Anisotropic Type Determination and Soil Structure Evaluation in Parts of the Gully Erosion Zones of SE Nigeria using Azimuthal-Offset Resistivity Sounding Technique and Erodibility Characterization.

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ABSTRACT

Geoelectric and geotechnical studies were integrated in the evaluation of soil and anisotropic structural elements related to the occurrence of gully erosion in parts of SE Nigeria, namely Umuagu-Urualla, Nanka and Agulu. The results of the geoelectric survey were plotted as radii to generate anisotropy figures. The figures are elliptic in shape, indicative of the presence of electrical anisotropy and exhibited prominent peaks which are characterized by moderately high to short axes ratios typical of dip anisotropy.

The direction of electrical anisotropy for the sites varies from NW–SE and E–W in Umuagu–Urualla, NW–SE and NE–SW in Nanka, and NE–SW and N–S in Agulu in line with the axis of the maximum peak in the figures. These anisotropically determined directions agree with the dominant propagation axes of gullying activities in the respective sites which authenticate the fact that gullying is related to subsurface structural elements. The coefficients of anisotropy (λ) determined from the sites vary from 1.20 for Umuagu Urualla and Nanka to 1.30 for Agulu.

These values are relatively higher than the value of one (1) for a homogeneously isotropic earth medium indicative of anisotropic subsurface. Other likely anisotropic features in the sites are bedding laminations, grain boundary cracks, and mineral grains aligned in preferred directions within the depth of investigation. The results of the geotechnical study reveals that the soils completely collapsed on immersion, behavior typical of materials that belong to the 4th class of the classification based on the crumb test. A loss of strength on saturation as is exhibited in the manner of collapse is attributable to the low plasticity of the samples and hence the high susceptibility of the soils to erosion gullies. The geological formations within the sites get easily saturated due to their lithological structure, and more channel surface runoffs along structural and dipping trends down slope. This explains why these areas contain gullies of alarming magnitude.

(Keywords: coefficient of anisotropy, electric anisotropy, erodibility, plasticity)

INTRODUCTION

Erosion is the washing away of the loosely cemented particles of the soil by agents of wind or water. Most of the soil components that are washed off are the fine grained particles, which fall between <0.002 and 0.06mm in diameter on the British Scale (BS). Erosion is known to grade from sheet to rill and finally to gully, with devastating effects in most cases.

Gullying activities are the predominant ecological disasters in south eastern Nigeria, which are chronic in nature. A high percentage of the regions land mass are under severe gullying and landslide activities, while a large proportion of its population is at risk of loss of soil to degradation. This region has recorded tremendous incidences of gully with varying degrees of hazards that are associated with them. The general observation is that these areas that are affected by the gully have a characteristic nature of soil and geologic structures which generally favour the occurrence of the gullies.

Many workers (Fubara, 1986; Grabs, 1992; etc.) attributed gullying activities to mainly anthropogenic factors in the areas. This however is at variance with the morphology of the gully features in the affected areas and probably suggests that the geological and geotechnical characteristics of the soils are the main factors that account for the occurrence of gullies in the region (Egboka and Okpoka, 1984, Ehirim and Ebeniro, 2006). These activities are suggested to be due to natural forces but their extent and severity are attributed to man's ignorance and unintentional actions (Onu and Ehirim, 2000).

LOCATION

The study areas are located in Agulu, Nanka and Urualla gully erosion sites within Longitude 7°00 to 7° 15'E and Latitude 5° 56' to 6° 15'N (Figure 1). These areas lie within the Nanka Formation in the Anambra basin and are underlain by the Tertiary Bende – Ameki Formation. These areas happen to be the most ravaged by gully erosion and landslide activities in the region.

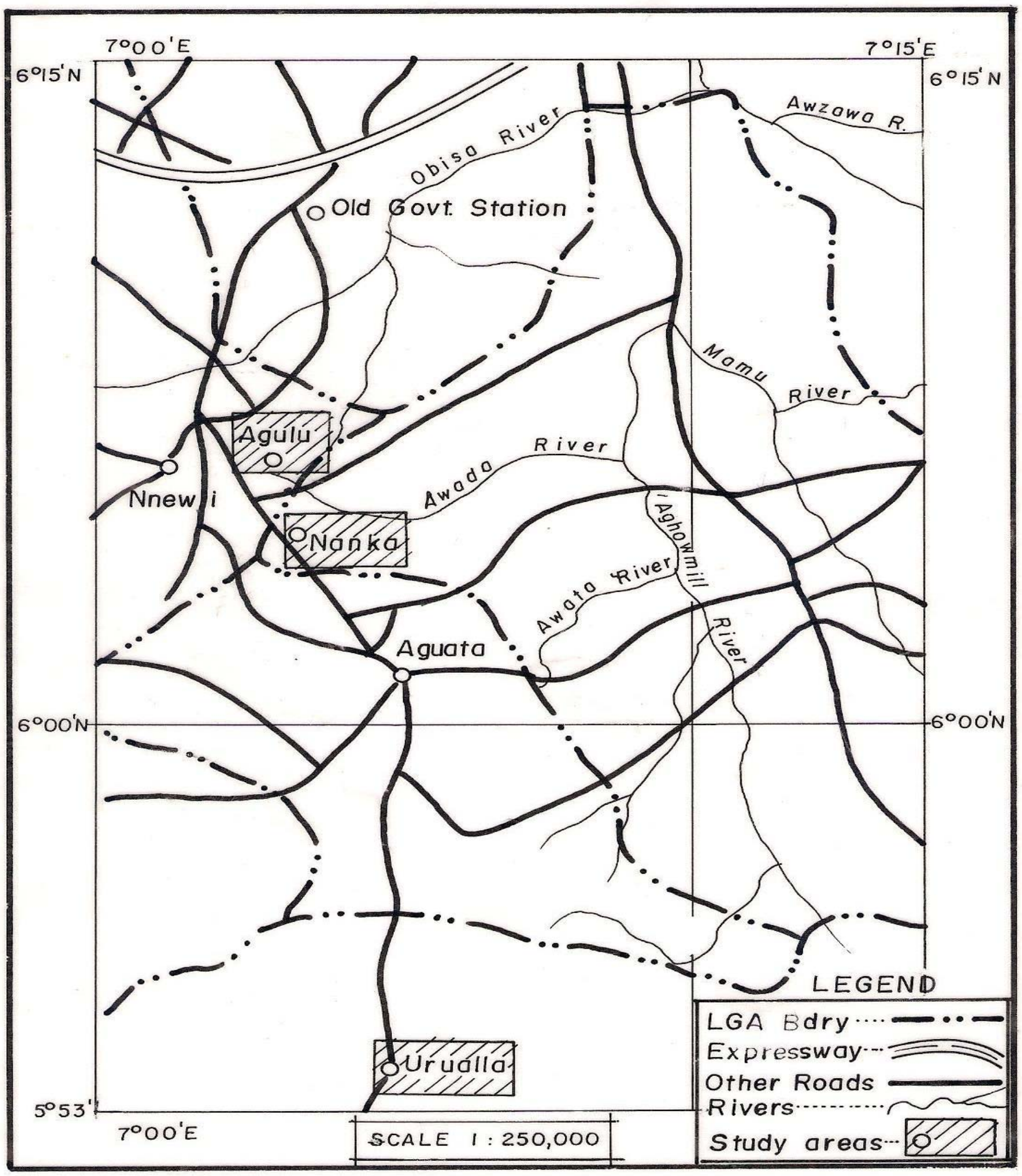

Figure 1: Location Map of the Study Area.

The Bende – Ameki Formation in the area is characterized by many structural irregularities in their lithologic character and exhibits anisotropic behavior due to fractures, grain boundary cracks and aligned mineral grains in preferred directions, giving the formation its characteristic electrical anisotropy in space and time. Typically, any observed change in resistivity with direction is interpreted as indicative of fracture anisotropy. However, azimuthal variations in resistivity may also be produced by lithologic and dip anisotropies (Watson and Barke, 1988). These structures are oftentimes zones of weaknesses in the rock structures and can aid in initiating and facilitating soil degradation and associated crustal instabilities in the areas.

Azimuthal resistivity survey has been used (Skjernaa and Jorgensen, 1993 and Busby, 2000), as a technique for mapping and characterizing electrical anisotropies in terms of the nature, direction, and coefficient of electrical anisotropy; and was adopted in this study. The erodibility of the soil determined by the simple dispersion test of Benites (1968) involved the examination of the susceptibility of the soil structure to collapse upon saturation.

The aim of this work is to integrate electrical resistivity measurements with geotechnical studies in the evaluation of soil structure and anisotropic type with a view to determining soil structural features that may have the potential to initiate and enhance the process of gullying in the study area.

GEOLOGY AND PHYSIOGRAPHY OF THE AREA

The area is located within the Anambra Basin, which constitutes a major depocenter of clastic sediments and deltaic sequences. The Basin resulted from the second tectonic activities of the lower Benue Trough to the effect that the Abakaliki sector was folded and uplifted while the Anambra platform experienced subsidence.

The geology of the Anambra Basin has been described by several authors (Short and Stauble, 1967; Burke et. al., 1971; Kogbe, 1989; etc). The age of the sediments in the basin ranges from Cretaceous to Pleistocene. The erosion of the Abakaliki uplifted and folded belts during Mid-Cretaceous times, resulted in the development of a proto Niger Delta sequence consisting of Nkporo, Mamu, Ajali and Nsukka Formations. The third and last depositional cycle of the lower Benue trough started with a major transgression that deposited the Imo shale during Paleocene period.

This was followed by a regression that started during Eocene and continued to the present day with the deposition of the sediments of the Tertiary Niger Delta. The sediments deposited during this period included Bende-Ameki, Nanka, Ogwashi-Asaba, and the Coastal Plain Sands (Benin) Formations in that sequence (Figure 2). These have many structural irregularities in their lithologic character and exhibits anisotropic behavior due to fractures, grain boundary cracks and aligned mineral grains in preferred directions, based on the character of sediment deposition in the basin.

The Nanka sands (Formation), which is the host formation of the area under study is made up of thin beds of argillaceous rocks in places and are mainly loose and friable with a characteristic coarse to medium unconsolidated sands. The areas lie in the rainforest zone, where the annual rainfall exceeds 1500m. The intensity of rainfall most of the time exceeds 25mm per hour, a factor which encourages gullying activity. The rainy season starts from late February and ends towards mid November (Ogbukagu, 1976). The relief ranges from 75m on the hills to 30m on the adjoining lowland.

METHODOLOGY

Azimuthal electrical surveys were carried out using the Abem Terameter SAS 300B, with the Offset Wenner electrode configuration. Electrode expansions of 20, 40 to a maximum of 60m were adopted. Measurements were made by rotating the array about a center point at 45^{o} increments in four Azimuthal directions. The resistance R(Ω) data obtained from the measurements were converted to equivalent apparent resistivity ρa (Ωm) values for subsequent data analysis.

Disturbed soil samples were collected from the walls of the gullies at different depths and from the different locations and properly packaged for the laboratory erodibility characterization using a simple dispersion (crumb) test of Benites (1968), which involved the examination of the susceptibility of the soil structure to collapse upon saturation.

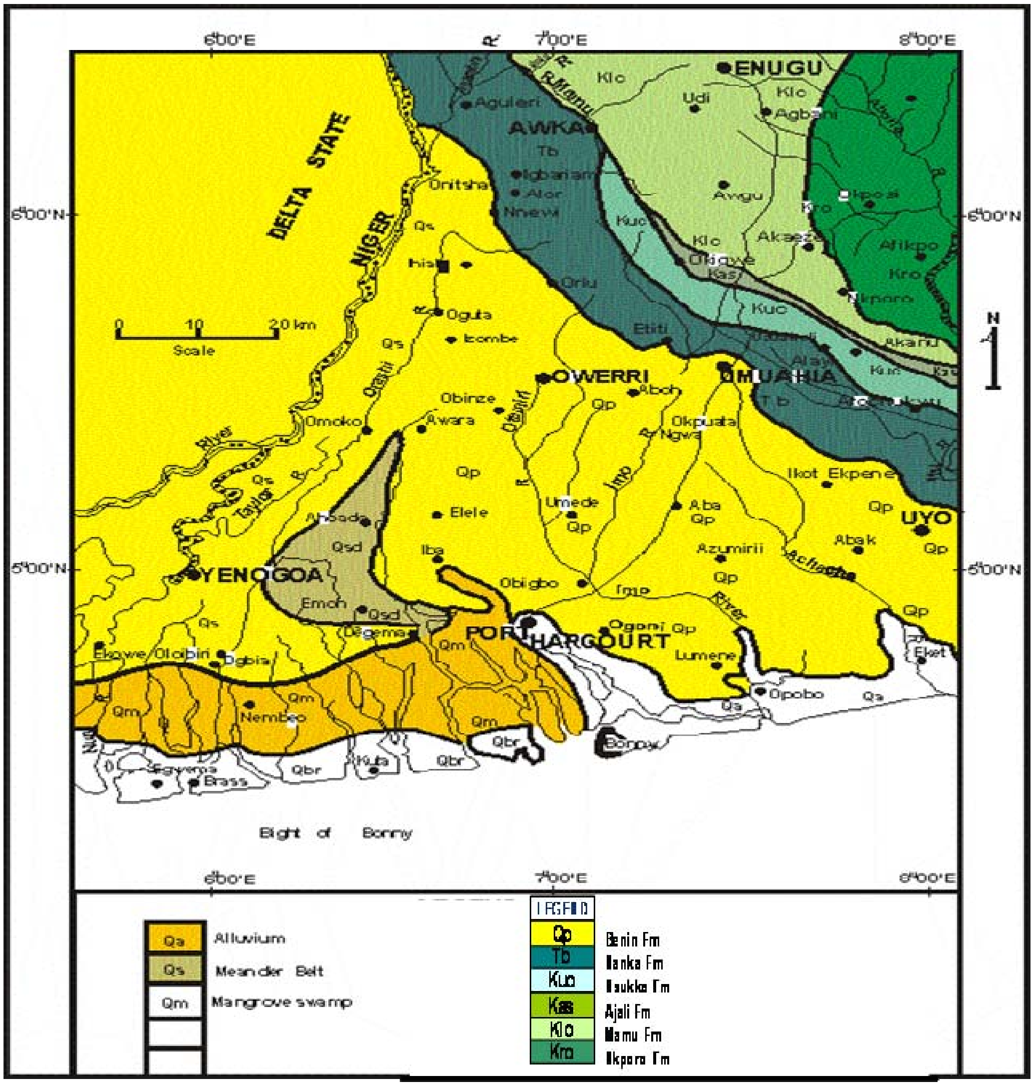

Figure 2: Geologic Map of the Study Areas.

RESULTS OF INVESTIGATION

The measured apparent resistivity data were plotted as radii to generate anisotropy figures. The figures are elliptic in shape indicative of the presence of electrical anisotropy (Figure 3). The figures exhibited prominent peaks which are characterized by moderately high to short axes ratios. The direction of electrical anisotropy for the sites varies from NW–SE and E–W in Umuagu–Urualla, NW–SE and NE–SW in Nanka, and NE–SW and N–S in Agulu in line with the axis of the maximum peak in the figures.

The coefficients of anisotropy determined from the sites vary from 1.20 for Umuagu-Urualla and Nanka to 1.30 for Agulu. These values are relatively higher than the value of one (1) for a homogeneously isotropic earth medium (Habberjam, 1975).

The erodibility characterization of the soil samples from the various erosion sites were found to belong to class 4, being marked by high degree of erodibility resulting from the complete collapse of the soil samples (Table 1).

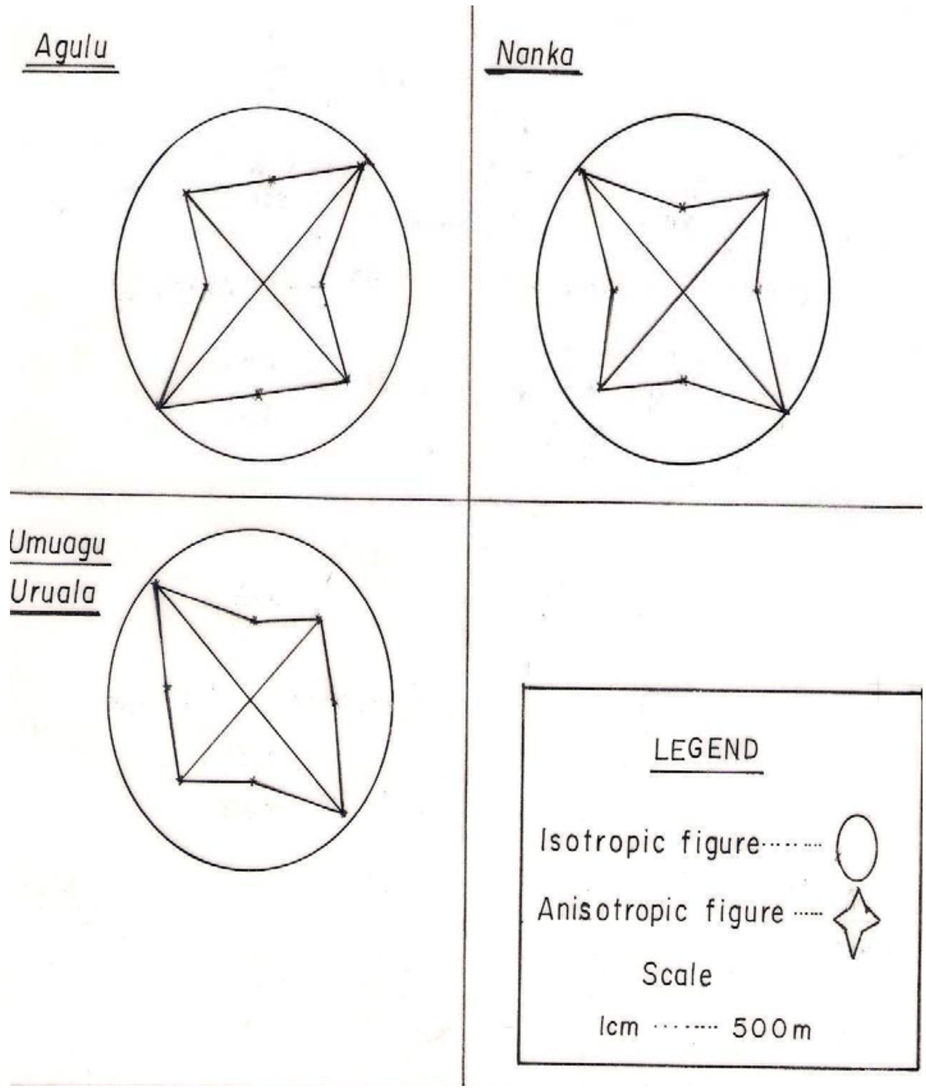

Figure 3: Anisotropy Figures of the Study Areas.

Table 1: Soil Erodibility Characterization of the Soils at the Erosion Sites.

Location	Behavior after 5-10 Mins. of Immersion	Erodibility Degree	Class
Agulu -1	CC	High	4
Agulu – 2	CC	High	4
Agulu – 3	CC	High	4
Agulu – 4	CC	High	4
Nanka – 1	CC	High	4
Nanka – 2	CC	High	4
Nanka – 3	CC	High	4
Umuagu-Urualla -1	CC	High	4
Umuagu-Urualla -2	CC	High	4
Umuagu-Urualla – 3	CC	High	4
Umuagu –Urualla – 4	CC	High	4

CC = Complete Collapse

DISCUSSION

The results of the field measurements showed that the direction of electrical anisotropy lies predominantly in the NW-SE and E-W, NW-SE and NE-SW, and NE-SW and N-S in Umuagu - Urualla, Nanka and Agulu erosion sites, respectively. These anisotropically determined directions agree with the dominant propagation axes of gullying activities in the respective sites which authenticate the fact that gullying is related to subsurface structural elements.

The coefficient of anisotropy determined for the sites vary from 1.20 in Umuagu-Urualla and Nanka to 1.30 for Agulu. These values are departures from the value of one (1) for an isotropic homogeneous earth medium, implying an electrically anisotropic subsurface in the investigated sites (Habberjam, 1975). The anisotropic figures exhibited prominent peaks which are characterized by moderately high long to short axes ratios indicative of dip anisotropy in contrast to the high long to short axes ratios characteristic of fracture anisotropy (Skjerraa and Jorgensen, 1993). Other likely anisotropic features in the sites are bedding laminations, grain boundary cracks, and mineral grains aligned in preferred directions within the depth of investigation.

On the other hand, the soils completely collapsed on immersion, a behavior typical of materials that belong to the 4th class of the classification based on the crumb test. This is indicative of high erodibility with a strong linkage to the absence of silt and clays, as is supported by the result of the grain size distribution (Ekeocha, 2008), which showed that the soils are uniformly graded and compares with results of Babalola (1988).

Expectedly there is a loss of strength on saturation as is exhibited in the manner of collapse, attributable to the low plasticity of the samples and hence the high susceptibility of the soils to erosion gullies. This supports the assertion of Akpokodje et al. (1986) that plasticity is the main factor that affects the loss of strength of a soil upon remolding with a given amount of water.

As is observed from the results, the samples lack fines (silt and clays) that cement the particles together and this is known to constitute part of the causative agents of erosion gullies and subsequent development among other factors. The soil within the sites allow insignificant infiltration due to their lithological structure, and more channel surface runoffs along structural and dipping trends down slope. This explains why these areas contain gullies of alarming magnitude.

CONCLUSION

The coefficient of anisotropy determined for the sites vary from 1.20 in Umuagu-Urualla and Nanka to 1.30 for Agulu. These values are indicative of anisotropic subsurface in the investigated sites. The sites are dominantly characterized by dipping anisotropies in the NE–SW and NW–SE directions. Other likely anisotropic features in the sites are laminations, grain boundary cracks, and mineral grains aligned in preferred directions within the depth of investigation.

The soils of the study area were observed to be weak and non resistant to erosion. They are also poorly graded and almost devoid of silt and clay particles which would act as cement. The samples belong to the 4th class on the basis of the crumb (erodibility) test. The erosion and attendant gullies that occur in the areas are thought to have been initiated and enhanced by a number of factors among which include the composition and structure of the soil, topography of the area and rainfall.

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