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2DNear-Surface Litho-Structural Geophysical Investigation at the Vicinities of Two Gully-Erosion/Landslide Sites in South-Eastern Nigeria

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Abstract: *Integrated shallow-surface litho-structuralgeophysical survey has been carried out at the vicinities of two gully erosion sites in Anambra basin, south-easternNigeria. The study was aimed at delineating shallow surface lithologyand structuressuspected to be causatives to rampantmassive structural failures at the basin.2D seismic refraction tomography (SRT) and electrical resistivity tomography (ERT) data were collected along survey lines oriented parallel and perpendicular to the strikes of gully sites. Modelled SRTdata showed p-wave velocity in therange of about* $300 - 2000\ ms^{-1}$ *while ERT data showed apparent resistivity datain the range of about* $1 - 25{,}500\ \Omega m$*. Integral interpretation made with both methods showed that the ranges encompass those of weathered lateritic soil, saturated sandy soil, clay, sandy clay, clayey sand and sandstones. Particularly, ERT tomograms showed that clay, sandy clay and clayey sand were predominant. Structurally, SRT showed obvious occurrences of shallow landslide slip surfaces delineated as major refracting layers while the ERT tomograms showedmoderate heterogeneity and minor relatively flat layering of soil formation.In conclusion, the interpreted lithology and structure in the foregoing most probably, are causative to the relatively active and severely active gully sites in the Anambra basin, south-eastern Nigeria.*

Key Words: *gully,landslide, seismic, resistivity, tomography.*

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I. Introduction

Gully erosion is a highly visible form an antecedent removal of soil by running water. It is a linear deep erosion feature with active head cut, unstable side wall, subject to mass movement and non-graded longitudinal profile with temporal water flow (Sidorchuk, 2001). It is the most striking erosion typecausing global deterioration, environmental natural disasterand socioeconomic setbacksdue to its notableunpredictable occurrence (Abdulfatai, Okunlola, Akande, Momoh, & Ibrahim, 2014; Beijing, 2002). Gullies growthcould be rapidly and very large in dimension making effective control technically difficult or prohibitively expensive.

In south-eastern Nigeria, gully erosion is an endemic environmental problem and outstandingly in Anambra State (Okoyeh, Akpan, Egboka, & Okeke, 2014). Of all the states in the south-eastern zone, Anambra state has been identified as one of the worst-hit having about 1,000 active erosion sites in its domain (Mgbenu & Egbueri, 2019). Comparatively, the distribution of gully erosion sites in south-eastern states of Nigeria at different stages of development (Egboka, 2004; Igbokwe et al., 2008), has shown that Anambra State records the highest number active gully erosion sites with the majority of them not successfully controlled. Records have shown that in Anambra State of Nigeria about 37% of the total landmass is severely gullied, 28% moderately gullied and 35% mildly gullied (Igbokwe et al., 2008). Two of these gully sites were selected for study in this research namely that located at Uruagu–Nnewi of Anambra state and another located at Nanka-Oko boundary both in Anambra basin.Presently, the erosion at these sites has amounted to massive loss of land, landslides and failure of superstructures (Figure 1a). Major triggering factors of the gullies in the area include rainfall, construction of buildings, transportation routes, and anthropogenic activities. The degradation is invariably an environmental degradation of the ground surface owing to gravitational mass wasting (Robert & Lynn, 2001). Its multiple on-site and off-site effects of gully erosion/landslides has threatened sustainable development in south-eastern Nigeria. Hence, the sites were chosen due to the urgent need of erosion control and mitigation at the sites owing to lives that are increasingly being threatened, property and infrastructural facilities which are continually prone to great danger in the basin.

The Uruagu-Nnewi gully site has been noticed to be actively progressing for the past decade. The expansion and failure of the gully has resulted to failure of somebuildings and major roads close its boundary prior and during this investigation (Figures 1b).

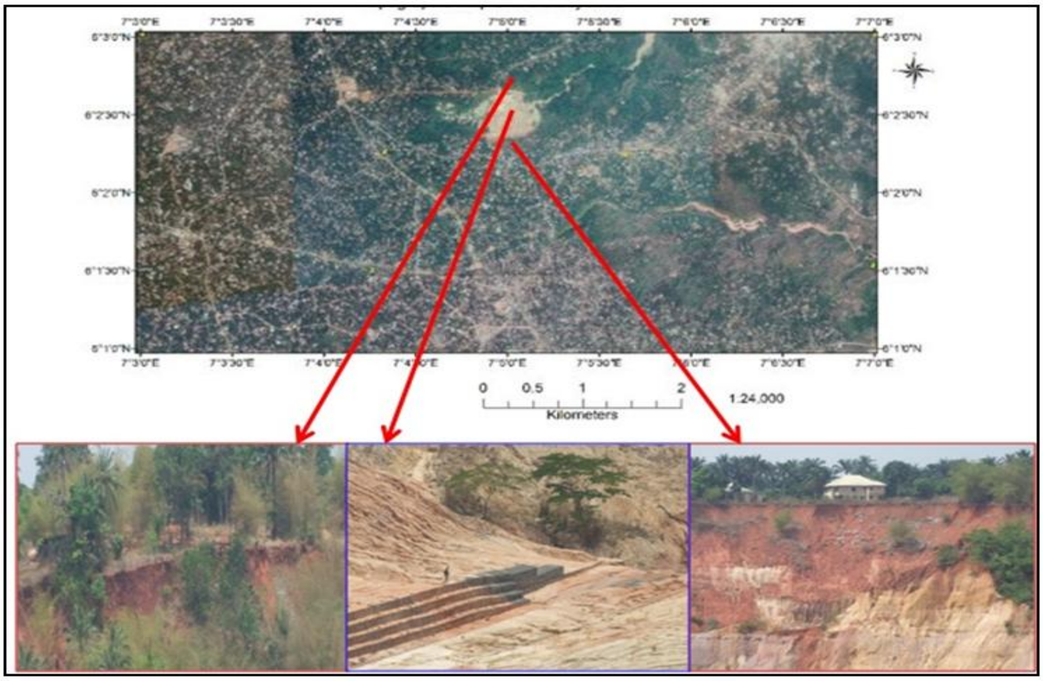

Figure 1a: Google Earth View and Some Pictures of Some Parts of the Nanka-Oko Gully Interior

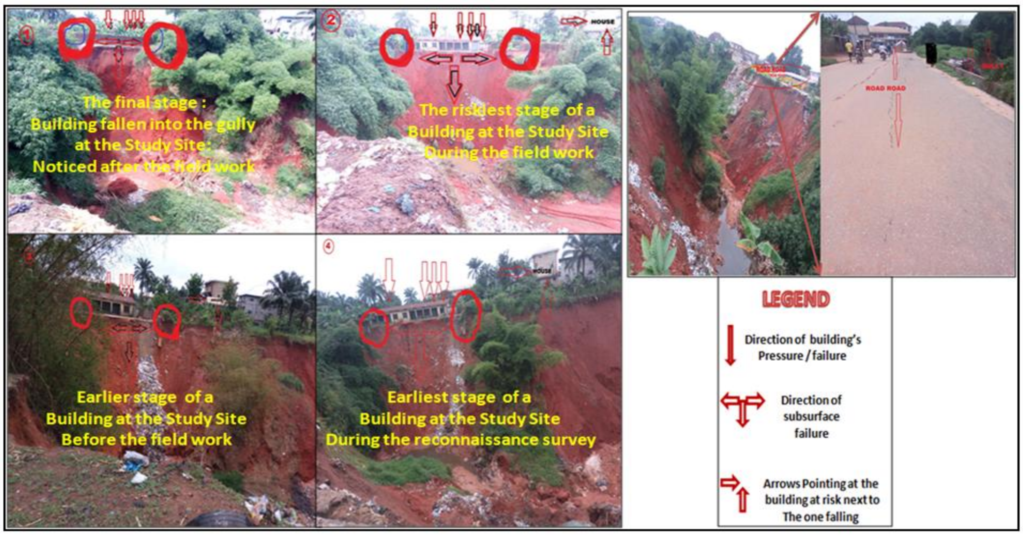

Figure 1b: Active and Progressive failure of a superstructures and a Major Road at the Uruagu-Nnewi Gully site

Before this present investigation, Malaysia(Abidin et al., 2012) applied 2D SRT in evaluating the continuous subsurface ground damage to ascertain landslide geometry. investigated a large landslide in glaciolacustrine clays in the Trieves area with SRT and ERT to correlate them with geotechnical and morphological features. (Rezaei, Amiri, & Beitollahi, 2016) used SRT to check site effect relating to the amplification of ground motion under earthquake loading. SRT and ERT were integrally used for study of structural failure of three building sites in Zaria area, northern western Nigeria (Egwuonwu, 2012). On the other hand, (Alessandro et al., 2014) carried out shallow and deep ERT to distinguish the geological boundary between shallow Quaternary sedimentary deposits and clayey bedrock characterized by moderate resistivity contrast. (Pánek, Hradecký, & Šilhán, 2008) applied ERT in the study of various types of slope deformations in anisotropic bedrock hence showed the best results of promising seams of bodies of active, water-saturated landslides or lacustrine deposits behind landslide dams. (Obiabunmo, Umego, Obiekezie, & Chinwuko, 2014) carried out thirteen Schlumberger Vertical Electrical Soundings (VES) at Oba and environs of Anambra State which share the same geological environment.

However, in this present study, two dimensional (2D) seismic refraction tomography (SRT) and Electrical Resistivity Tomography (ERT) methods were practically adopted for the investigation. The techniques were used integrally to determine the internal distribution of the shallow earth materials, identification sliding surface geometry, most probable directions of mass movement and water effect on slopesat the gullies' vicinities. The SRT technique consists of inverting the first arrival times to obtain image of p-wave velocity distribution. Refraction tomography usually produces a good lateral velocity change representation of the near surface which has complex velocity structures.As a matter of fact, SRT performs well in many situations where traditional refraction techniques fail(Bery & Saad, 2012; Carpenter, Higuera, Thompson, Atre, & Mandell, 2003). Its models play would play critical role in the analysis of the subsurface, lithology, structures and prominent fracturing.The ERT survey involves injection of current into the ground via a pair of electrodes and then the resulting potential field is measured by a corresponding pair of potential electrodes. 2D ERT has been found to be time saving and more accurate subsurface modelling technique. Because it measures the resistivity changes both in the vertical direction (sounding), as well as in the horizontal direction (profiling) along common survey line at the same time. It is also cost effective because while 1-D resistivity sounding survey involves few readings, 2D imaging surveys involve about 100 to 1000 measurements at a shorter time when carried out with the aid of a computerised electrode selector (Egwuonwu, 2012).

II. Methodology And Results

The 2D SRT technique was applied unveil the compressional speed along refracted ray paths through the soils and rocks in the vicinity of the gully site. Signal input channel of Seismograph *ES3000* was connected to arrayed twenty-four geophones firmly inserted into the ground and aligned along mapped profile lines. At Nanka-Oko site, geophone spacing fixed at 5 m whereas at the Uruagu-Nnewi site, the geophone spacing was limited to the range of 2 to 3 m being a more built-up site. Adjustments of settings were done on the field laptop to suit the array. Shots were triggered by a 50 kg sledge hammer when *insitu*noise was reduced to the bare minimum. To ensure adequate scanning of the surface, the shots were made at each geophone location spaced either two 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 before and after the first and the last geophone along each profile lines. The eight profile lines upon which the ERT was measured profiles were equally occupied for the SRT. 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.

During the ERT survey, *ABEM SAS 1000*Terrameteraided by Electrode selector *ES10-64*bothwere powered by a unit of external 12 volts battery, and used for data acquisition. Two cable reels of 21 takeoutseach,were usedfor the eight profiles of 2D ERT, therefore forty-two electrodes were networked with the terrameter viacable jumpers. Hammering on the electrodes and wetting of the ground with salt water were ensured in situations where the groundsurface contact was not found sufficiently moist. In*LUND* resistivity mode of the *SAS 1000*Terrameter, Wenner 32SX protocol of measurements was used register the apparent resistivity values at various points on trapezoidal 2D vertical subsurface. Some precautionary measures taken in the field and these include avoidance of high voltage conductors, conducting wire fences, transformers, and other electrical conductive sources capableof damaging the instrument were ensuredduring the ERT measurements.

The SRT data recorded in SEG-2 format were processed using two softwares namely *SeisImager Rev.4_08* software (for Uragu-Nnewi site) and *REFLEX-Wversion 3.0* (for the Nanka-Oko site*)*. The *SeisImager Rev.4_08* software is a master program consisting of four modules namely; *Pickwin, Plotrefa, Wave Eq* and *Geoplot*for data analyses. Particularly, While the *Pickwin*was used to load data and *pick* the first-breakswere, the *Plotrefa* was used for interpretation. For each profile line, the first arrival travel time from the shot point sources were used to create 2D seismic wave velocity distribution of the subsurface. The arrival times per profile line were inverted to obtain 2Dimage of P-wave velocity distribution. The *REFLEX-W* allows trace header coordinates which are stored within the header of each trace. Hence the modules offered by the software include 2D data analysis, wave propagation modelling and interpretation.

Likewise, data inversion was carried out to show the models for the subsurface responses to apparent resistivity.*A RES2DInv* software program was used to plot 2-D resistivity models by finite-differencemethods. This was achieved by having an initial model is modified in an iterative manner so that the difference between the model response and the observed data values is reduced to the barest minimum (Loke, 2004). Least-squares optimization method was used for the iterations. Hence, three distinct 2D images output were shown after the iterations' algorithms namely, the measured apparent resistivity pseudosection, the calculated apparent resistivity pseudosectionand the true resistivity model after a definite number of iterations of the inversion program. This ranged between 3 and 7 iterations.The 2D tomograms obtained from the ERT (in Ohm-meters) and SRT (in meters per seconds) for some survey lines at one of the sitesare shown in figures 2 to 4 respectively.

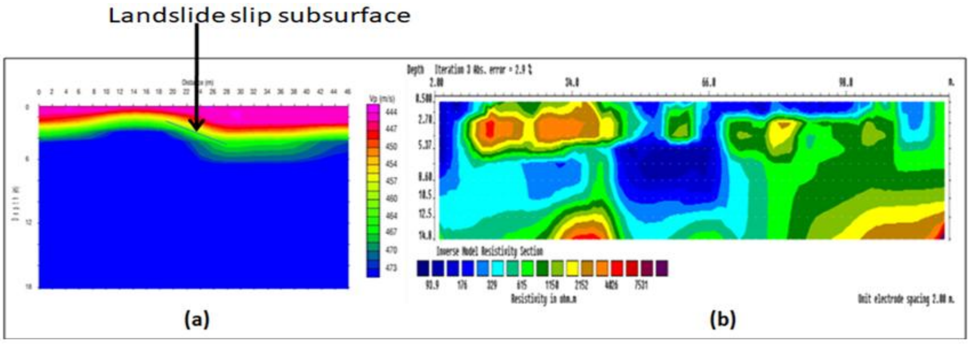

Figure 2: 2D P-wave velocity and Electrical Resistivity Model Tomograms at a common survey line at Uruagu-Nnewi Site

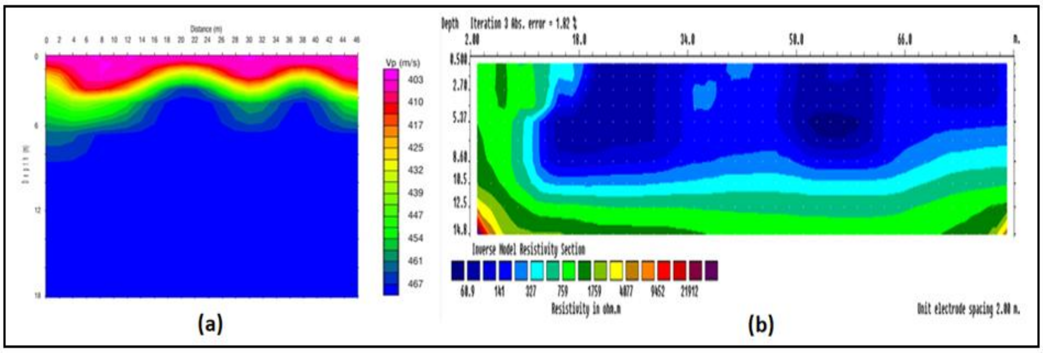

Figure 3: 2D P-wave velocity and Electrical Resistivity Model Tomograms at a common survey line at Uruagu-Nnewi Site

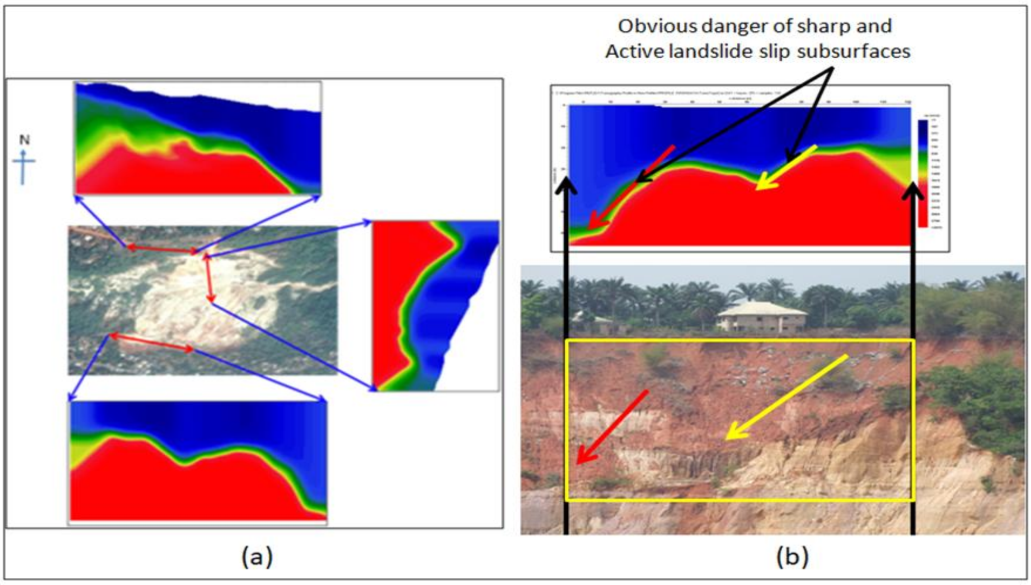

Figure 4: 2D P-wave velocity Model of seismic Refraction Tomograms at three profile lines surveyed at Nanka-Oko Site (a) showing the orientation of the survey lines and the tomogram and (b) showing the danger of sharp and active landslide slip surfaces

The SRT tomogram could be seen to consist of layers of soil of rocks distinguished by different ranges of p-wave velocity. These range from 300 m/s to about 2500 m/s and is attributed to various soils and rocks of distinguished seismic properties. Base on the standard p-wave velocity range published by several researches and authors in the previous studies namely (Chii & Osazuwa, 2010; Egwuonwu G. N., Ibe S. O., & Osazuwa I. B., 2011; Kearey, Brooks, & Hill, 2002; Nwosu & Emujakporue, 2016), the tomogram encompasses p-wave velocity range for clay, shale, sandy clay, sandstone, dry sand and lose sand.The range of resistivity 1 Ωm to about 25,500Ωm is delineated from processed and modelled data. Meaningful interpretation shows that of this wide range, clayey sand $(50 - 1{,}500\ \Omega\text{m})$, sandy clay$(40 - 300\ \Omega\text{m})$ and saturated soils of various grades $(4 - 98\ \Omega\text{m})$ were observed to be most prominent at the gully's vicinity (FatobaJ O., Salami B. M., & Adesida A., 2013; IEEE 142, 2011; Obiabunmo et al., 2014; Telford, Geldart, Sherif, & Keys, 1990). The shallow surface resistivity distribution is heterogeneous hence, layering at the shallow depths is very minor. Due to the occurrences of intercalates, suspected fractures, the subsurface could be considered to be characterized by undulations which enhances saturation in rainy seasons, hence weakens the shallow surface columns. Both transverse and longitudinal profiles to the strike of the gully were predominantly characterized by very low resistivity values interpreted to be clayey heterogeneity permeable and expansive soils hence making the vicinity to be prone to the failure of both subsurface structures and superstructures in the area.

Structurally from the ERT survey, the shallow-surface contour colorations are predominantly heterogeneous, showing high variability at low contour intervals. Uniformity in the formation of layered subsurface of the soil is not observed common among the delineated profiles. However, relative uniform layers could be observed at some of them and none of these is noticeably a dipping layer in the ERT tomograms. Remarkably but in minority, structural features suspected to be fractured zone and syncline occur (Figure 2 and 3). From the SRT surveys, the refracting surfaces at shallow depths indicate some landslide slip portions at Uruagu-Nnewi site (Figures 2 and 3)and more obviously landslide slip surfaces shown at Nanka-Oko subsurface are predominantly sharp.

III. Conclusions

Results' observations showed that Nanka-Okogully instability is more severe than that of Uruagu-Nnewi site. However, based on the lithological and structural analyses of the SRT in agreement with (Chii & Osazuwa, 2010; Egwuonwu G. N. et al., 2011; IEEE 142, 2011; Kearey et al., 2002; Nwosu & Emujakporue, 2016; Telford et al., 1990)and,the ERT results and interpretations which agree with (FatobaJ O. et al., 2013; IEEE 142, 2011; Obiabunmo et al., 2014; Telford et al., 1990); the following conclusion are hereby drawn about the two gully sites:

i. Unconsolidated clay, sand, sandy clayey, clayey sand, loose sand, sand stones andweathered lateritic soil predominantly occupy the shallow depths of the gullies' vicinities
ii. The shallow-surface soil formation at the are weak, heterogeneous and frequently prone to saturation
iii. The subsurface structures are characterized by undulations, suspected synclines and landslide slip sub surfaces ranging from gentle to sharp ones at the gullies' vicinities.

The interpreted lithology, anomalous structures and defects, could integrally be causative to the instability and failure of gully sites. These delineated soils have high saturation capacity which invariably weakens the gully walls hence leading to landslide. The clayey, weak and heterogeneous soils at shallow depths of siteswould pose danger and when exacerbated by saturation due to frequent flooding seasonal in the area, the danger is more obvious. A proactive measure is thereby suggested in bid to curb the menace. Suggested areas for further studies may include deep and detailed seismic reflection tomography, textural characterization, clay swell test and other geotechnical measurements. Targeting gully control or mitigation of it is very eminent in the developing south-eastern Nigeria hence conscientious attention of indigenous geophysicists, civil engineers and government is invariably required to achieve its check as a matter of urgency.

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