of annual rain **(R)** and the rainfall intensity **(I)**. It can be derived by the equation established by Wischmeier and Smith (1978), thus

$$\mathbf{E}=\mathbf{R}\ (11.9+8.7\ \log_{10}{}^{1})$$

For computing the rainfall energy, the rainfall map generated earlier was used. For rainfall intensity the value of 25 mm/hr was used for the study area watershed and thus the rainfall energy maps were generated.

b) Estimation of the Rate of Soil Detachment

Soil detachment is a function of soil detachability index defined as the weight of soil detached from the soil mass per unit of rainfall energy. It was computed by using the equation, modified as follows

$$\mathbf{F} = \mathbf{K}\cdot (\mathbf{E}\cdot \exp(-0.05\cdot\mathbf{A})\ ) \cdot 1.0\cdot 10^{-3}\ [24.3]$$

where **F** is the rate of soil detachment in kg/m^2, **K** is the soil detachment index and **A** is the percentage rainfall contributing to permanent interception.

v. Generation of Overland Flow Maps

The objective of this exercise was to generate a map indicating the volume of overland flow. The Overland flow **(Q)** is dependent on moisture storage capacity **(MS)** of surface soil which can be derived from field capacity. It is also dependent on the soil bulk density **(BD)**. Moreover it is dependent on rooting depth **(RD)** of various cover types, the ratio of actual to potential evapotranspiration **(Et/E0)**, the amount of annual rain **(R)** and the number of rainy days **(Rn)**. The overland flow maps were generated as follows

$$Q = R \cdot \exp(-Rc / R_0\ )$$

Where,

Rc =1000.MS.BD.RD.(E t /E0)
R0 =R/Rn

vi. Generation of Transport Capacity of Overland Flow

The objective of this is to generate a map indicating the transport capacity of overland flow. Transport capacity of overland flow **(G)** is dependent on the volume of overland flow **(Q),** the crop cover management factor **(C)** and the topographic slope factor (**S**). This was calculated for each of the States by using the equation;

G = C·Q2.0 · sin S·10−3
G = C * SQ(Q)* SIN(DEGRAD(S))/ 1000

vii. Estimation of soil loss in erosion

Soil loss estimation is calculated from the transport capacity of overland flow **(G)** and the estimated rate of soil detachment **(F)**. If the transport capacity is higher than the rate of soil detachment, the soil detachment value will be taken as the soil loss. Similarly, if the rate of soil detachment is higher than the transport capacity of overland flow, the value of the transport capacity will be considered as the soil loss.

Soil loss estimation

Since the lower value of the transport capacity of overland flow and the estimated rate of soil detachment is taken, the minimum function MIN of ILWIS was used to obtain the soil loss.

Soil loss or **Erosion** = MIN(**G**, **F**)

The result of soil loss analysis is shown in table 2. While Fig. 9 shows the soil loss maps for the five States.

3. CONCLUSION

In conclusion, we present here the major findings of the project.

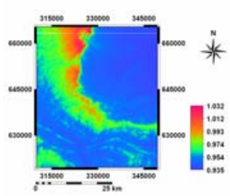
3.1 On Gully Development and Expansion

i. Nature of Topography: The study revealed that gully developments are more pronounced in areas with high terrain undulation. In these areas, the slopes of the ground are steep and vary. This inevitably results in increase in the speed and volume of the overland flow and subsequently the rate of detachment and transportation of soil particles.

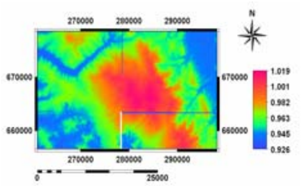
S/No.	State	Soil Loss Tons/ Ha/ Yr	
		Min (In Low Areas)	Max (In High Areas)
1.	Abia	9.20	10.16
2.	Anambra	9.11	10.03
3.	Ebonyi	8.71	9.60
4.	Enugu	9.46	10.54
5.	Imo	9.23	9.93

Source: Laboratory Analysis

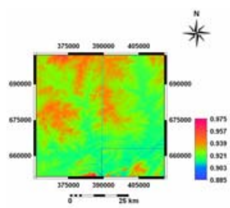
Table 1. Soil Loss in Gully Areas



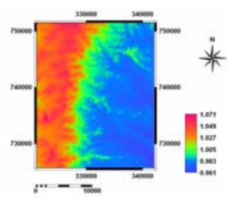
(a) Abia State



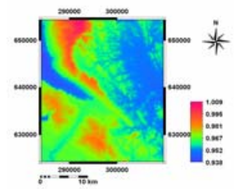
(b) Anambra State



(c) Ebonyi State



(d) Enugu State



(e) Imo State

Figure. 9(a-e). Soil Loss in Gully Areas.

ii. Nature of Soil : In all the States, the soil is mostly loose and very porous. The soil particles are not consolidated and therefore detach easily when imp acted by flood water. This is what facilitates the development of deep and wide gullies found in most areas.

iii. Agricultural Practices: Large portions of the vegetation cover are cleared annually for farming purposes, thereby exposing the top soil to erosion. With the soil exposed, it is no longer capable of resisting the erosive actions of the rainwater. The continuing action of the rain favours high rate of infiltration, enough to lubricate the underlying strata. Consequently this provokes heavy carrying away of the soil and leads to run off. This results in gulling as witnessed in many of the areas.

iv. Settlement Patterns, Urban and Infrastructural Development: Settlement patterns, the nature of housing and infrastructural development contribute to the development of gullies in the region. Settlements are not planned, houses are built indiscriminately without consideration to natural flood paths and drainage system. Infrastructures such as roads are built without proper environmental studies and tend to facilitate the gulling processes. The dense population in the region is also a factor. As population increases, the need to provide housing and other facilities increases also. Where this is not properly managed as is the case in the region, construction of new houses, roads etc will only exacerbate the situation. For example Anambra State has probably the highest population density in the whole of Sub-Saharan Africa. With gully erosion destroying much of the land surface, there will be high population pressure in housing, water supply road construction power supply among others. This results in massive pressure on the available land. The desperate and unplanned move to satisfy the need for more and more housing only creates favourable condition for gully development. In Anambra State for example, there is very high land consumption for various landuses. No wonder Anambra State has the highest concentration of active gully sites in the region.

iv. Sand Mining (Laterite Excavation): One of the booming business in South Eastern Nigeria is sand excavation. The excavations are carried out by individuals along the existing roads sides. The action of rain which results into floods causes the washing off of the land surface and as it moves, deposits sands that have even blocked roads in some area. In some of the States, people have illegally acquired the permission to excavate sands commercially and these mining sites eventually develop into huge gullies as rainwater continues to impact on them.

5. 1. 2 Socio - Economic Impacts of Gullies

The effects of gully erosion in this region is tremendous. We have identified the following as the major impacts of gully erosion;

- **Displacement of Large Population of People:** In Anambra State, the entire communities in Umuchiana, near Ekwulobia in Aguata L. G. A. were completely displaced in 2006 due to the expansion of gully sites. The Amuchu community in Njaba L.G.A of Imo State suffered the same fate. In Ugurike in Ikeduru L.G.A., the road that links the community with Ekwerazu, Mbaise has almost been washed off.
- **Destruction of Houses:** cracking of houses and falling of buildings into gully sites are common features in the erosion prone areas. People have lost their life

investments into gullies in areas like Agulu, Nanka, Nnewi etc in Anambra State. People have become refugees in their ancestral homes. The damage on the psyche of these people can be imagined.

- **Destruction of Roads and Transport Infrastructures:**

The major federal highways in the areas have been virtually destroyed in many portions or completely cut off. For example;

i. Enugu – Onitsha Expressway at Nachi and Onyeama mine near Enugu
ii. Enugu – Port Harcourt Expressway at Ntigha near Umuahia
iii. Ekwulobia – Oko Road in Aguata L.G. A of Anambra State
iv. Oguta – Owerri Road at Ikwesa town
v. Awka – Ekwulobia Road at Agulu town.

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