Gully Erosion Study in Bida Town, North-Central Nigeria Using Integrated Geoscience Techniques

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Abstract

The present study used different geoscience techniques to determine soil characteristics and subsurface conditions that lead to the gully erosion in Bida area, north central Nigeria. Geological, hydrogeological, geotechnical and geophysical investigations were employed in this study. The geological mapping revealed Bida Sandstone as the principal lithology in the area and it agrees with the stratigraphic configuration of the study area. The well inventory showed a shallow water level (1.4 m to 6.9 m), with groundwater flowing towards the central portion of the area, which coincides with the areas been ravaged by gully erosion. A total of 24 soil samples were collected from four different gully sites in Bida and subjected to geotechnical analyses. The value of Moisture Content (MC) ranged from 2.95% to 18.08% with an average value of 10.66%. The Maximum Dry Density (MDD) varied from 1.89g/cm^3 to 2.04g/cm^3 with a mean value of 1.94g/cm^3 while the Optimum Moisture Content (OMC) is in the order of 10.30% to 11.40% with average value of 10.85%. The low values of MDD and OMC indicates loose formation with little or no binding materials and soils with these characteristics are prone to gully erosion. The results of the sieve analysis indicate that the area is dominated with fine to medium grained sand. The plasticity test showed that the soil samples from the study area are non-plastic except for sample locations L1C and L4C with very low plasticity (plastic limit between 4.40% and 29.60%, liquid limit from 10.78% to 14.40% and plasticity index of 10.00% to 18.82%). This implies that the soil in the study area is non-cohesive soils. The 2D resistivity carried out at gully erosion sites indicate intermediate to high resistivity values of 110 Ωm to 190 Ωm in the profile distance interval of 5m to 60m, this is characteristics of non-plastic soils like sandstone. Underlying the intermediate to high resistivities is the layer flanked by zones of significantly lower resistivities indicating zones of water saturation with resistivity of about 67 Ωm. The study established the dominance of gully erosion in Bida area can be attributed to the presence of non-plastic and friable sandstone formation, increased rainfall, shallow water table, intensity of groundwater flow, saturation of the subsoil, poor drainage system, sand mining along river course and deforestation. Remediation techniques such as construction of concrete terracing and planting of trees, cover crops and wind resistant grasses as well as proper drainage system for the entire Bida town is highly recommended.

Keywords: **Gully Erosion, Combined Geoscience Methods, Bida Town, North-Central Nigeria**

Introduction

Gully erosion is the removal of soil or soft rock material by water, forming distinct narrow channels, larger than rills, which usually carry water only during and immediately after rains. It is a highly visible form of soil erosion that affects soil productivity, restricts land use and can threaten roads, brigdes, buildings and human life (Okunlola *et al*., 2014). It is a serious form of soil degradation often involving an initial incision into the subsurface, by concentrated runoff along zones of weakness such as joints and faults (Onwuemesi and Egboka, 1991; Oke and Amadi, 2008). It is any erosional channel that is so deep that it cannot be crossed by a wheeled vehicle or eliminated by ploughing. It reduces agricultural productivity by destroying valuable land resources, increases sediment concentrations, deteriorates water quality and fills up reservoirs and its rehabilitation has been challenging. According to Egboka (2010), the greatest impact of erosion in Nigeria lies in the outright volumetric loss of soil and decreases in nutrient capacity, moisture retention capacity, organic matter content and the depth of soil.

It is regarded as an indicator of desertification (UNEP, 1994). The main causes of gully erosion are climate change and anthropogenic pressure (Torri and Poesen, 2014). Ecological hazards such as erosion have made people to abandon their ancestral homes. Roads and farmlands have been destroyed due to erosion while in most cases; it results to loss of life and properties (Obiefuna *et al*., 1999). While some floods results from accumulation of excessive surface runoff, overflowing of rivers or break in protective structures such as dams is also a major factor. (Egboka and Nwankwor, 1986; Akpata and Atanu, 1990; Oke *et al.*, 2009).

The study area, Bida is one of the most erosion ravaged area in North-central, Nigeria with a lot of critical and very active erosion sites. The present research employs geological hydrogeological, geotechnical and geophysical methods to unravel the causes of gully erosion in the area. This is with the view to ascertain the extent of erosion and its impacts to the environment, as well as providing remediation measures. With increase in population growth, coupled with anthropogenic activities such as construction along river channels, sand mining, deforestation and blockage of drainage systems, poor planning and disposal system, the situation is even made worse (Ezechi and Okagbue, 1989; Onwuemesi, 1990).

Climate and Vegetation

The climate of Niger State is like that of West Africa. The daily temperature varies from about 24°C at the middle of the wet season to about 37°C at the peak of dry season. The wet season which starts late, lasts for about six to seven months from May to Mid-October or sometimes Mid-November, with an average rainfall of about 300mm, while dry season is about five to six months with little or no rainfall (NiMet, 2019). Temperatures have generally been unusually higher in the last five years due to climate change. The dry season is equally marked by the influence of harmattan, a north-eastern wind (tropical continental mass) and it is often laden with fine dust from the Sahara Desert. The influence of this harmattan is most felt from the months of December to February. The predominant vegetation consists of broad-leaved trees, shrubs and grasses. Along the river channels, the vegetation becomes more wooden and acquires some forest affinities (Amadi, 2009).

Study Area Description

The study area Bida is located southwestern part of Minna, Capital of Niger State. Bida, the headquarters of Nupe kingdom is situated between latitudes 9°2′00′′ N - 9°6′00′′ N and Longitudes 5°58′00′′ E - 6°40′00′′ E (Figure 1). It is within the Bida Basin of Nigeria. The basin which is a boat-shaped trough trends in a Northwest to Southeast direction with both ends tapering like a keel of a boat (Adeleye, 1971). The land area is about 50krn^2 and majority of the people are farmers while some engage in brass, glass and blacksmith works. The area has a good road network and is drained by River Kaduna and its tributaries. The area has a low to moderate relief with a few scattered laterite-capped medium grained sandstone hills. It is accessible through Mokwa, Minna, Zungeru, Suleja and Doko roads (Figure 1).

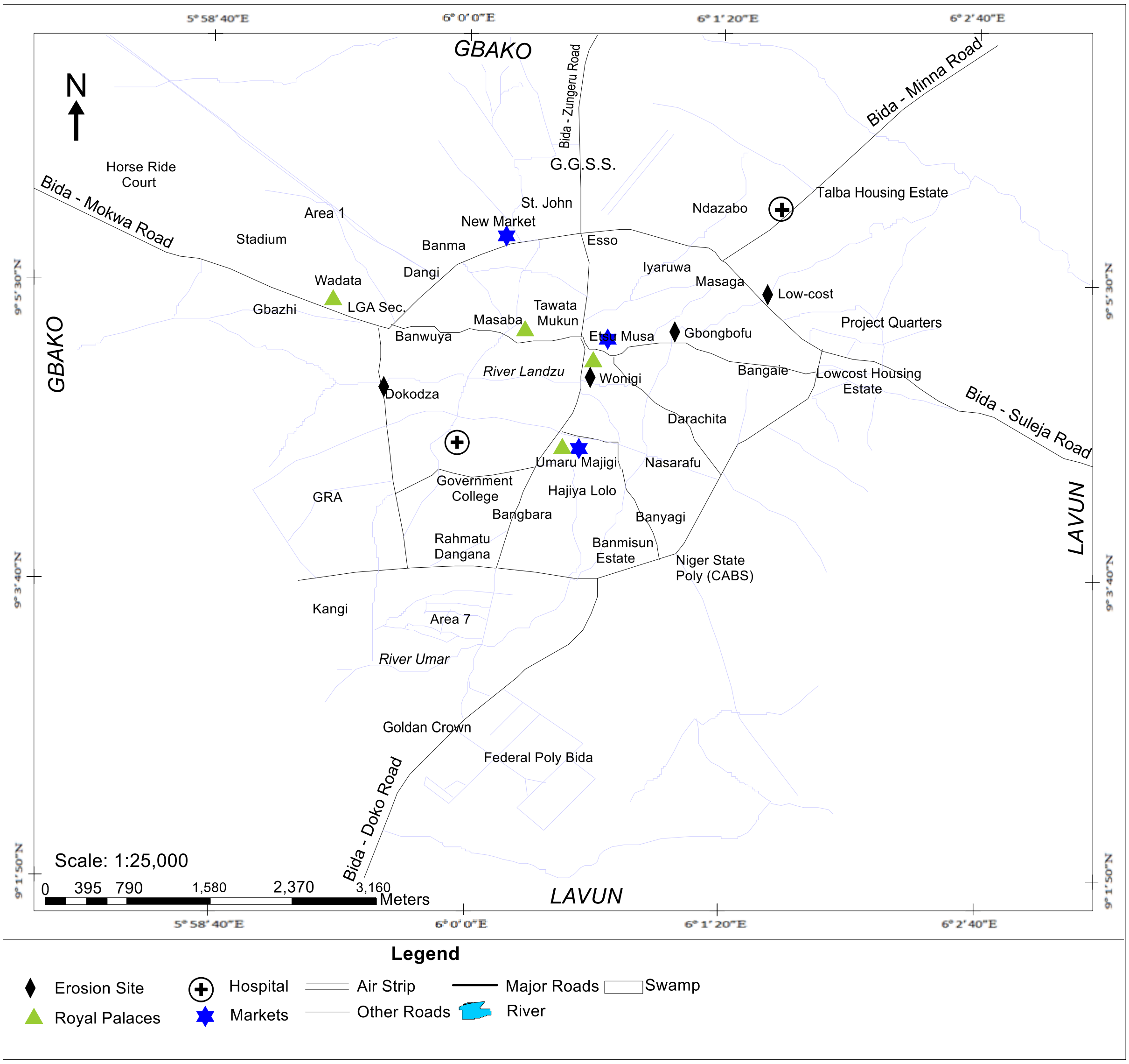

Figure 1: Map of Bida Town (Modified after Amadi, 2009)

Geology of Bida Basin

The Bida Basin is one of Nigeria's inland basins that constitute another set of a series of Cretaceous and later rift basins in Central and West Africa whose origin is related to the opening of the South Atlantic (Adeleye, 1976). The Bida Basin is a NW-SE trending intracratonic sedimentary basin extending from Kontagora in Niger State to Lokoja in Kogi State (Figure 2). The basin is regarded as the north-western extension of Anambra Basin in the south-eastern Nigeria, both of which were major depocenters during the second major sedimentary cycle of southern Nigeria in the Upper Cretaceous era (Obaje, 2009). The Bida basin is the area occupied by the Bida sandstone. The Bida Sandstone is divisible into two members: the Doko and Jima members. The Doko Member is the basal unit and consists mainly of very poorly sorted pebbly arkoses, sub-arkoses and quartzose sandstones. These are thought to have been deposited in a braided alluvial fan setting. The Jima Member is dominated by cross-stratified quartzose sandstones, siltstones and claystones.

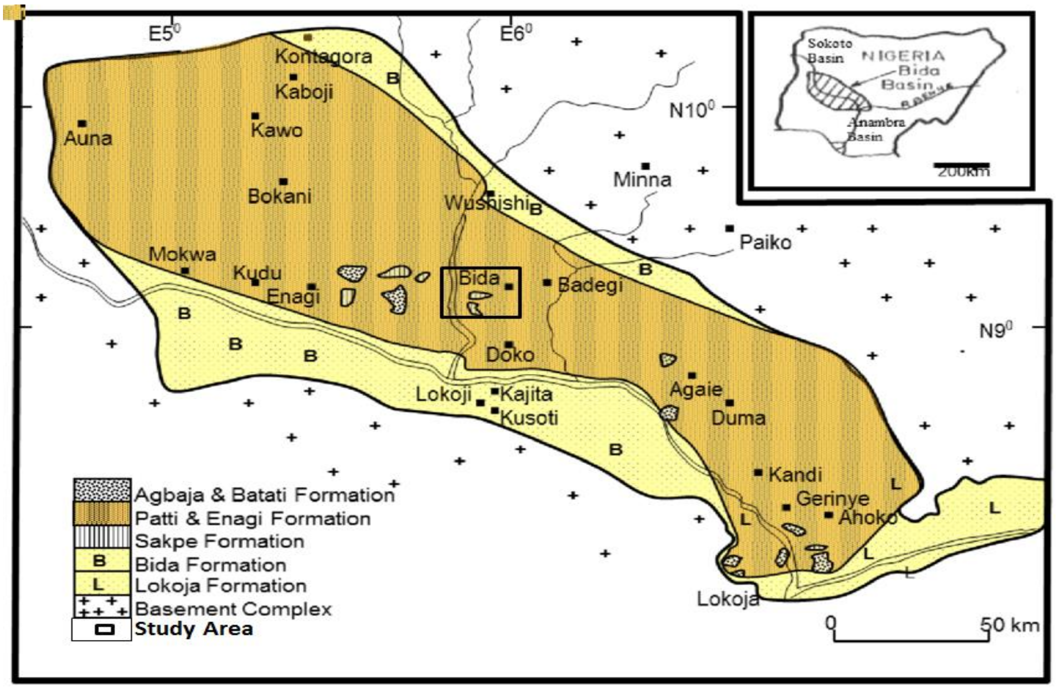

Figure 2: Geological map of Bida Basin showing the study area
(Modified from Adeleye, 1976; Obaje *et al*. 2011)

Materials and Methods

Fieldwork and Sample Collection

Geological mapping and sampling were carried out in the 4 different gully erosion sites located at Dokoza, Wonigi, Gbongbofu and Low-Cost areas of Bida Town. The Garmin Global Positioning System (GPS) was used to take coordinates at each gully sites visited. Exposed outcrops at the gully erosion sites were studied on hand specimen and soil properties such as the texture, colour and cohesiveness were noted. A total of 24 soil samples were collected for geotechnical analyses. Four undisturbed soil samples, one from each gully erosion site were collected and properly wrapped to preserve its natural moisture content. Twenty disturbed soil samples, five from each site were also collected at varying depths (0.0 m to 7.5 m) from the gully site walls and labelled accordingly, before putting them into appropriate sample bags. The geotechnical tests carried out includes: specific gravity, moisture content, compaction test, Atterberg limits (Liquid limit, Plastic Limit and Plastic Index) and sieve analysis. It is believed that these tests will aid in unravelling the causes of gully erosion in Bida area. The analyses of the soil samples were carried out at the laboratories of Department of Geology and Department of Civil Engineering, Federal University of Technology, Minna, Niger State. Hydrogeological investigation was executed through well inventory method by measuring the depth to water from hand dug well and motorized hand pumps in the area. This was achieved with the aid of the GPS and water level metre. Geophysical investigation was carried out using the 1D Vertical Electrical Sounding (VES), and the 2D Subsurface Electrical Imaging (SEI). The Wenner-Alpha array appropriate to image horizontally and vertical running layers of the subsurface was employed for this study. The 2D resistivity imaging was used in measuring and interpreting subsurface characteristics with respect to erosion imaging. The characteristics include depth and tomology of the subsurface lithology, stratigraphy and groundwater table. The 1D Vertical Electrical Sounding (VES) using the Schlumberger array was carried out at Gbongbofu area because of limited space while 2D Wenner Alpha array was carried out in Dokoza, Wonigi, Low-Cost areas (Plate1). The data for this research work was acquired by a multi-electrode resistivity data acquisition system with the activation of 4-point-electrodes. A multi-electrode system developed by ABEM instrument AB, was used for data acquisition in this study. The system consists of a standard earth resistivity meter (ABEM Terrameter SAS4000), four alternate electrode cables, each wheeled on a ream, four coated steel electrodes with various connectors and four metal hammers (Plate 1). The change in voltage is measured at the receiver electrodes.

Plate 1: Geophysical Investigation at Dokoza gully erosion site in Bida town

Results and Discussions

The geological mapping of the study area revealed the major rock type in the area as sandstone, belonging to the sandstone formation of the Bida Basin. Field observation revealed that the four erosion sites have been active after over the years. In Dokoza, texture of the sandstone varies from fine to medium grain with a reddish colour which implies they are ferrugenized sandstone, a characteristic of Bida Sandstone Formation because it is overlaid by oolitic ironstone (Amadi, 2009; Obaje, 2009). No prominent sedimentary structure was observed. Around the Gbongbofu, the topmost part is reddish in colour and the texture ranged from fine grained sand to medium grained sand. The next layer is light brown in colour with also fine to medium grained sandy soil which is unconsolidated and friable. At the bottom is light-brown sandstone which is medium grained sand. The width of the gully erosion ranged from 35 metres to 50 metres. At Low-Cost area, two major layers of sandstone that was observed. The topmost layer is greyish in colour and the texture is fine grained. The second layer is light-brown and it is medium grained in texture. The gully erosion site at Gbongbofu is already threatening the buildings in the vicinity and is currently used to dump refuse (Plate 2). The situation is the same at Dokoza gully erosion site as some nearby buildings has been abandoned by their owners due to ravaging gullies leading to the development of cracks on the walls of the building, which are widening day by day (Plate 3).

Plate 2: Gully erosion site at Gbongbofu area of Bida Town, Niger State

Plate 3: Gully erosion site at Dokoza area of Bida Town, Niger State

The depth to water in the study area ranged from 1.4 m to 6.9 m. The groundwater system in area flow towards the central portion of the study area (Figure 3). When water table intercepts the ground surface, a wetland, spring, pond or fadama is formed (Amadi *et al*., 2013). Bida Town has experienced increased rainfall in the last decade due to climate change and the propensity of the water to begins to erode the loose and friable sandy formation in the study area cannot be overemphasised. The shallow groundwater table, the intensity of the groundwater flow and the saturation of the soil media enhances the erodibility of the formations in the study area. Groundwater flows from areas of high hydraulic head to areas of low hydraulic head in accordance with Darcy's law of groundwater movement. The intensity of flow coupled with the saturation concept of the subsurface lithologies can result to the formation gully erosion in non-plastic and friable soils (Alao and Amadi, 2012).

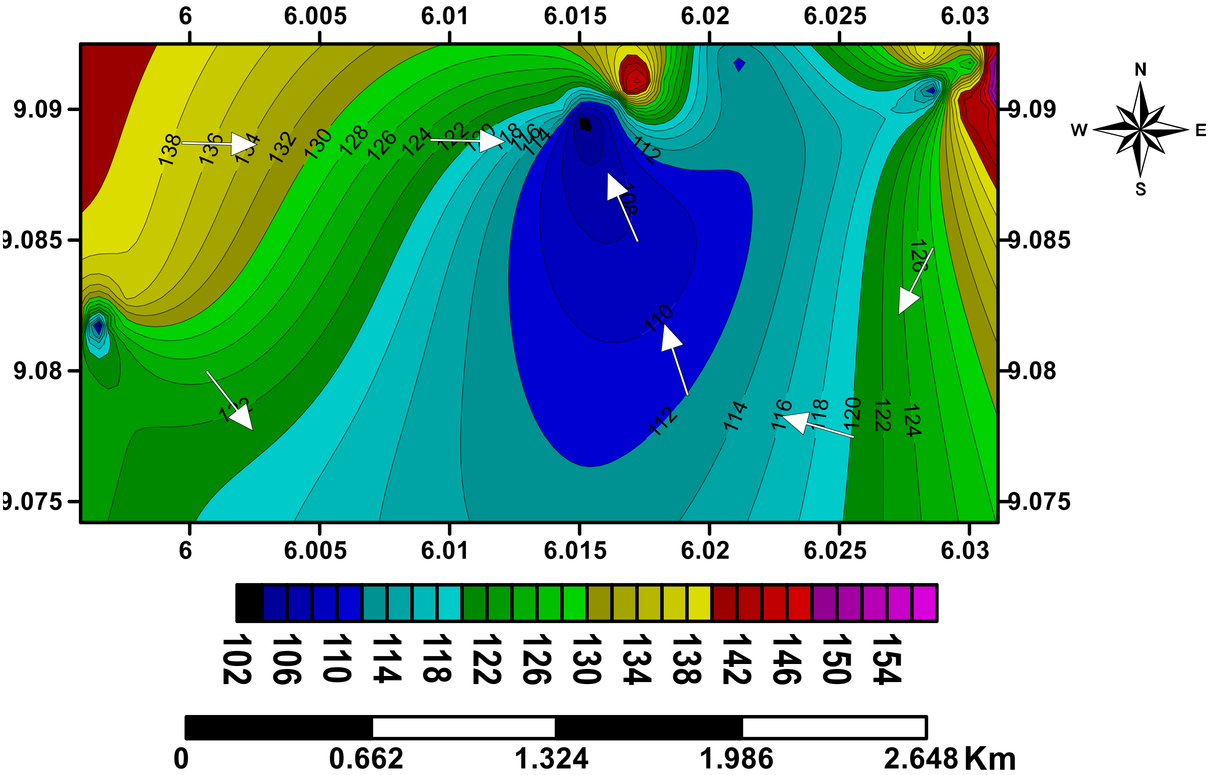

Figure 3: Groundwater flow direction

The soils in the area are adjudged non-plastic except Dokoza erosion site at 7.5m and Low-Cost at depth of 3.5m (Table 1). The plasticity values at these depths (plastic limit between 4.40% and 29.60%, liquid limit between 10.78% to 14.40% and plasticity index between 10.00% to 18.82%) suggests very low plasticity, which implies that 10% of the analysed soil samples have very low plasticity while 90% are non-plastic, loose, unconsolidated, friable and non-cohesive, characteristics of soils with high erodibility factor. A soil which shows plasticity index value lower than 10% and a liquid limit value lower than 20% is a cohesionless soil, with high permeability and seepage (Amadi *et al*., 2012; Nwankwoala *et al*., 2014; Enwedo *et al*, 2016). According to Clayton and Juckes (1978), they pointed out that Plasticity Index PI<35 should be considered low plasticity due to low content of clay materials.

The specific gravity results for soil samples from the erosion sites in the study area ranges from 1.75-2.49 which is an indication of that the soil contains large amount of organic matter or might be due to presence of porous materials, according to the American Society for Testing and Materials (ASTM) general guide for specific gravity. Organic rich soils have low mechanic strength leading to high rate of gully erosion (Nwankwoala and Amadi, 2013). Soils with specific gravity between 2.60 to 3.0, are classified as tropical iron rich lateritic soils with high sand proportion. This classification agrees with the geological, hydrogeological, geotechnical as well as geophysical results. The consistency in results obtained through the different geoscience-based techniques has established permeable, non-plastic and friable sandstone formation is responsible for the actives gully erosion site ravaging Bida Town.

From the compaction test, the Maximum Dry Density (MDD) ranged from 1.89g/cm^3 to 2.04g/cm^3, with an average of 1.94g/cm^3 while Optimum Dry Density (OMC) varied from 10.30% to 11.40%, with average of 10.85% from the compaction graphs. From the compaction test results, the Maximum Dry Density values are generally low which indicates that the soils are friable and unconsolidated (Chikwelu *et al*, 2014; Amadi *et al*, 2015; Unuevho *et al*., 2018). These findings conform to the geological and hydrogeological results revealing porous and permeable sandstone formation with depth to water very low.

Table 1: Results of Atterberg limit

Location	Sample ID	Depth (m)	Liquid Limit %	Plastic Limit %	Plasticity Index %
Dokoza	L1A	3.0	NP	NP	NP
	L1B	4.0	NP	NP	NP
	L1C	7.5	10.78	29.60	18.82
Wonigi	L2A	3.0	NP	NP	NP
	L2B	3.5	NP	NP	NP
	L2C	4.0	NP	NP	NP
Gbongbofu	L3A	1.0	NP	NP	NP
	L3B	1.5	NP	NP	NP
	L3C	5.5	NP	NP	NP
Low-Cost	L4A	2.0	NP	NP	NP
	L4B	2.5	NP	NP	NP
	L4C	3.5	14.40	4.40	10.00

The result of the sieve analysis (Figure 4) indicates that the study area is dominated by fine grained to medium grained sandy soil. The hydraulic properties of sandy formation (high porosity and permeability and non-plastic) differentiate it from other soils. The absence of clay within the sandstone formation is the reason for the lack of plasticity of the soils in most locations. This is also the reason why there are more active erosion sites in Bida than in Minna. Geology of the area is a major contributing factor to geohazards such as gully erosion.

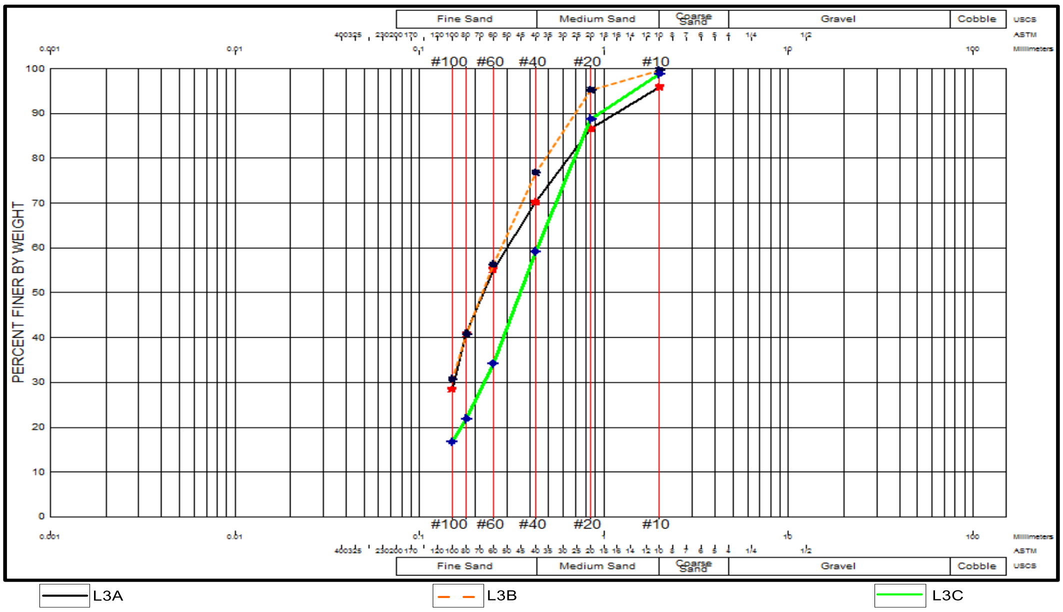

Figure 4: The Particle Size Distribution Curve for soil samples (L3A, L3B and L3C) at Gbongbofu area

The moisture content test conducted is shown in Table 2. Soils hold different amounts of water depending on their texture and structure. The moisture content ranged from 2.95 % to 18.08 % with an average of 10.66 %. Soils with high moisture are prone to erosion than soils with low moisture content values (Nwankwoala *et al*., 2015).

Table 2: Results of the moisture content

	L1E Dokoza	**L2E Wonigi**	**L3E Gbongbofu**	**L4E Low-Cost**
Wt. of Can (g)	24.26	23.26	24.23	23.29
Wt. of dry soil (g)	89.89	95.68	92.81	84.27
Wt. of wet soil + Can (g)	127.54	136.24	123.28	110.05
Wt. of dry soil + Can (g)	114.15	118.94	117.04	107.56
Water content (g)	13.39	17.30	6.24	2.49
Moisture Content %	14.90	18.08	6.72	2.95

Results of the 1D Vertical Electrical Sounding (Figure 5), reveals 3 geoelectric layers at Gbongbofu gully erosion site, which depicts the lithological units. The dominant curve type for the study area is Q type. The first geoelectric is the top soil, the second geoelectric layer is sandstone formation while the third geoelectric layer is sandy-clay/clayey-sand formation. These 1D geoelectric layers correspond to the 2D electrical sounding that was carried in the same study area. Top-soil is the first layer followed by second geoelectric layer, which are the gullible layer as a result of saturation and intensity of groundwater flow and heavy rainfall enhances the erodibility of the second layer. The first and second geoelectric layer are susceptible to erosion because of lack of binding/cementing materials. The third layer may be slightly resistant to erosion due to the presence of clayey materials which are completely absent in the first and second layer (Figure 5).

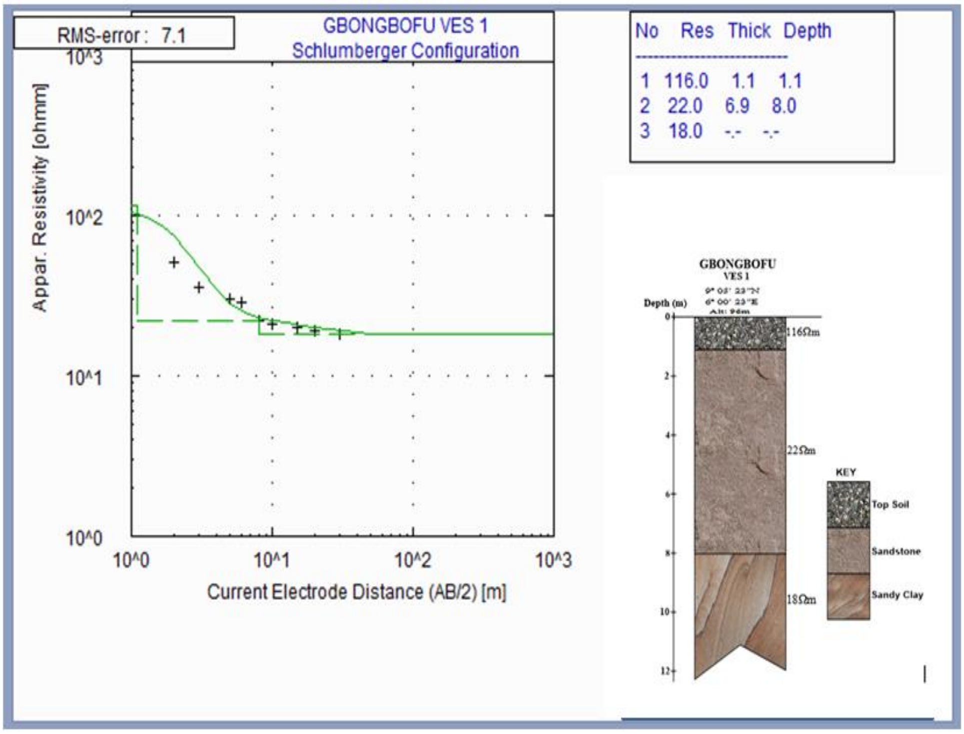

Figure 5: Vertical Electrical Sounding Curve at Gbongbofu Gully Erosion Site

The inverted 2D resistivity sections of Dokodza show intermediate to high resistivities at the surface in the first part of the section in the profile distance interval of 5m to 60m (Figure 6). This portion of the profile corresponds to fine to medium grained sandstone. These formation could provide rapid infiltration paths and hence increased vulnerability of the sediments to surface runoff. Underlying the high to intermediate resistivities is the layer flanked by zones of significantly lower resistivities indicating zones of sandstone saturated with water. At the profile distance between 65m to 70m there exist an intermediate resistivity of about 67 Ωm corresponding to silty-sand/clay-sand formation. The soils at the first and second layer are prone to erosion because of its lack of cohesiveness (non-plasticity and friable).

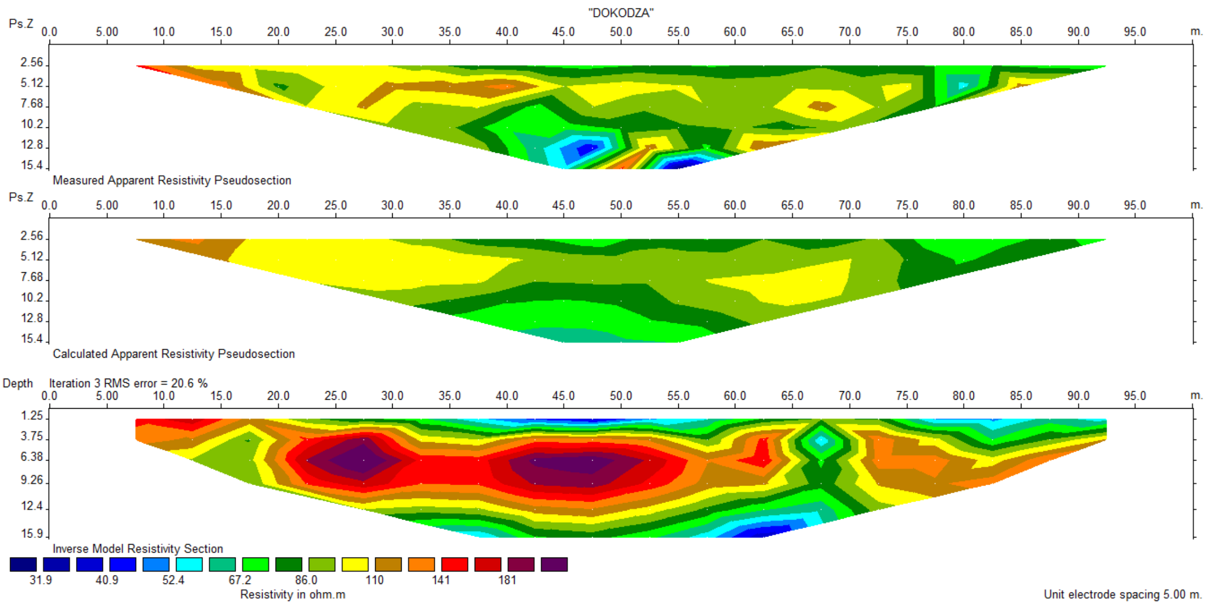

Figure 6: 2D Transverse at Dokoza Gully Erosion Site

The 2D pseudosection and inverted resistivity sections of the Low-Cost (Figure 7) show moderate resistivity value of 90 Ωm at the surface indicating loose sand. A region with low resistivities range of about 8 Ωm to 50 Ωm, corresponding to groundwater saturated zone, is visibly underlying the surface layer with depths reaching over 15 m. This is the region the highest vulnerability to gully erosion due to the the friable top soil formation is been grasually eaten up by the high intensity of groundwater flow from the saturated zone which is directly overlain by the top-soil. The problem is further compounded by high rainfall arising from climate change as well as lack of drainage system in the study area.

The 2D inverse model resistivity section of Wonigi profile (Figure 8) shows a well-defined highly resistive anomaly at the profile distance of 30m to 45m intruding two low resistivity portion at the 5m to 30m and 45m to 80m on the surface profile. The significantly lower resistivities of 6 Ωm to 20 Ωm extending to the depth range of 3.7m to above 15m are indicating zones of saturated formation. This findings further justify the results of the pseudosection, sieve analysis, moisture content, Atterberg limits, maximum dry density and optimum dry density. The synergy of these geoscience techniques (geological, hydrogeological, geotechnical and geophysical) in geohazard (erosion) studies has been efficiently and effectively demonstrated in this study.

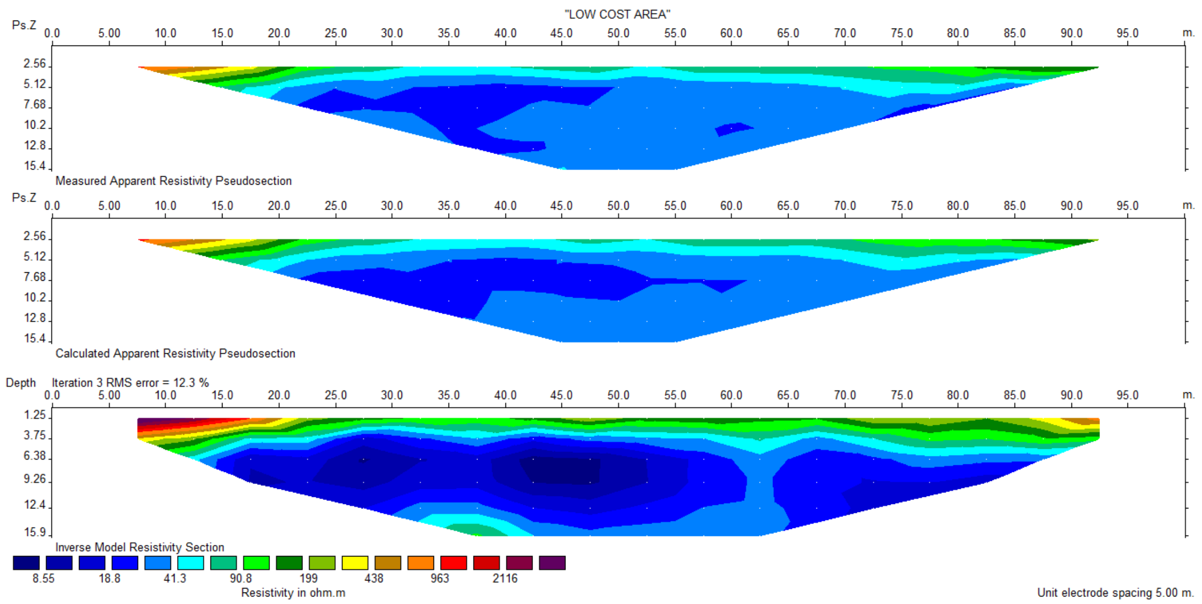

Figure 7: 2D Transverse at Low-Cost Gully Erosion Site in Bida Town

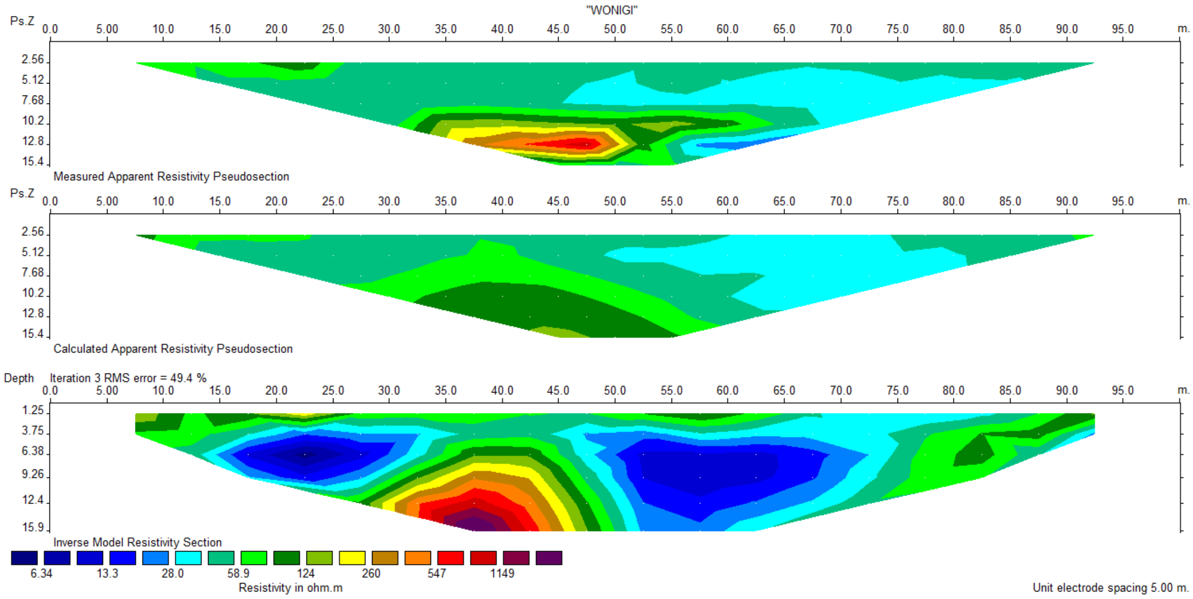

Figure 8: 2D Transverse at Wonigi Gully Erosion Site in Bida Town

Conclusion

The study has established that the dominance of friable, non-plastic sandstone formation with very tiny clay intercalations in the area as well as shallow water table, close to the surface saturated zone, increased rainfall due to climate change and poor drainage system couple with sand mining along water channels as the factors responsible for the gully erosion menace in the Bida area. Settlements along the river channels in the study area especially around Dokoza, Wonigi and Gbongbofu areas prevents water from flowing along its natural course, and it also contributes to the formation of gullies in the study area. Human activities such as building and indiscriminate farming and dumping of refuse without consideration to natural water flow course encourages gully erosion within the study area. The utility of integrated geoscience techniques in the study of gully erosion in Bida town has been elucidated in this study.

Recommendations

Construction of concrete terracing of gully affected areas is recommended to mitigate the impact. It will also restrict the widening of the existing and new gullies in the study area. Trees, plants and cover crops should be planted around the bare land in the study area. This is because low groundcover leads to increased amount of soil loss through run-off arising from heavy rainfall. Proper drainage system should be constructed and dumping of wastes at gullies sites should be discouraged by enlightening the people. Drainages should be constructed on both sides of roads in Gbongbofu and Low-Cost areas, as it will go a long way in preventing flooding and erosion in the area.

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