Investigation of karst features at Ogbunike area, south-eastern Nigeria using 3D resistivity and GIS methods

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ABSTRACT

3 Dimensional electrical resistivity and Geographic Information System (GIS) methods have been employed in the study of karst system at Ogbunike in south-eastern Nigeria. Hypsometric, slope and curvature map, both plan and profile were derived from the digital elevation or terrain model of the study area for surface analysis to identify landform features characteristic of karst terrains. Vertical Electrical Sounding (VES) and 3D Electrical Resistivity Tomography (ERT) was used to image, investigate and characterize the morphology of subsurface karst features at the study area. Morphometric analysis shows places of higher relief to be more dominant in the southern portion of the study area with the presence of characteristic mound features or isolated hills of karst terrain especially at the cave location. Slope maps showed values that range from 0-20 degrees with places predicted to be of karst terrain showing higher slope values. Curvature maps both plan and profile show that convex and concave landforms are more dominant in places that have undergone karstification. Ten Vertical Electrical Sounding (VES) curves were interpreted to identify lithological intervals that correspond to zones of equal average electrical resistivity. Zones of possible cavities were identified for VES locations 1, 2, 3, 4 and 6 as studied in current research that were associated to doline features and sediment-filled cavities. A possible interval of air-filled or open cavity was interpreted for VES 5 in current work. The volume slice of the 3-D ERT data shows common karst features such as solution doline, chimneys and caves. This study supports the knowledge that a karst system exists at the Ogbunike area. The results of this study also suggest the spatial extent of karstification to be extensive.

Key Words: Karst features; 3-D resistivity; GIS; Ogbunike; Morphometric analysis

INTRODUCTION

Karst has been defined as the product of subaerial exposure of soluble rocks, distinguishable on the basis of features formed from rock dissolution, precipitation, erosion, sedimentation and collapse [1]. These features and processes that form them produce a variety of characteristic surface and subsurface landforms. Caves and cave deposits such as cement and sediments are also one of the common features associated with karst terrains. Karst systems are physical systems made up of mainly two component processes; One process dissolves the rocks through chemical weathering from the action of acidified meteoritic waters and the second process removes the dissolved solutes from the system. Karst and karst features particularly caves maybe thought of as products of the enhancement of permeability pathways in rocks through the process of rock dissolution, precipitation, erosion, sedimentation and collapse by the action of groundwater and percolating surface or meteoritic waters. They are included as part of the diagenetic processes in places underlain by carbonate rocks.

Karst is common in almost all rocks of varying lithologies but it is more common in places underlain by limestone. Features common to karst include; caves, closed depressions or dolines, sinkholes, dry valleys, isolated hills and bare rock outcrops. Not all of these features are present in all karst terrains. The understanding of karst systems and karst terrains is of major importance to various fields especially hydrogeology and engineering geology. To the engineering geologist, karst provides unique styles of difficult ground conditions with open voids, potential collapse and subsiding soil cover and to the hydrogeologist, condition where surface water is difficult to retain and underground water is difficult to exploit [2].

The existence of the Ogbunike cave has been known for over 50 years. Accounts from locals say that the collection of caves has been in use for over a century by the indigenous people. Like most common features in the earth, the caves hold some spiritual significance to the locals even to present day. The Ogbunike cave is located within a valley, behind a dense collection of tropical rain forest trees.

For a long time, conventional techniques of investigation have been used together with geophysical techniques such as Ground Penetrating Radar (GPR), gravity, Electromagnetic (EM), and seismic surveys [3]. One advantage of most geophysical techniques is that they are non-invasive. Recently, the ERT and Multichannel Analysis of Surface Waves (MASW) techniques have been applied to the study of karstic terrains [4]. Kidanu in 2016 used the ERT and MASW techniques to image the subsurface morphology of an active sinkhole in Greene County, Missouri [5]. Yassin used the ERT technique to map karst features and estimate the depth to bedrock at a location in Peninsula Malaysia. Stepišnik in 2008 used the ERT technique to investigate collapsed doline floors located in Diva[illegible]a, Slovenia [6]. Also, Geographic Information System (GIS) methods have been successfully been applied in the study of karst systems using distinctive landform signature [7]. This study combines GIS methods of morphometric and geomorphological surface analysis using Digital Elevation or Terrain Models (DEM) to predict the extent of karstification within the study area away from the known location of the cave and the geophysical method of 3D ERT to study the underground features of the Ogbunike karst system at the location of the Ogbunike cave.

Geology of the study area

The Ogbunike area is part of the Niger Delta basin. Works by Reyment, Short and Stauble, Murat, Weber, Nwajide have established the understanding of the evolution and stratigraphy of the Niger Delta Basin [8-12]. The structural development of the Niger Delta basin is understood to be related to the rifting of Precambrian basement rocks in the event which formed the African and South American tectonic plates. Short and Stauble in 1967 suggest that the deposition of the rock units found in the modern delta took place in three depositional cycles [9]. The first cycle started with a marine incursion which ended with a minor folding event in the Santonian. The second cycle started with the formation and development of the proto-delta from the Cretaceous [13] and stopped with a marine transgression. The third cycle is defined by continuous growth of the delta to the Recent [12,14]. The outcropping stratigraphic units of the Niger Delta are made up of four rock units; Imo Formation, Ameki Group, Ogwashi and Benin Formations at its centre [15].

The Formation at the surface of the study area is the Nsugbe Formation. Part of the outcropping rock units of the Cenozoic Niger Delta Basin. It is found mainly in the northeastern part of the region, where they overlie sediments of the Anambra Basin [15]. It underlies an area estimated to be over 1000 km^2, part of which is covered by river alluvium between the Anambra River

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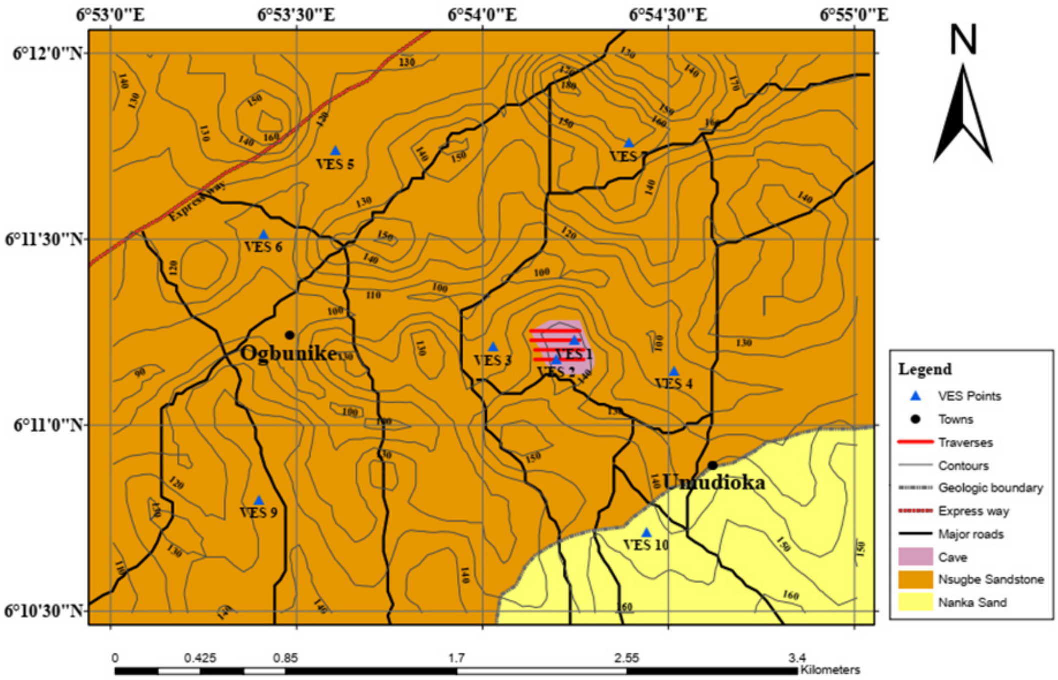

Figure 1) Map of study area showing the surface geologic formations, VES locations and Ogbunike cave.

and the Niger River as a ridge [12]. Its textural characteristic is unique, composed in part of cobble size clasts within beds of conglomerate. It exhibits a degree of induration unknown in the Nanka Formation and has a prominent, fluvial dissected topographic expression. It also contains the presence of ferruginized sandstone. Field work shows that the area is strewn with ferruginous sandstone boulders, especially around North of Onitsha forest reserve. A small portion of the study area is underlain by the Nanka Formation towards the southeast (Figure 1).

MATERIALS AND METHODS

Two basic sets of data were used as input for this study; remote sensing or GIS data (digital elevation or terrain model) gotten from Google earth and geophysical data (VES and 3D ERT) acquired from geophysical survey. Surface analysis was then done using the remote sensing data (digital elevation model or DEM) as the input. Using ArcGIS Pro (v2.5), the following terrain attributes were derived from the DEM: hypsometry, slope, plan (horizontal) and profile (vertical) curvatures. The drainage network was also derived. Karst landforms were identified from the DEM and derived terrain attributes by surface disturbance caused mainly by meso to macro scale features, such as dolines, poljes, mogotes and karren in a well-developed karst environment as illustrated by Summerfield and Stokes [16-17].

Sets of vertical electrical resistivity sounding curves were derived from vertical electrical resistivity sounding surveys done using traditional four electrodes and the Schlumberger array technique. Also, 2D sets or lines (profiles) of ERT data were acquired along the width profile of the caves and combined to get a 3D volume of electrical resistivity.

The various datasets were integrated and interpreted to identify characteristic karst features. The workflow involved three steps starting from geological analysis to surface analysis in order to study the surface geomorphology of the Ogbunike karst terrain. Geophysical analysis was done to identify and investigate the subsurface geomorphology of the Ogbunike cave.

RESULTS AND DISCUSSION

Morphometry

A hypsometric map of the study area classified in elevation intervals of 25 m is presented in Figure 2. Elevation is commonly below 200 m with an altimetric amplitude of around 180 m. Areas of more pronounced high altitudes are towards the southeastern portion of the study area. The area where the cave is located and known shows high altitude at its peak with respect to the background but not as pronounced as the southeastern portion of the study area. Similar landforms are seen towards the northern portion of the study area.

The slope map of the area is presented in (Figure 3). High slope values are associated with karst areas or places where karstification has played some role in modifying the geomorphology. Lower slope values are associated with valleys and non-karstic areas. Slope angles range between 0°C and 20°C.

Maps of horizontal and profile curvature are shown in (Figure 4 and Figure 5) respectively. Convex horizontal curvature indicates flow divergence and rounded landforms while concave ones represent accumulation zones at the footslopes. Convex vertical curvature represents acceleration flow towards the footslope, and concave, deceleration. The horizontal curvature map shows the predominance of flat surfaces. Convex forms occur more in the karst areas and may be related to the presence of mogotes or isolated hills a common feature of karst terrains. There appears to be some structural and lithological control for the occurrence of the convex forms. Flat surfaces describe places of higher relief, streams and valleys. Concave surfaces are commonly related to steep slopes and high amplitudes occurring mainly in the northern portion of the study area (Figure 6).

On the profile curvature map, flat surfaces are predominant again with a predominance of concave surfaces in the karst areas. There appears to be some structural and lithological control to the occurrence of these surfaces. Concave surfaces are related to valleys and degradation relief and they occur along the edges or slopes of the mogotes or isolated hills, a common feature in the Ogbunike karst area.

GEOPHYSICAL INTERPRETATION

Vertical electrical sounding

Ten VES curves were obtained, two within the vicinity of the cave location and eight outside the vicinity of the cave. Using inversion, 1-D pseudo-section organized as strip logs of the earth's electrical resistivity distribution at the VES station or location was derived. The mean average trend of the VES curves shows increasing electrical resistivity with increasing depth. Deviation from this trend was interpreted to be due to lithological changes, rock fluid content or due to the nature of the problem under investigation, the presence of cavities which may be air-filled or filled with sediment that differs from the host. This distinction is important as will be seen from the results of the interpretation. A cavity, whether air-filled (open), partially filled by rock debris from the collapse of the roof or filled by sediments which differ from the host is important to the hydrogeology and engineering geology of the study area. The result from the two VES curves acquired within the cave location show similar electrical resistivity distribution. Except for the VES station 10, most of the VES point location or stations fall in the portion of the study area underlain by the Nsugbe sandstone. At the base of both pseudo-profile or sections is a rock unit with medium to high electrical

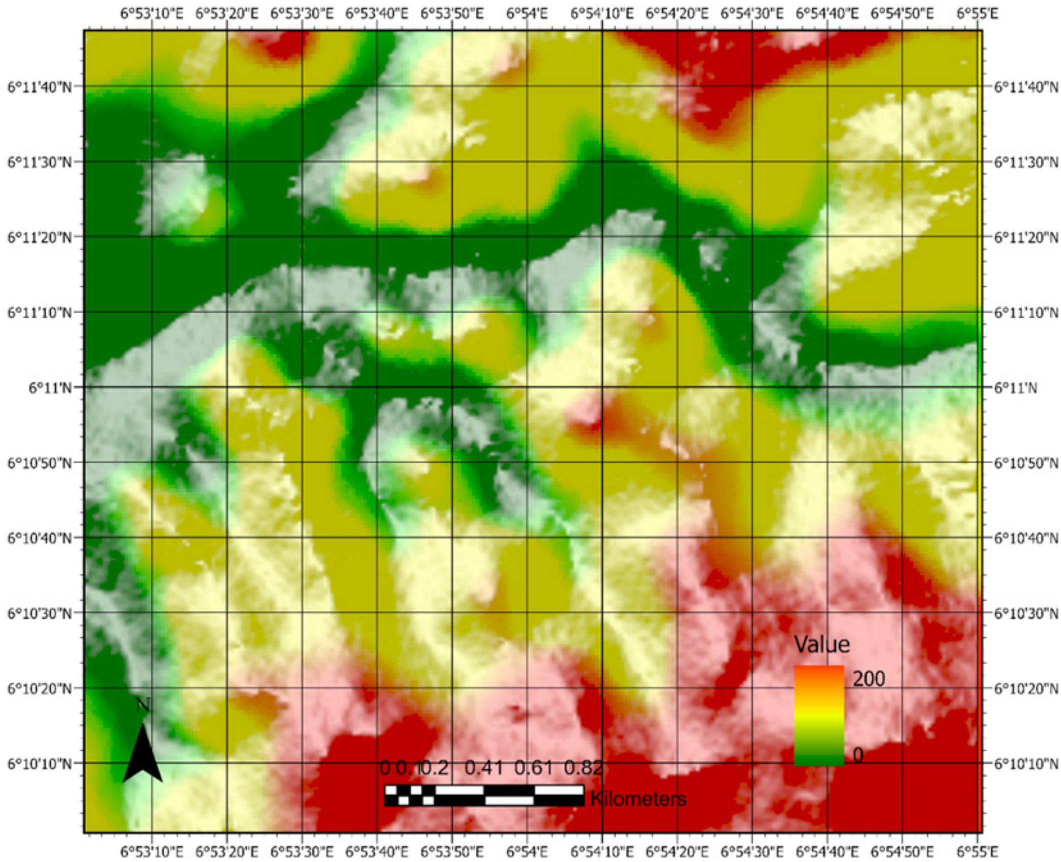

Figure 2) Hypsometric map of the study area.

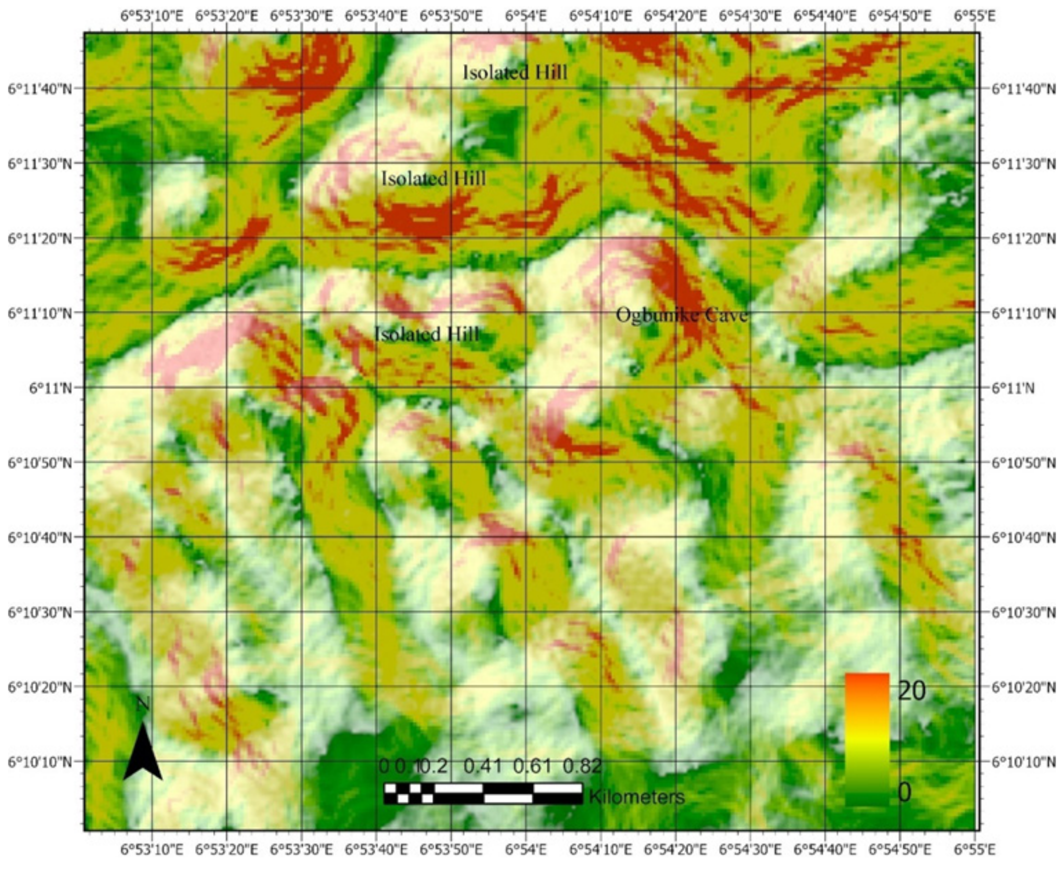

Figure 3) Slope map of the study area.

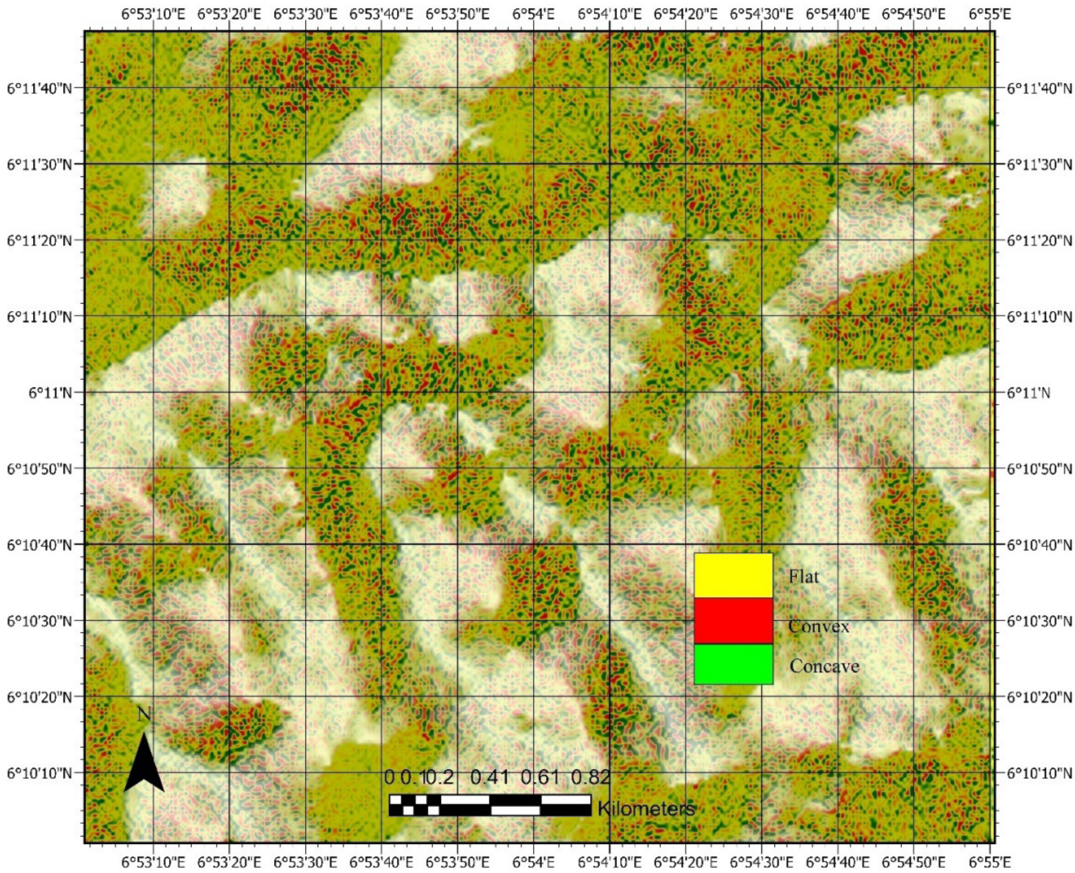

Figure 4) Plan curvature map of the study area.

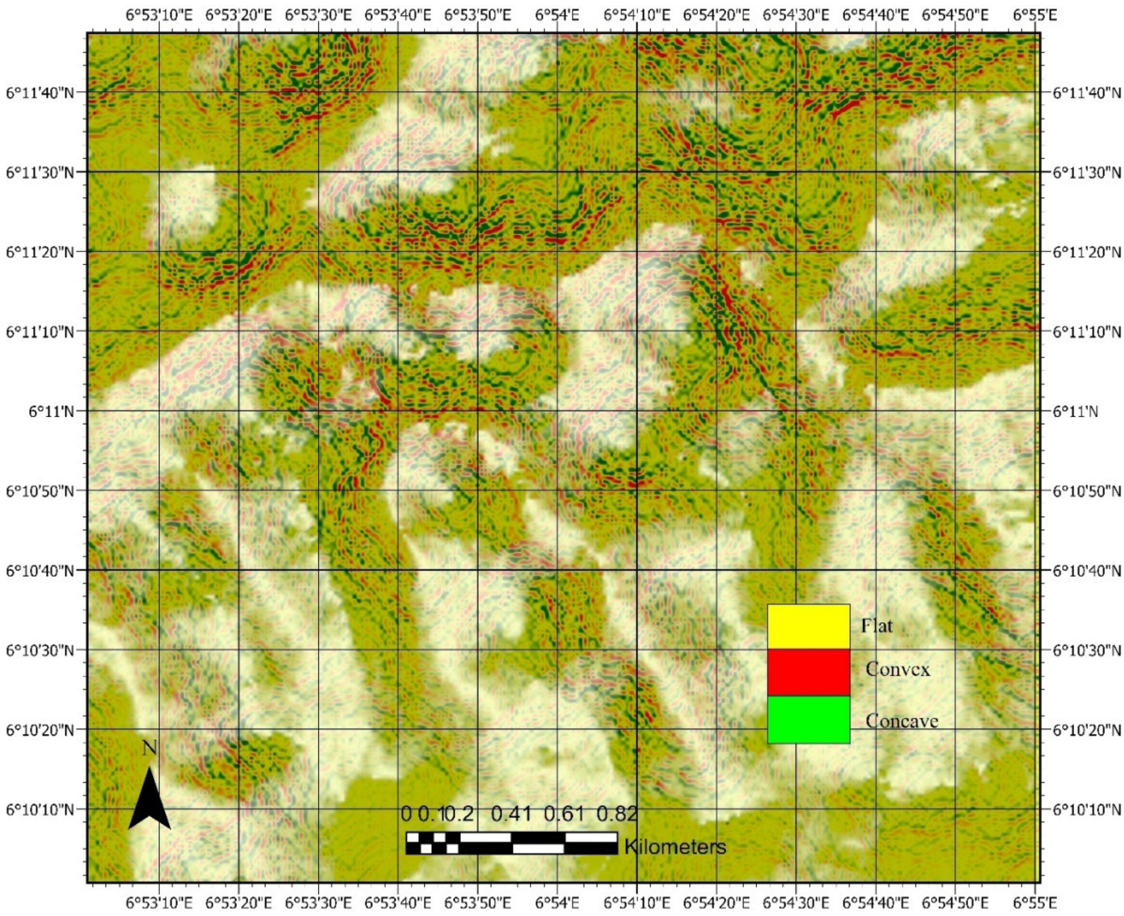

Figure 5) Profile curvature map of the study area.

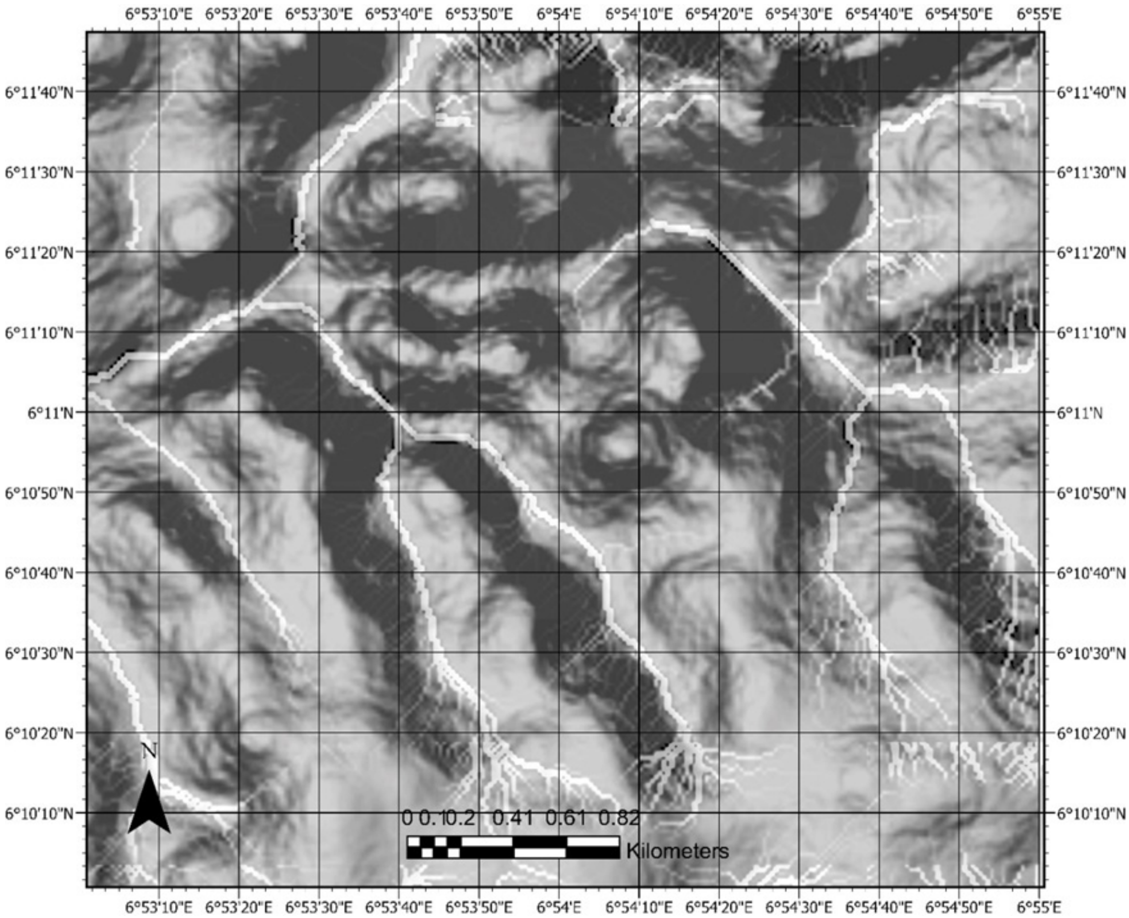

Figure 6) Combined hillshade and drainage map of the study area showing places of high and low relief.

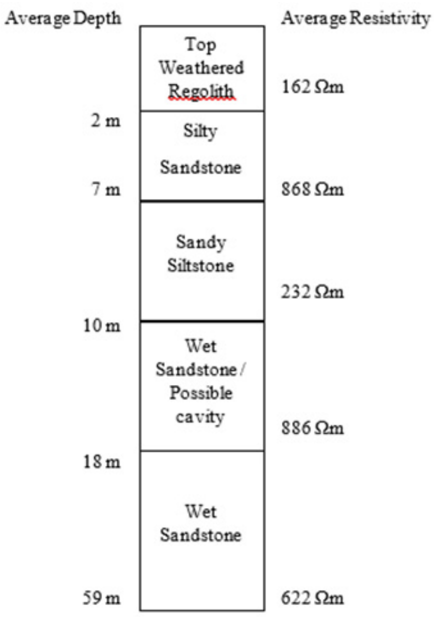

Figure 7) Pseudo-section of the electrical resistivity distribution at ves location 1.

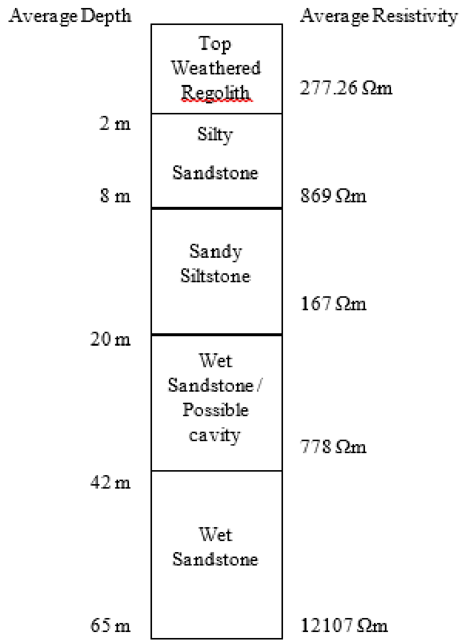

Figure 8) Pseudo-section of the electrical resistivity distribution at ves location 2.

resistivity, interpreted to be the base rock unit or regolith above which the caves formed. The rock unit is made up of sandstone. The sandstone rock unit is succeeded and overlain by a rock unit of medium electrical resistivity. This rock unit is made up of silty sandstone with possible occurrence of cavities. This interval is succeeded or overlain by a unit of lower resistivity made up of possibly sandy siltstone. This unit is then succeeded by a unit of medium electrical resistivity interpreted to be made up of silty sand, which is overlain by a thin veneer rock unit of low electrical resistivity of weathered overburden (Figure 7 and Figure 8).

3D model gotten from the inversion of 3D electrical resistivity data acquired over the Ogbunike cave shows a clear delineation or outline of the cave. The observed and calculated resistivity distribution shows that the subsurface at the location of the cave is extremely heterogeneous especially in the upper sections. Three isosurfaces were generated to help delineate better and enhance the outline or profile of the features observed in the 3D image or model (Figures 9-11). Most of the features occur as long horizontal shafts. Towards the north-western part of the volume slice, the cave is closer to the surface and deeper as one move towards the south-west. Other common

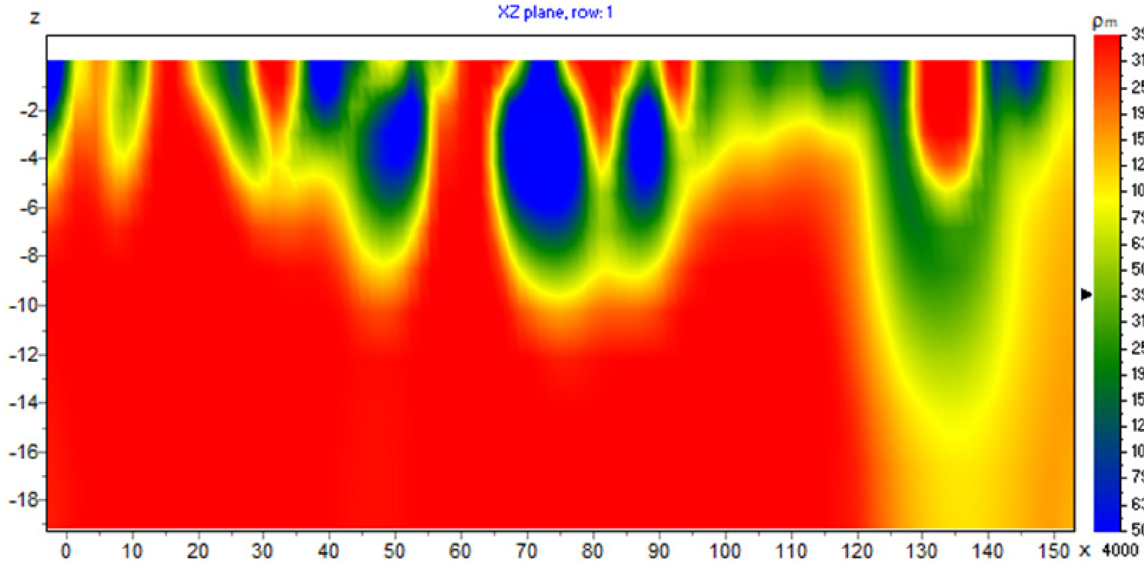

Figure 9) Volume Slice of the outmost profile or section along the x-direction after noise filtering.

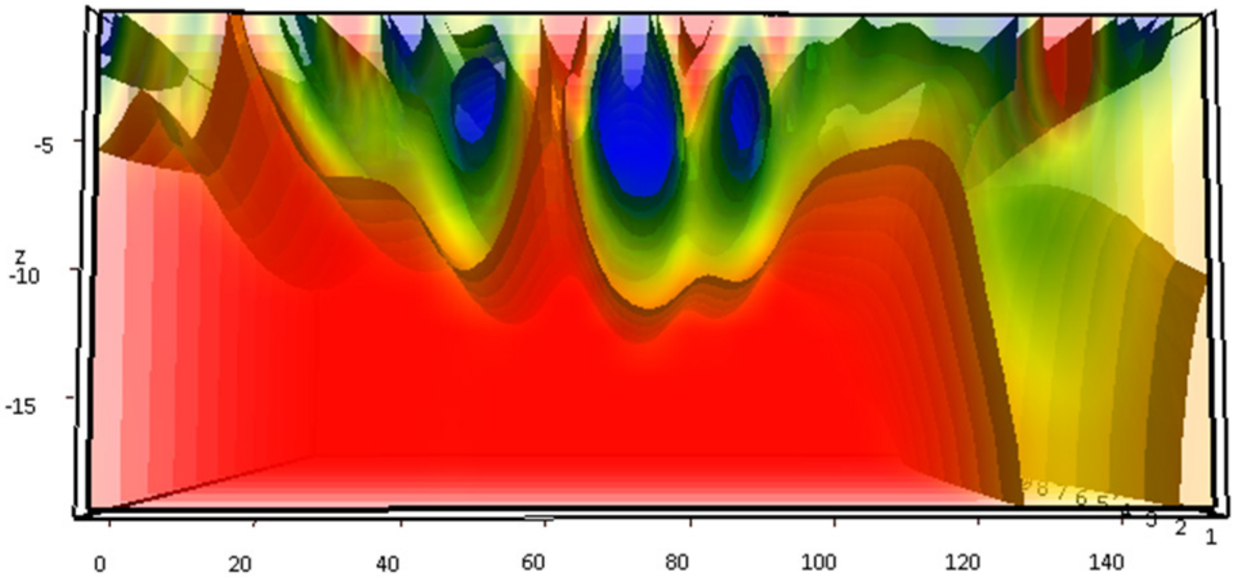

Figure 10) Volume slice of the outmost profile or section along the x-direction with the derived isosurfaces for model derived after noise filtering.

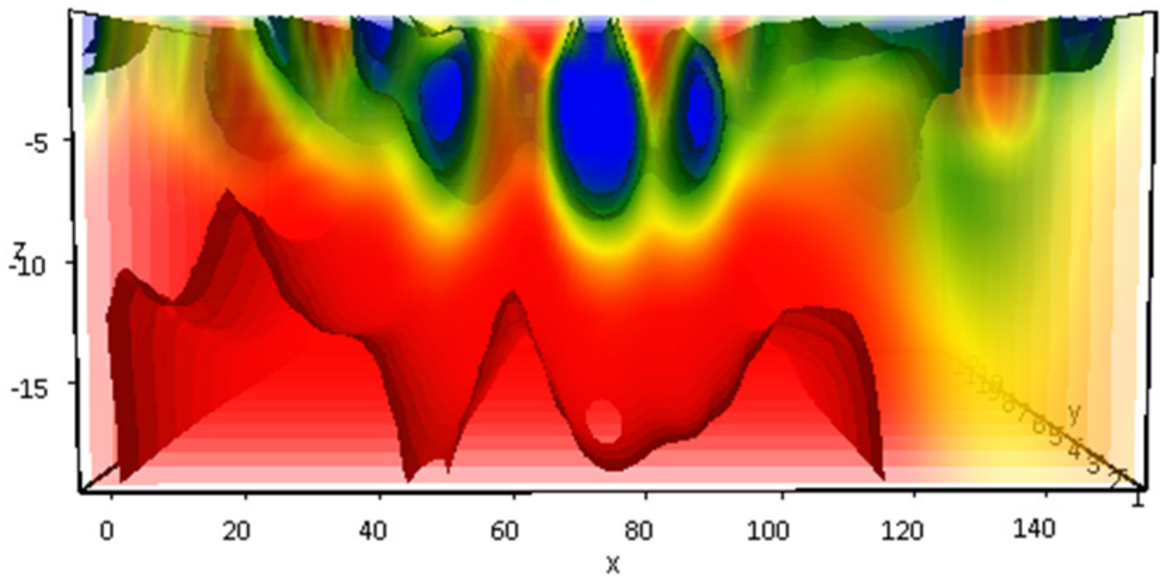

Figure 11) Volume slice of the outmost profile or section along the x-direction with derived isosurfaces enhanced for better visualization of the cave geometry.

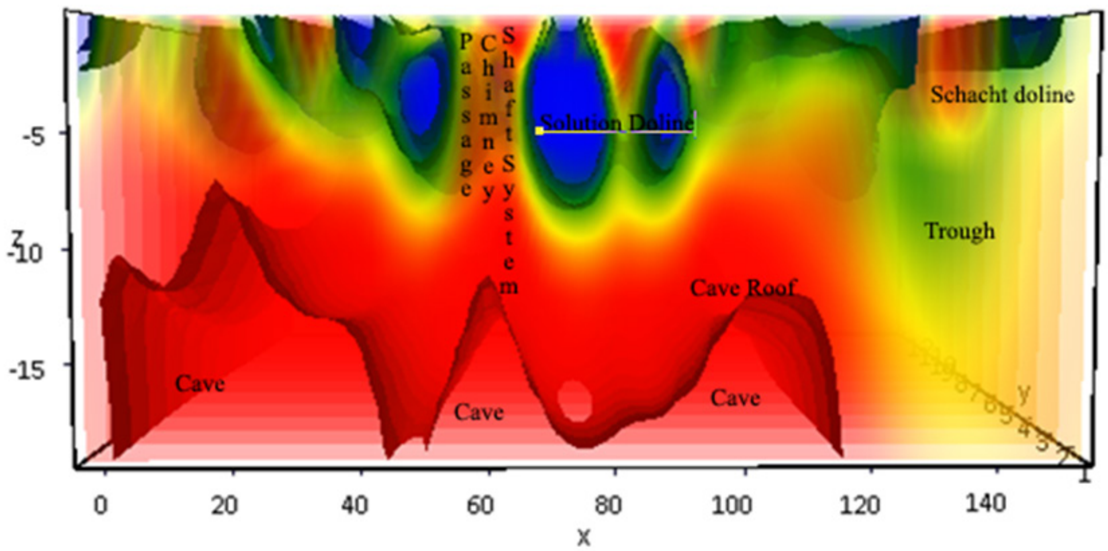

Figure 12) Volume slice of the outmost profile or section along the x-direction with derived isosurfaces and interpretation of the features seen on the image.

features associated with karst systems were also identified on the volume slice, features such as chimneys, dolines, the caves and cave roof (Figure 12).

CONCLUSION

The results of this study have successfully verified the existence of an advanced karst system in the Ogbunike area. Subsurface geophysical methods were employed to successfully map the extent of the karst system. Morphometric and geomorphological analysis show that the Ogbunike karst system is a mound type karst system made up of predominantly isolated hills of mogotes (sandstone). Typical subsurface features such as dolines and chimneys were observed on the subsurface image obtained from the 3D electrical resistivity survey. The distribution of both shallow and deep cavities within the study area possesses a high risk and source of engineering geological hazard.

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