PRELIMINARY GULLY HAZARD ASSESSMENT USING 2D-ERT AND 2D-SRT GEOPHYSICAL SURVEYS: A CASE STUDY IN SOUTHEASTERN NIGERIA

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Abstract

Two-dimensional Electrical Resistivity Tomography (2DERT) and Seismic Refraction Tomography (2DSRT) were concurrently applied in assessment of a gully site with the view of assessing its stability and risk level. Eight profile lines oriented parallel and perpendicular to the boundary of the gully were surveyed. As a result, apparent resistivity model tomograms in the range of 1-9,000 Ωm and p-wave velocity models in the range of 300-700 ms^{-1} were obtained from the two techniques respectively. Interpretation of the models obtained show predominance of unconsolidated clay, shale intercalates, clayey sand, sandy clay and weathered lateritic soil at shallow depths. Low amplitude undulating refracting layers, landslide slip subsurface and loose horizons were also delineated at shallow depths. The predominance of weak, clayey and unconsolidated lithology at the gully site suggests evidence of unstable gravitational equilibrium which imply environmental hazard. The plausible deductions made from the two techniques support the usability of the techniques in the assessment of risks at gully sites.

Keywords: Tomography, lithology, clayey, slip subsurface, fractures

1.0 Introduction

Natural disasters are unpredictable shallow-surface global environmental problem which constitute major threat to lives. These include earthquake and tsunamis, volcanic activities, flood, hurricane, gullies and landslides (Abidin *et al.*, 2012). Particularly, gully erosion has been identified as one of the most striking disaster, constituting major global environmental problems (Abdulfatai *et al.*, 2014). Also, landslide as a kind of disaster, are principally associated with gully occurrences as rapid, mass wasting downslope under the influence of gravity depending on topography, hydrology, the structure of underlying bedrock, soil and bedrock type, coupled with some other minor factors (Jadwiga *et al.*, 2012).

Gully erosion and landslides are severe form of soil and rocks' degradation caused by concentrated runoff along lines or zones of weakness (Musa *et al.*, 2016), saturation of near-surface soils due to anthropogenic activities hence, amounting to increment of infiltration and sediments' detachment (Chaplot *et al.*, 2005 a, b). On the surface of the earth today, what may naturally trigger significant slope failure include rainfall, snowmelt, reservoir impoundment, typhoons, earthquakes, volcanic eruptions, construction of buildings, transportation routes, dams and reservoirs, canals, and communications systems (Robert and Lynn, 2001). Rainfall and earthquakes among the several factors are globally considered as the two most predominant triggering factors (Runqiu and Weile, 2011). Depending on an area's geology which is a key factor, land use act, geomorphology, climate, soil texture and bio diversity of the area could lead to active gully erosion and landslide problems. Particularly, in any horizon of the solid earth, the rock type would suggest predominantly an area's susceptibility to erosion more than other prevailing factors (Abdulfatai *et al.*, 2014). The socioeconomic impact of any prominent and active gully erosion and landslide menace would become obvious when they expand into built-up environment and unstable hillside areas under the pressures of increasing populations (Robert and Lynn, 2001). Therefore, direct and indirect costs become inevitable owing to reduction of traffic and destruction of natural landscape (Guthrie, 2013).

In south-eastern Nigeria, gully erosion is an endemic environmental problem which has continued to pose a challenge to geoscientists and other indigenous environmental scientists of West Africa. Outstandingly, Anambra State of the south-eastern Nigeria is worst hit having about 1,000 active erosion sites identified (Okoyeh *et al.*, 2014). These have been exacerbated by anthropogenic, intense urbanization, deforestation, agricultural, commercial and industrial activities elluviated (Egboka and Okoyeh, 2016). Comparatively, the distribution of gully erosion sites in south-eastern states of Nigeria at different stages of development has shown that Anambra State records the highest number active gully erosion sites in Nigeria with majority of them not successfully controlled. The records have shown that in Anambra State of Nigeria, about 37% of the total land mass is severely gullied, 28% moderately gullied and 35% mildly gullied (Igbokwe *et al.*, 2008). The widespread impact of gully erosion in the state resulting from anthropogenic impacts, annual rainfall and subsequent flooding has led to the occurrence of landslides taking place as creepy earth movement of rocks and debris flows on slopes previously weakened by infiltrating runoffs. The gully in Anambra basin has amounted to restriction of land use, especially for agricultural purpose, threatened roads networks, water supply schemes, electric power lines, school and residential buildings and above all, human lives. These are general threat to sustainable development just as in the other parts of the world (Frankl *et al.*, 2013). Particularly, Nnewi, a commercial town in Anambra State of the south-eastern Nigeria, is currently being wrecked by one of such gully erosions occurring right in the heart of the town

namely Uruagu-Nnewi (figures 1a and b). For over two decades, there has been rapid increase in this gully erosion and landslide development. The surface view of the gully shows unstable steeply sidewall and eroded scarp face. Records of the occurrence and its consequences include loss of superstructures and losses of massive land are documented in the State's news archive. Currently the increment of gully's width and depth has become an alarming threat to lives, superstructures, infrastructural facilities and property of settlers surrounding it. Approximately, the dimensions of the gully extend beyond 800 m in length, 70 m in width and between 110 m and 150m in depth.

Figure1: (a) Base map of the study area showing location of Uruagu-Nnewi (b) the study site showing the eight (8) profiles occupied for the study (modified after Google Earth, 2019)

The menace at the area has socioeconomically affected the industrialization and infrastructural development at an alarming rate. Meanwhile, frantic remedial efforts have been made by the immediate community owing to the absence of both the state and Nigeria federal government intervention which were neither proactive nor successful.

Fundamental geophysical investigations are imperative in unveiling the condition and features of the geohazards. Since the manifestation and advancement of the incessant occurrence of gully erosion and subsequent landslide in the selected study site, geophysical subsurface imaging has not been carried out to investigate the menace. Hence, geophysical survey is intended in this study to unveil the current subsurface condition at Uruagu-Nnewi, south-eastern Nigeria infer the cause(s) of the geohazard. The investigation using 2D subsurface tomograms have provided valuable interpretations for strategic mitigation of the risk. Also, the study will form a data base which would provide civil engineers useful information for checking the erosion and construction of superstructures at the site's vicinity. Therefore, this study focuses on assessment of gully using two geophysical imaging techniques (2DERT and 2DSRT) in order to estimate the stability at its vicinity. The qualitative interpretations and inferences drawn herein are expected to aid plausible mitigation of the menace.

2.0 Location and Geology of the Study Area

Uruagu-Nnewi is located between latitudes $06^{\circ}00'58''N$ and $06^{\circ}01'14''N$ and, between longitudes $06^{\circ}54'32''E$ and $06^{\circ}54'47''E$ in the Nigeria national grid. The area is within the rain forest vegetative zone of south-eastern Nigeria having a tropical climatic condition which is influenced by two major trade winds. One of such is warm moist south trade winds which occurs during the rainy season (April – October) and north-east trade winds which occurs during the dry and dusty harmattan (November – March). The study area in Uruagu-Nnewi is located within the *Anambra* basin, underlain by *Nanka* formation which is a lateral equivalence of *Ameki* formation. Anambra basin has a synclinal mega structure located at the south-western edge of *Benue* trough, Nigeria; a platforms during *Albian–Santonian* period with reduced sedimentation. A major folding episode occurred in the Benue trough during late Cretaceous (Benkhelil, 1989). Extensively, the stratigraphy of sedimentation of Anambra basin consists of six separate and distinct formations namely: *Mamu* formation (lower coal measure), *Ajali* sandstone, *Nsukka* formation (upper coal measure), *Imo* formation, *Ogwashi–Asaba* formation and the *Nanka* formation (Figure 2). The *Nanka* Formation consists of *Nsugbe* sandstones as its lateral equivalence. The basin is characterized by alternating layers of shales, clayey sandstone and fine-grained fossiliferous sandstone with thin limestone bands (Reyment, 1965). In a nut shell, the study area is predominantly covered by loose, friable unconsolidated *Nanka Sands* (Eocene) and underlain by impermeable *Imo Shale* (Palaeocene). The *Nanka Sands* constitutes the *Agulu-Nanka-Ekwulobia-Orlu* escarpment significant in the hydrogeological and geohazards occurrences in the area (Egboka and Okoyeh, 2016). That is, the unconsolidated, loose, friable and uncemented properties of the *Nanka* formation facilitate the concentration of the gully erosion sites in the area (Nwajide, 1990).

Figure 2: Geologic Map of the Nigeria showing Anambra Basin and adjoining areas in Southeastern Nigeria (After Ogala. and Akaegbobi, 2014).

3.0 Techniques of Data Collection

Environmental and engineering geophysics using ERT and SRT has been considered plausible approach for delineation of the gully's vicinity. The two techniques are non-invasive and non-destructive for the exploration of the subsurface hence, are unscathed and dependable for this survey. Eight profile lines (named P1 to P8), four on each side of the

gully, were occupied for the 2D SRT and ERT measurements respectively. At both sides of the gully, two survey lines were laid parallel to the strike of the gully while the other two were laid perpendicular to it for the survey using the two techniques.

SRT technique performs well in several situations where traditional seismic refraction techniques failed (Carpenter *et al.*, 2003; Bery and Saad, 2012). Generally, seismic refraction method among its numerous applications, finds a unique relevance in the determination of rock competence for engineering works (Varughese *et al.*, 2011). However, in this work, SRT technique was chosen to help in exploration and identification of the sliding surface geometry, water effect on slope, feature of lithology and mass movement of the subsurface sediment (Cumming and Clark, 1988; Mauritsch *et al.*, 2000; Narwold and Owen, 2002).

In the 2D SRT technique, signal input channel of a seismograph namely *ES3000* was networked with twenty-four geophones firmly inserted into the ground and aligned along mapped profile lines and to a field laptop for recording. Adjustments of the settings in the recording mode were made in the field laptop to suit the array. Shots were triggered with a 50 kg sledge hammer when the noise at the site was reduced to its minimum. To ensure adequate scanning of the surface, the shots were made at each geophone location spaced either two or three meters from each other. In order to mask *edge effect* on the resulting 2D SRT tomography model, 2 to 3 other offset shots were made before and after the first and the last geophone along each profile lines. It was ensured throughout the measurement for the SRT data collection that there was adequate signal enhancement during setting and that the electrical timing device was properly fixed to the sledge hammer for triggering of recording. Thus, all the good seismic signals deliberately generated by the source *insitu* and observed in the seismograph were saved in the field laptop.

The Electrical Resistivity Tomography (ERT) also known as Electrical Resistivity Imaging (ERI) choice is time saving having high accuracy as a subsurface modelling technique. 2D ERT survey measures the resistivity changes both in the vertical direction (sounding) and horizontal directions (profiling) concurrently along a single survey line. ERT was chosen because in 1-D resistivity sounding, less dense data are usually registered. However, in the 2D imaging survey, about 100 to 1000 measurements are usually made [13]. Of all the arrays in resistivity method, the choice of Wenner array technique was made for measurement because it has a moderate depth of investigation and its signal strength is inversely proportional to the geometric factor used for calculation of apparent resistivity values, hence it has among other arrays, the strongest signal strength (Loke, 2000).

During the ERT survey, *ABEM SAS 1000* Terrameter aided by Electro selector *ES10-64* co-powered by a unit of an external 12 volts battery was used for data acquisition. Two Lund imaging system cable reels of 21 takeouts each were used for the measurement on the eight profiles of the 2D ERT. That is, forty-two electrodes were networked with the terrameter via cable jumpers for measurements. Hammering on the electrodes and wetting of the ground with salt water were ensured in situations where the ground surface's contact with electrodes was not found sufficiently moist. In the *LUND* resistivity mode of the Terrameter, Wenner 32SX protocol of measurements was used to register the apparent resistivity values at various points on trapezoidal 2D vertical subsurface. Precautionary measures were taken in the field were ensured during the ERT measurements; such as avoidance of high voltage conductors, conducting wire fences, transformers, and other electrical conductive sources capable of damaging the instrument.

4.0 Data Processing and Results

The data recorded from the SRT measurements were in SEG-2 format were processed using *SeisImager version Rev.4_08* software. The software is the master program consisting of four modules namely; *Pickwin*, *Plotrefa*, *Wave Eq* and *Geoplot* for data analyses. Particularly, *Pickwin95* and *plotrefa* modules were used for the seismic refraction wave analysis. The *Pickwin* module was used to load the seismic refraction data in the *SEG2.dat* file format. The first-breaks were “picked”, stacked and stored and the *plotrefa* module was used for interpretation. In the *plotrefa* module, stored first break files were imported as travel time versus distance plots. Afterwards, were the execution of the *time-term* inversion and “*ray tracing*” in order to generate rays for the models (Seisimager, 2009). Finally, the p-wave velocity models (in meters per seconds) for each of the survey lines were plotted after reasonable iterative calculations (Figures 3a-10a). The tomograms shown in the figures were vertically exaggerated schematically in order to enhance their eligibility for clearer reference. The measurements were made over a real heterogeneous earth, therefore it was ensured that adequate processing of the data vis-a-vis filtering and iterations for generation of model tomograms were reliable.

The ERT data collected from the field were first of all in *.s4k* file format. The data were then converted to interpretable format (*.dat*) using the Terrameter’s *utility* software. Then, the converted data were imported into *RES2DInv* Software package for iterative inversion modeling after adjustments were made in the inversion settings. Hence the data inversion was carried out whereby each of the profile line model were assessed for similarity to the actual measured values. That is, the inversion essentially shows a model for the subsurface whose response agrees with the measured data subject to certain restrictions. Hence the *RES2DInv* software was used to plot 2D inversion resistivity models by finite-difference methods. This was achieved by having an initial model modified in an iterative manner so that the difference between the model response and the observed data values is drastically reduced to the barest minimum (Loke, 2004). Least-squares optimization method was used for the iterations thereafter three distinct 2D images output were obtained after the iterations’ algorithms. They are the measured apparent resistivity pseudosection, the calculated apparent resistivity pseudosection and the true resistivity models. After a definite number of iterations ranging between 3 and 7 of the inversion program, the processed pseudosections for the eight survey lines were displayed. The 2D tomograms obtained from the ERT and SRT geophysical techniques of survey are shown in figures 3 to 10 for the eight survey lines respectively.

Fig.3: 2D Electrical Resistivity and P-wave velocity Model Tomogram at Profile P1

Fig.4: 2D Electrical Resistivity and P-wave velocity Model Tomogram at Profile P2

Fig.5: 2D Electrical Resistivity and P-wave velocity Model Tomogram at Profile P3

Fig.6: 2D Electrical Resistivity and P-wave velocity Model Tomogram at Profile P4

Fig.7: 2D Electrical Resistivity and P-wave velocity Model Tomogram at Profile P5

Fig.8: 2D Electrical Resistivity and P-wave velocity Model Tomogram at Profile P6

Fig.9: 2D Electrical Resistivity and P-wave velocity Model Tomogram at Profile P7

Fig.10: 2D Electrical Resistivity and P-wave velocity Model Tomogram at Profile P8

5.0 Interpretation and Discussion

The model results obtained from the two geophysical methods, aided by the knowledge the geology of the study area was considered for plausible interpretation (Dobrin, 1976). In addition, some published standard values of p-wave velocities and apparent resistivity range of values from some recent published findings at the area of similar geology with the study area were also considered interpretation. From the SRT results (figures 3a-10a), the rainbow colour models represent the p-wave velocity values in the in the subsurface. The models show p-wave velocity range of about 300 ms^{-1} to 700 ms^{-1} for the earth materials within the vicinity of gully site. Based on the geology of the area and published related works, the p-wave velocity values fall within range of unconsolidated soils (300 ms^{-1} to 800 ms^{-1}) such as sand ($350 - 900 \text{ ms}^{-1}$), lateritic dry sand ($200 - 1000 \text{ ms}^{-1}$), sandy clay ($360 - 430 \text{ ms}^{-1}$) and suspected air-filled columns of range ($300 - 330 \text{ ms}^{-1}$) (Parasnis, 1987; Osemeikhain and Asokhia, 1994; Hugh, 1995; Kearey *et al.*, 2002; Chii and Osazuwa, 2010; Nwosu and Emujakporue, 2016). The interpretation is in agreement with the geological assertion that the study area is characterized by *Nanka formation* which is overlain by lignite *Ogwasshi Asaba* formation both in Anambra basin is characterised by an unstable platform of a regional escarpment subtended by sandy, highly-fractured and faulted Nanka sands/Formation (Egboka and Okoyeh, 2016). Secondly, the SRT model tomograms have shown slip subsurface (P1, P4 and P7) and undulations (P2, P5 and P6) delineated as shallow refracting layer. The seismic refraction interfaces, particularly, the slip subsurface which are considered to be landslide slip subsurface, the undulating subsurface and the incompetent sandy and clayey lithology indicate danger of instability at the site's vicinity.

Considering the electrical resistivity imaging results, the 2D resistivity models (Figures 3b-10b) show a wide range of resistivity value ($1 - 53,500 \Omega m$). This in turn indicates various lithology and their structural features at the vicinity of the gully. The wide range of resistivity encompasses the resistivity values for clay and shale of various grades of consolidation, sandy clay, clayey sand, saturated soil, sandstone (dry), saturated sand stone and weathered laterite (Obiabinmo *et al.* 2014; Fatoba *et al.* 2013; Agbo, 2008 and Telford *et al.*, 1990). In a nut shell, the ERT survey tomograms show that the shallow depths, the soil and rocks are predominantly characterized by clay and sandy clay of various grades of which some are weak and saturated. At depths, the clayey soils are inferred as scarce conglomerate of fairly consolidated shale. Also, based on the individual ranges of resistivity values for the interpreted subsurface materials in the foregoing namely clay, sandy clay, clayey sand, saturated soil, sand stones and weathered laterites; the predominance levels from the ERT interpretation were numerically quantified. These were estimated and represented comparatively in a bar chart (figure 11). The chart confirms the predominance of clayey at shallow depths at the gully's vicinity.

Fig.11: Bar Chart of Predominance levels for Interpreted lithology from the ERT Survey.

Considering the interpreted lithology, the 2D ERT tomograms show variability in resistivity at low ranges of contour intervals. There is evidence of undulating and rugged layers of relatively high resistivity (Profiles P2 to P4), relatively heterogeneous topsoil (Profile P3), a slight dipping layer mapped as shown at profile P3 (figure 8) and inferred fracture subsurface at shallow depths (Profiles P1, P4 and P5). Based on the interpreted results of the 2DSRT and 2DERT models, there is agreement with the geology of Anambra basin which has its youngest alluvium filled with plastic sediments ranging from moderately drained sands, silt and sandy clay with top layer of black of upper Campanian to brownish humus and laterite (Uzoije *et al.*, 2013). Also, supportive to this is the interpretation of the tomogram that its lithology is in agreement with the assertion that Nnewi is sitting directly on the flange of lignite series underlain by *Bende Ameki* Formation, which consists of series of highly fossiliferous sandy clay, calcereous concretions and clayey sandstone (Onochi and Ibearugblem, 2012). The occurrence of undulation and inferred fractures particularly are signs of unstable geologic environs of the gully site hence, the gully's expansion and further devastation could be said to be progressive during this survey

6.0 Conclusions

Generally, from the 2DERT survey, the interpretations showed that the subsurface principally consists of clayey topsoil, sand, sandy clay, shale, weathered lateritic soil, and aqueferous zones both at shallow subsurface and at depths. Whereas suspected air-filled columns, dry sand, saturated sand, and sandy clay, were principally delineated by the 2DSRT technique. Common to the two geophysical techniques in terms of the mapped lithology is mainly the occurrence of clay, clayey sand, weathered lateritic soil and sandy clay at the gully's vicinity. The structural feature of the delineated lithology shows evidence of landslide slip and smooth undulating seismic refracting layers as delineated by the 2DSRT models. From the 2DERT inversion models, saturated clayey zones and inferred fractured consolidated zones were predominantly delineated in the topsoil. Other delineated features by the same electrical method at depths include heterogeneity of clayey soil, inferred undulating and rugged geologic layers. The summary of the foregoing interpretations vis-a-vis the lithology and structural features is integrally articulated in Table 1.

Therefore conclusions derived from the 2DERT and 2DSRT surveys at the gully site are:

- i. Confirmation of the occurrence of the unconsolidated clay with minor shale intercalates, sand, sandy clay, clayey sand at the gully's vicinity.
- ii. Delineation of weak and heterogeneous topsoil and relatively consolidated soil at depths
- iii. Delineation of rugged (undulating) layers, inferred fractures and most significantly, the landslide slip subsurface both at shallow subsurface and at depths.

Invariably, the zones of saturated clayey and sandy lithology are weak and loose grounds at shallow depths. The weakness and saturation of the soils around the gully site would most probably be continually exacerbated by flooding based on the rain forestry climate of the area. The zones of slip subsurface would be capable of causing further fall of the gully walls owing to the unstable equilibrium in gravity hence leading to the widening of the gully and subsequently, landslide. The troughs of the delineated undulating subsurface coupled with the fracture zones would be geologic synclines which enhances percolation into deeper horizons at the gully vicinity. Since frequent rain and flooding characterize the area; it apparently uncertain to predict a natural end of the soils and rocks failure at the site hence, proactive engineering remedial measures would be required. Particularly, further conscientious investigations by geophysicists, geologists and civil engineers are invariably required for adequate check and curbing of the menace. Researches on control and mitigation of active gully development can neither be overlooked nor considered as an overemphasis in such developing or civilized areas where gully erosion occurs. Further studies are recommended to build upon this survey and these include deep and detailed seismic reflection tomography, textural characterization, clay swell test and other relevant geotechnical measurements.

Table 1: Summary of Interpreted lithology and structural features in the subsurface at the Uruagu-Nnewi Gully site

Profile Identity	Orientation of Profile	Profile Length (ERT)	Profile Length (SRT)	Estimated Range of Electrical resistivity (Ωm)	Estimated Range of p-wave velocity (ms^{-1})	Predominant lithology (from 2D ERT)	Predominant lithology (from 2D SRT)	Predominant structural feature(s) (from 2D ERT)	Predominant Structural composition (from 2D SRT)	Integrated predominant lithology and structural features
P1	S80°W	126.0	46.0	50-2,800	440-470	clayey sand	sand and sandy clay	fractured / consolidated topsoil	slip subsurface	unconsolidated clay, sandy, clay, clayey sand and weathered lateritic lithology saturated at shallow depths while Structural features include heterogeneous, undulating, slip subsurface, inferred fractured zones at shallow subsurface
P2	N40°W	084.0	46.0	15-3,200	400-470	clay, clayey sand (saturated)	sand and sandy clay	shallow undulating	undulating subsurface	
P3	N40°W	084.0	46.0	270-2,900	490-670	weathered lateritic soil	sand and sandy clay	heterogeneous and undulating	undulating	
P4	S80°W	126.0	46.0	3-8860	360-430	clayey sand	sand and sandy clay	rugged and fractured	slip surface	
P5	S20°E	084.0	46.0	1-5,700	318-460	sandy clay	sand and sandy clay	Inferred wide fracture	Undulation (relatively flat)	
P6	N85°E	126.0	69.0	200-5,200	470-510	clay and sandy clay	sand and sandy clay	obvious fractured subsurface	relatively flat refractor	
P7	S05°W	084.0	69.0	190-4,600	370-430	clayey sand	sand and sandy clay	obvious fractured topsoil	slip subsurface	
P8	N87°W	084.0	69.0	17-39,700	490-670	clayey sand and sand (dry)	sand and sandy clay	Rugged shallow subsurface	Slip subsurface	

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