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GEOPHYSICAL INVESTIGATION OF FOUNDATION FAILURE AT MEDINA ESTATE, LAGOS, SOUTHWESTERN NIGERIA

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ABSTRACT

Integrated geophysical investigation involving Ground Penetrating Radar (GPR) and Electrical Resistivity methods were carried out at Medina Estate, Lagos southwestern Nigeria to map the subsurface lithology in order to delineate its peat stratigraphy that has been causing foundation failure in the area.

Twenty-one traverses (varying from 35-880 m in length) of Ground Penetrating Radar (GPR) survey were conducted along the streets of Medina trending NE-SW and NW-SE directions using the Mala 250 MHZ bi-static shielded antenna. Thirty-six Vertical Electrical Soundings (VES) were carried out using Schlumberger electrode array at some selected points along the established traverses within the area. The GPR data were processed into radar section using Rad Explorer software. The VES data were interpreted quantitatively using the partial curve matching method and 1-D forward modeling with Win Resist Software. Available litho-logs from boreholes drilled within the area were compared with the geophysical results.

Results of the GPR survey delineated three geologic layers which include the topsoil with high amplitude, parallel to sub parallel, horizontal reflections, with thickness varying from 1 to 2 m across the entire profiles and composed of lateritic clay; peat layer with low amplitude, parallel sinuous/wavy reflections with depth of occurrence ranging from 2.0 to 8 m and clay with low amplitude, planar, horizontal, sub-parallel reflections underlying the peat layer. Vertical Electrical Sounding results revealed the presence of three geological layers which are the topsoil, peat and clay and sandy clay with layer resistivity values ranging from 20- 225 Ωm, 5 – 90 Ωm and 36 to 366 Ωm and thickness values ranging from 0.5 – 2 m, 4.0-29.0 m and infinity respectively. Borehole information confirms the occurrence of shallow peat with depth ranging from 1.5 to 9 m and clay layer with depth ranging from 9 to 21 m beneath the area. The GPR survey results correlates with the well logs acquired in the study area. Based on the correlation of the geophysical results with the well logs, the GPR gives better information about the peat layer compared to the Electrical Resistivity Method.

The information obtained from this study shows that the soils at shallow depth are organic soils which are difficult foundation materials because they exhibit very high compressibility, as such making shallow foundation impossible except some form of soil improvement is carried out. The alternative approach is the adoption of deep foundations in form of piles.

KEYWORDS: Foundation Failure, Geophysical Investigation, Ground Penetrating Radar, Vertical Electrical Sounding, Peat.

INTRODUCTION

The continuous incidence of foundation failure of structure is becoming alarming in Nigeria. A number of factors such as subsurface geological material, inadequate information about the soil, poor foundation design and poor building materials have been attributed to this failure (Fatoba et al., 2013). This has led to the loss of life and lots of goods and properties worth millions of naira aside from the cost of rehabilitation or complete redesign and reconstruction at much higher cost.

Recently, the collapse of civil engineering structures has increased greatly for reasons associated with subsurface geological sequence (Omoyoloye et al., 2008). As a result, the need for subsurface geophysical investigation has become very crucial so as to prevent loss of lives and valuable properties that consistently occur with such a failure. Foundation assessment of a new site is required so as to provide subsurface and aerial information that normally assist civil engineers, builders and town planners in the design and citing of

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foundations of civil engineering structures (Omoyoloye et al., 2008).

For the past two decades, geophysics has proved quite relevant in road and site investigations and several of these engineering and geological problems have been successfully solved by geophysical methods (Nelson and Haigh, 1990; Adiat et al., 2009). The integrity of near surface geophysical investigation methods to complement geotechnical studies in some foundation engineering problems cannot be overemphasized (Falowo et al., 2016).

Therefore, this research aims at delineating the subsurface peat stratigraphy that has been causing foundation failure in Medina Estate, Lagos.

SITE DESCRIPTION AND GEOLOGICAL SETTING

Medina Estate lies within Latitudes 6°33' 6.02" to 6°33' 33.4" N and Longitudes 3°22' 49.3" to 3° 23' 5.51" E with area extent of about 47,064 sqm (Fig.1). It is one of the major estates that bordered Somolutown. The surrounding topography is gently undulating; with elevation ranging from 6 to 7 m. Flooding is persistent in Medina Estate (Lagos Metropolis). The causes, effects, and magnitude clearly inform urban dwellers and land owners on the drainage setting and types (Fig. 2).The drainage system of the state is characterized by a maze of lagoons and waterways which constitute about 22% of 787 sq.km of the state landmass. The major water bodies are the Lagos and Lekki Lagoons, Yewa and Ogun Rivers. Others are Ologe Lagoon, Kuramo waters, and Badagry (Oyedele, 2010).

The study area lies within the Dahomey Basin. The basin is generally long with a total length of about 800 km, narrow and parallel to the coastline. It extends from southeastern Ghana to the western flank of the Niger Delta. The Dahomey Basin is a peri-cratonic basin that developed during the initiation of rifting associated with the opening of the Gulf of Guinea in early Cretaceous (Burke et al., 1971; Klemme, 1975; Whiteman, 1982; Kingston et al., 1983). The general sequence for the rock unit from the top are the Coastal plain sands (Recent in age), Ilaro Formation (Eocene in age), Oshosun Formation (Eocene in age), Akinbo Formation, Ewekoro Formation (Paleocene), and Abeokuta Group (which is Cretaceous in age) lying on the southwestern Basement Complex of Nigeria (Fig. 3a).

The quaternary geology of the study area comprises the Benin Formation (Miocene to Recent), lithoral-alluvium and lagoon/coastal plain sand (Fig. 3b). The alluvial deposits consists mainly of sands with clay intercalations; lithoral and lagoon sediments formed between two barrier beaches and coastal plain sands. The coastal plain sands are non-fossiliferous except for plant remains which were used to date it. The alluvium represents the modern sediments deposited along the main river valleys that empty their contents into the lagoons (Offodile, 2002).

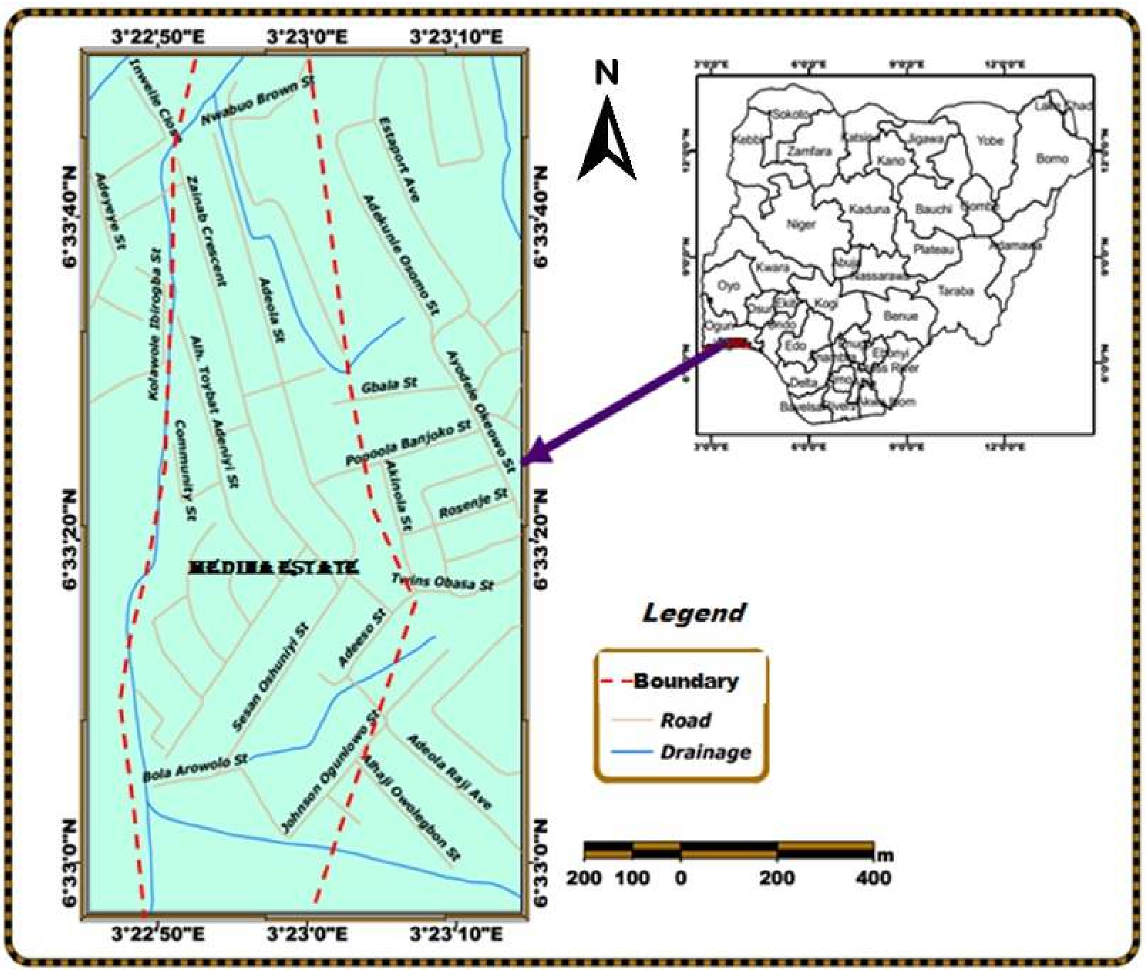

Figure1: Map showing the study area.

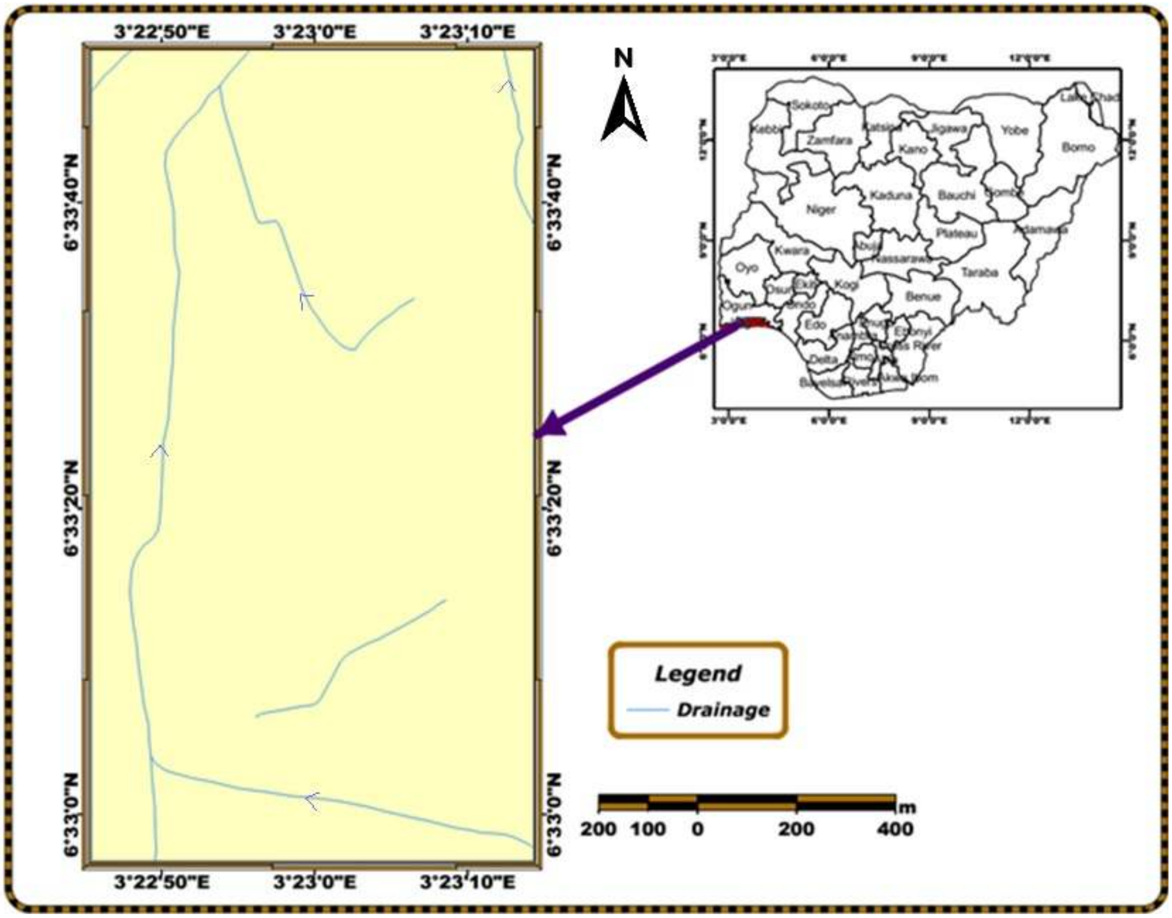

Figure 2: Drainage map of the study area.

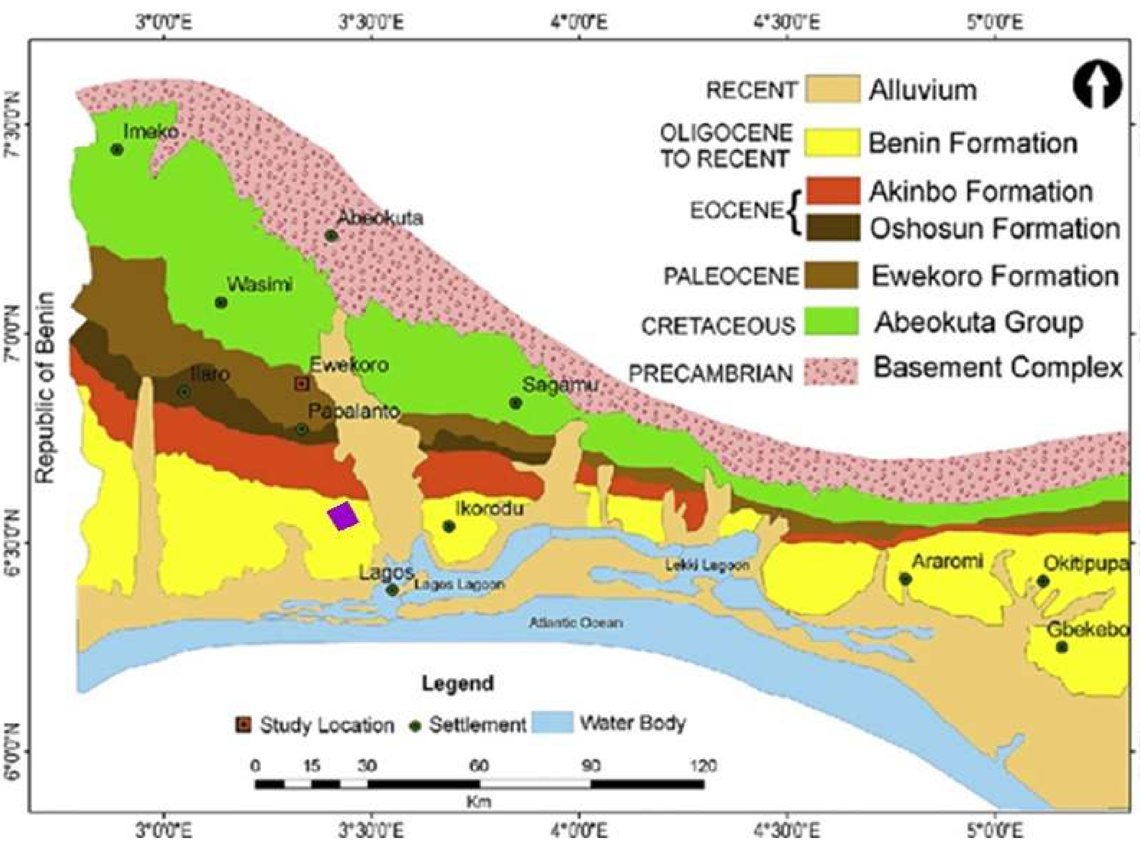

Figure 3a: General geological map of eastern Dahomey basin (After Billman, 1992)

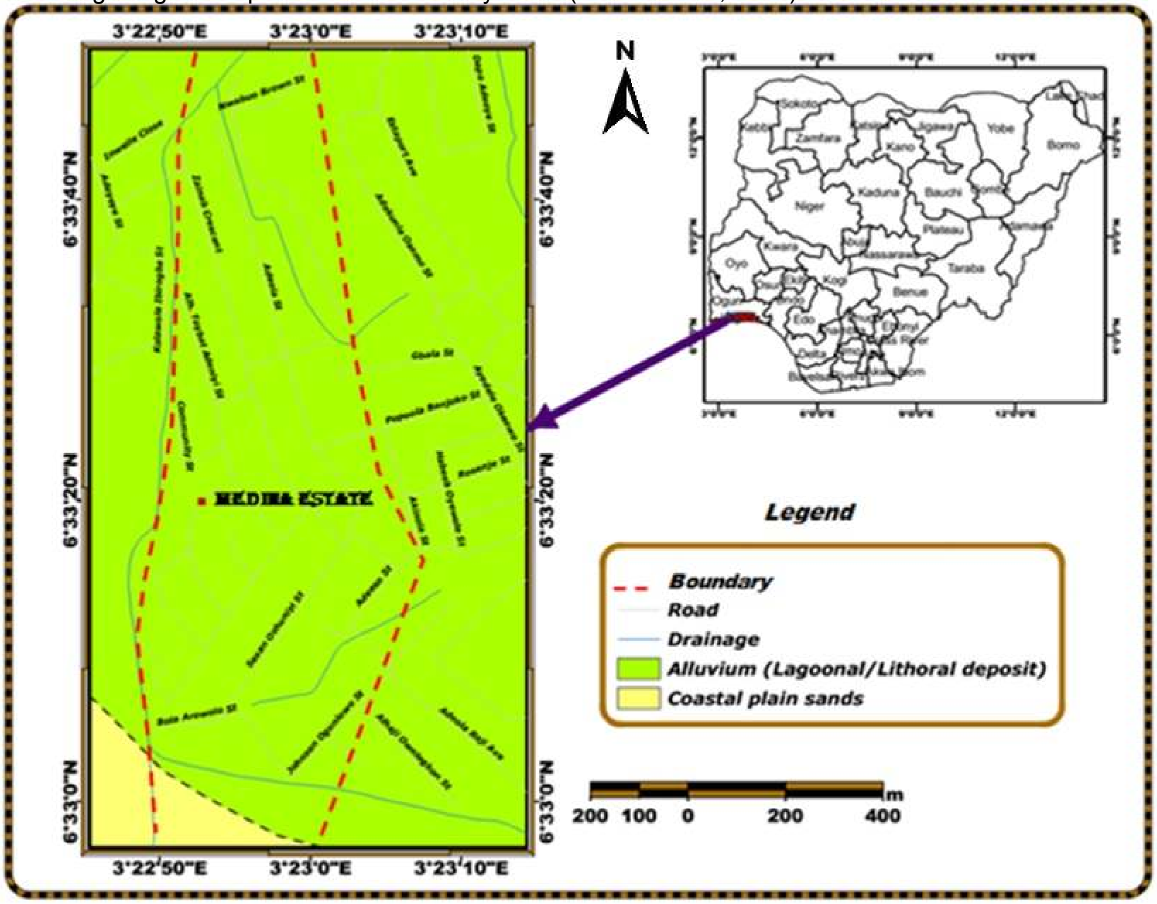

Figure3b: Geologic map of the study area

MATERIALS AND METHODS

The GPR data was acquired using the Mala RAMAC/GPR 250MHz bi-static shielded antenna geophysical survey equipment. Common offset mode where both the transmitter and receiver antennas move together in the direction of survey with a fixed offset or spacing between the units was adopted in acquiring the data set. The antenna is housed in a box attached to the wheel. The box was connected to the monitor unit which records and stores data as the antenna is being pulled manually on land at a walking pace during data collection. The system had an integrated odometer which measures distance along lines of traverse during measurements. The GPR data were acquired along twenty-one parallel traverses varying from 35 to 880 m in length trending NE-SW and NW-SE directions (Fig. 4).

The GPR unit was set to record at a 210 ns time window, with data stacking at 4 measurements and velocity at 0.04ns.The Mala system and antenna were pulled manually on land at a walking pace during data collection. The GPR data were processed using the Rad-Explorer software. The basic processing applied to the acquired GPR data include: data editing (which involves data merging and reorganization), DC removal (removes constant component of the signal in case there is one), Time zero adjustment (adjusts the zero-point of the vertical time scale to the time-zero), Band pass filtering (increases the signal/noise ratio) and amplitude correction (equalizes the amplitudes along the traces).

Vertical Electrical Sounding (VES) was acquired using Schlumberger electrode array. A pair of potential and current electrode was arranged in such a way that the potential electrodes were positioned in between the current electrodes and the positioning of the electrodes was set out using the measuring tape. The Campus-omega resistivity meter was used for the data collection which measures the apparent resistivity of the subsurface. A pair of potential electrode was connected to the potential unit and current electrode to the current unit of the resistivity meter using the insulated copper wire cables.A total of thirty-six depth-sounding stations that run from north-south with 100m intervals were occupied along the established GPR traverses.

The current electrode half spacing (AB/2) ranges from 1.0 m to 75 m in successive steps. The co-ordinates of each VES station were recorded with their respective elevation above seal level using a GPS device.The VES data were plotted on log-log graph with the apparent resistivity (ρ_a) values on the ordinate and the electrode separation (AB/2) along the abscissa. The curves were interpreted qualitatively through visual inspection and quantitatively through partial curve matching. The results were further iterated using WINRESIST Software.

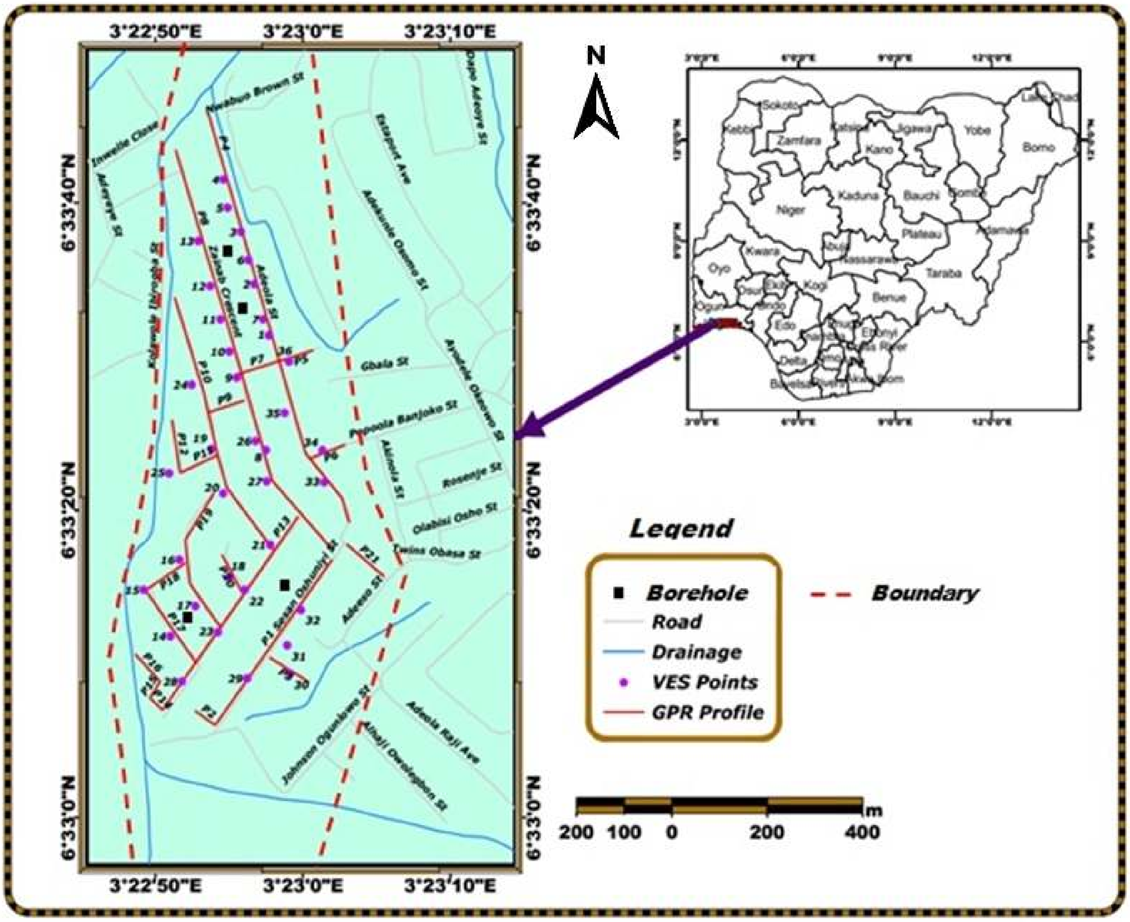

Figure 4: Field Layout of the study area showing the GPR profiles and VES points

RESULTS AND DISCUSSION

The results of the Ground Penetrating Radar are presented as radar sections while the electrical resistivity method results are presented as resistivity sounding curves and geo-electric sections (layer resistivity and thickness).

GPR RESULTS

The GPR results are presented as radar section in grey scale images that represents variations in facies signal amplitude. The facies were interpreted based on the reflection amplitude, frequency, continuity and configuration (Mitchum et al., 1977).Three radar facies were identified and correlated to their lithological equivalence in geo-electric section and borehole information obtained within the area. The depth of investigation of the radar signals range from 0-10m in the study area. The topsoil was characterized by high amplitude, parallel to sub parallel, horizontal reflections with thickness varying from 1 to 2m across the entire profiles and composed of lateritic clay. This was underlain by low amplitude, parallel wavy reflections and it was interpreted as peat with depth of occurrence ranging from 2 to 8 m. Low amplitude, planar, horizontal, poor reflections underlay the peat layer which was interpreted as clay/sandy clay (Figs. 5a, 6a, and 7a). The topsoil-peat boundary was marked by a strong reflection as a result of differences in electrical conductivity of the layers. However, the peat and clay interface revealed a moderate or faint reflection meaning that there is a gradual transition between the peat and clay. According to Comas et al. (2015), GPR is capable of capturing peat thickness variability at centimeter-scale vertical resolution, although peat thickness determination is difficult in areas associated with thick clay-rich transitional horizons at the peat–mineral soil interface.

To ascertain the GPR results (signatures) to actual subsurface conditions, the existing borehole litho-logs (BH1, BH2, BH3 and BH4) obtained within the study area were utilized (Figs. 5b, 6b and 7b). Clear radar signals were observed at the upper part of the profiles up to 2 m depth and start to show the characteristics of blur image with average thickness of 5 m. Greater than this depth, the radar signals start to attenuate resulting to poor reflections and this can be attributed to the presence of clay. The attenuation constant of clay is very high with respect to fresh water and other geological formations except seawater (Singh, 2005). Therefore EM waves passing through clay are highly attenuated to give poor reflections. The GPR results show a sharp boundary between the peat and the underlying clay along the entire profiles but could not give the thickness of the clay layer as the frequency terminates within the clay. Peat is highly conductive (i.e. has a low resistivity) due to mobile electrical charges from decaying vegetative matter and its abundant moisture content (Smith, 2002). Water molecules are highly polarized due to their dipolar nature. Within GPR frequency, dielectric permittivity of water is about 81 while most soils and materials within the same frequency range have dielectric permittivity between 4 and 7 (Daniels, 2004). The dielectric permittivity of air is 1. Thus the presence of water highly affects the magnitude of this property.

The apparent (measured) component of dielectric permittivity of a material is directly related to the radar signal velocity through the material. As a result of this, lower radar signal velocity implies higher magnitude of dielectric permittivity (Idi and Kamarudin, 2011).However, the presence of free-phase biogenic gas, a product of anaerobic decomposition of organic materials that are mostly trapped within the peat deposit, having same dielectric properties as air, reduces the overall magnitude of the dielectric permittivity and therefore enhances the radar signal velocity (Benedetto, 2010). The signature of the peat is consistent from one street to another as shown in the fence diagram (Fig. 8).

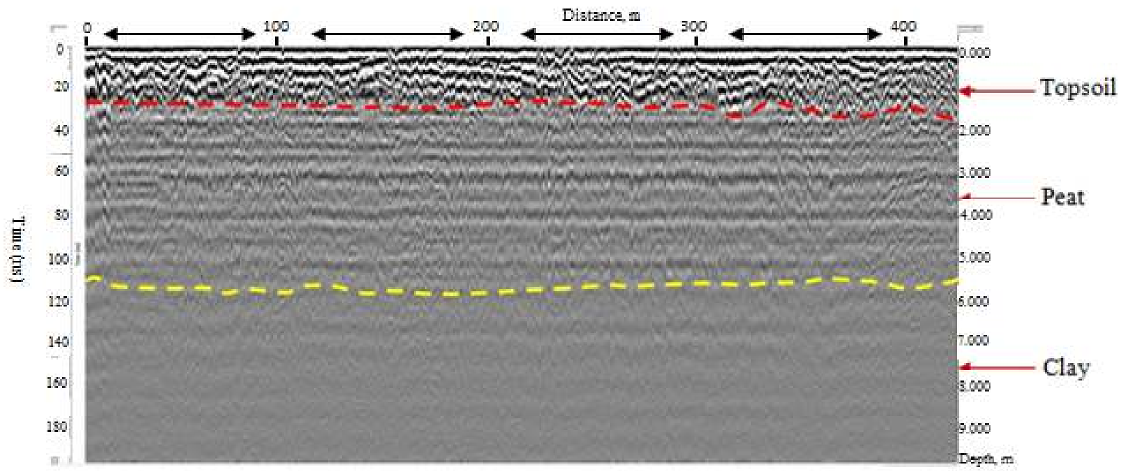

Figure 5a: GPR section of traverse 1

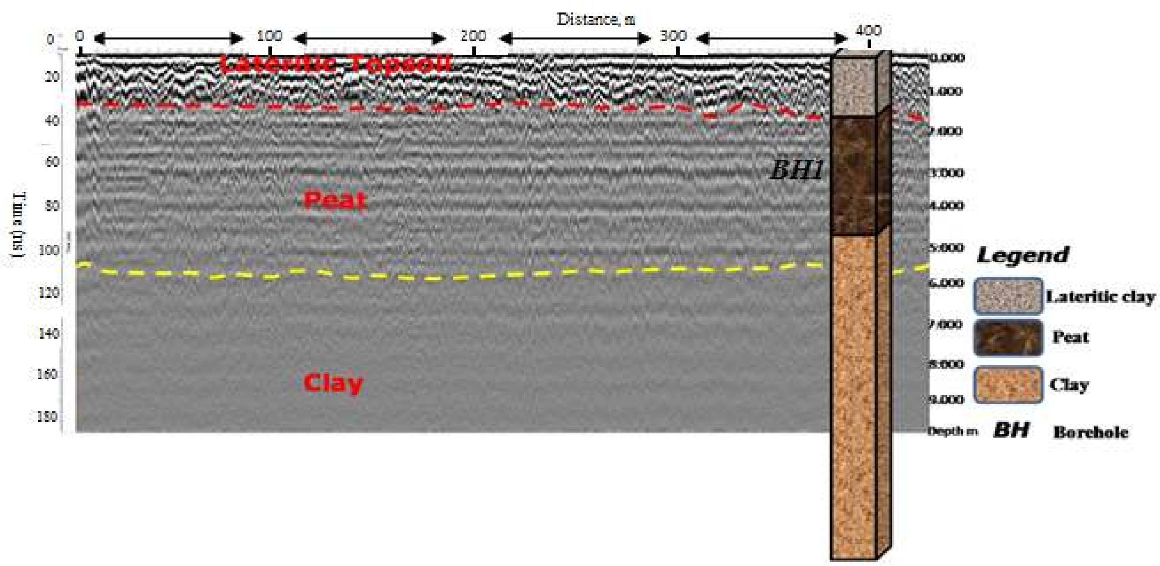

Figure 5b: GPR section of traverse 1 corroborated by borehole section BH1

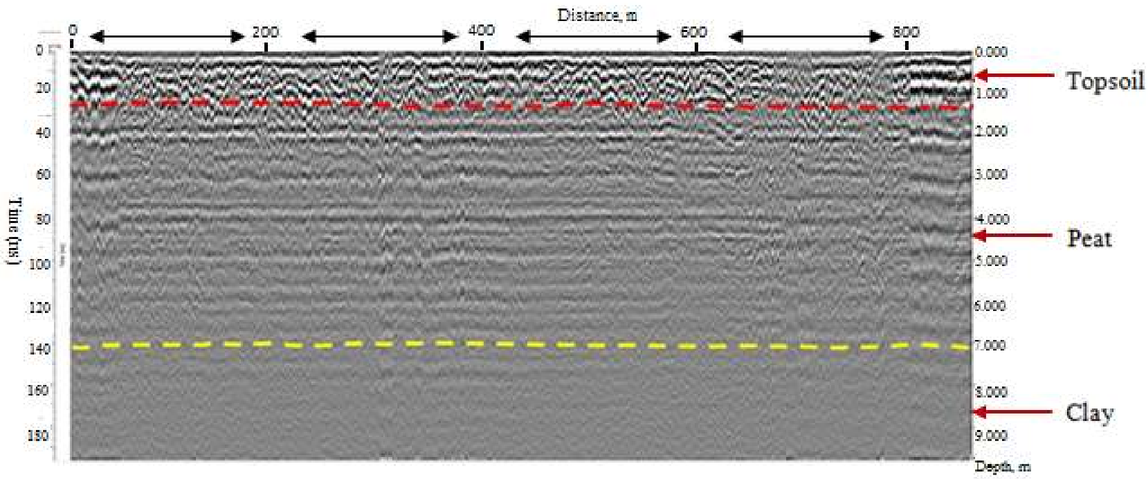

Figure 6a: GPR section of traverse 8

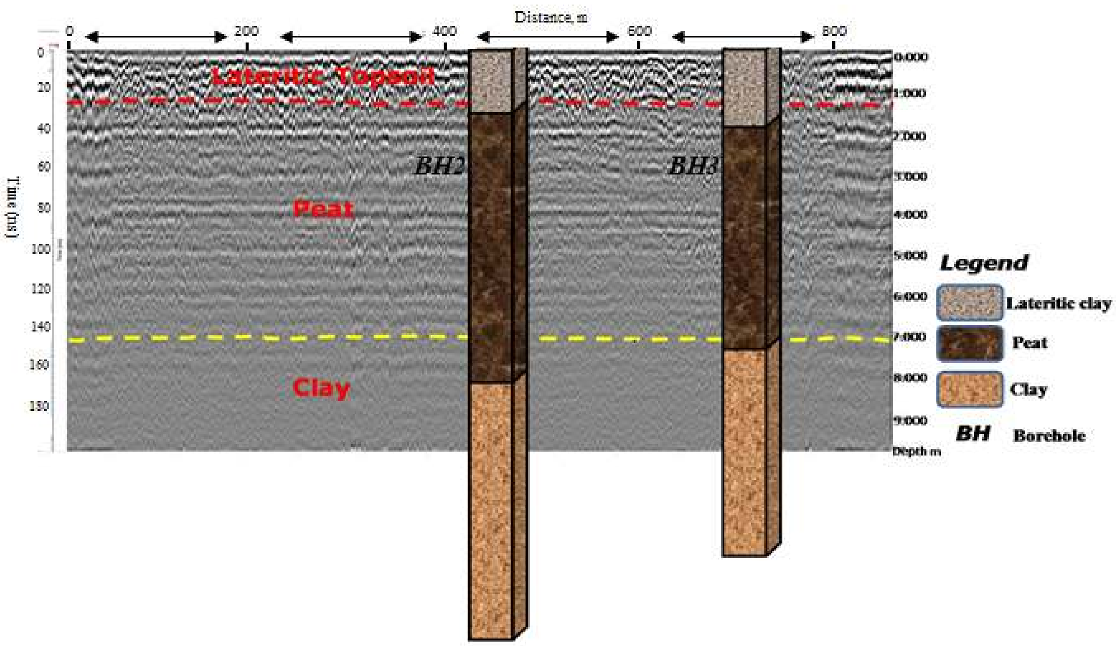

Figure 6b: GPR section of traverse 8 corroborated by borehole sections BH2 and BH3

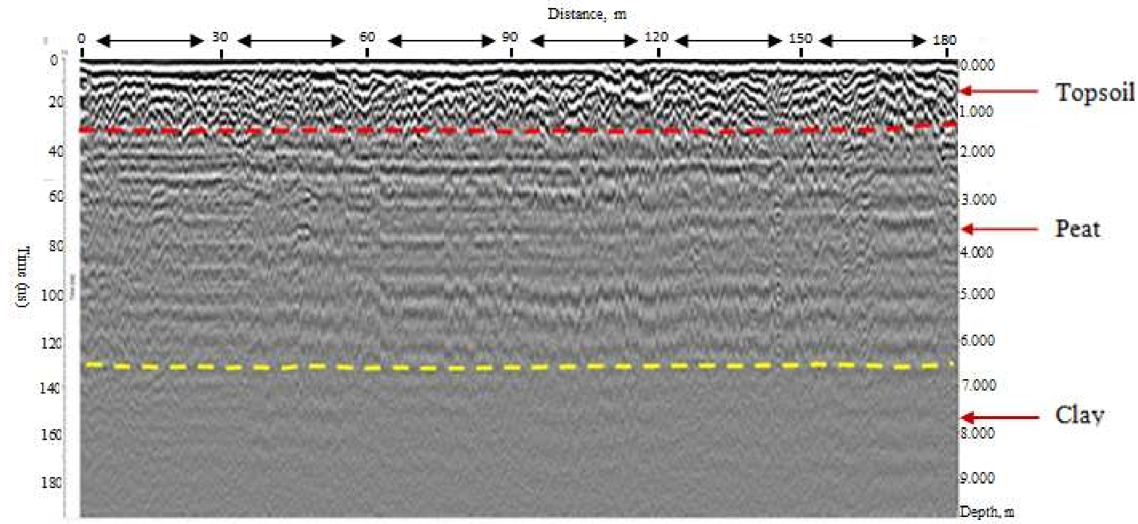

Figure 7a: GPR section of traverse 17

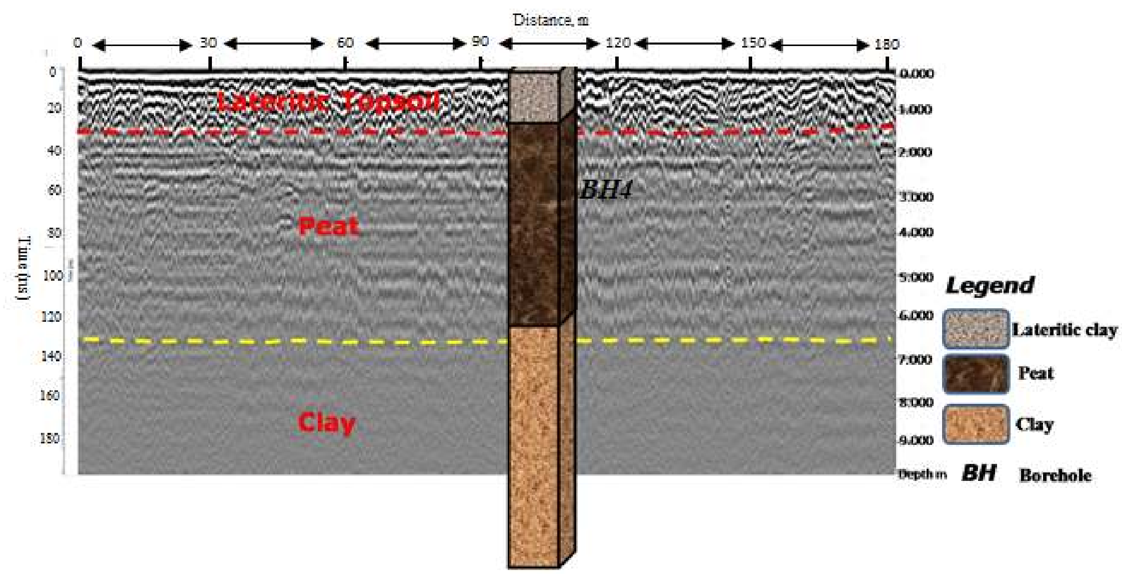

Figure 7b: GPR section of traverse 17 corroborated by borehole section BH4

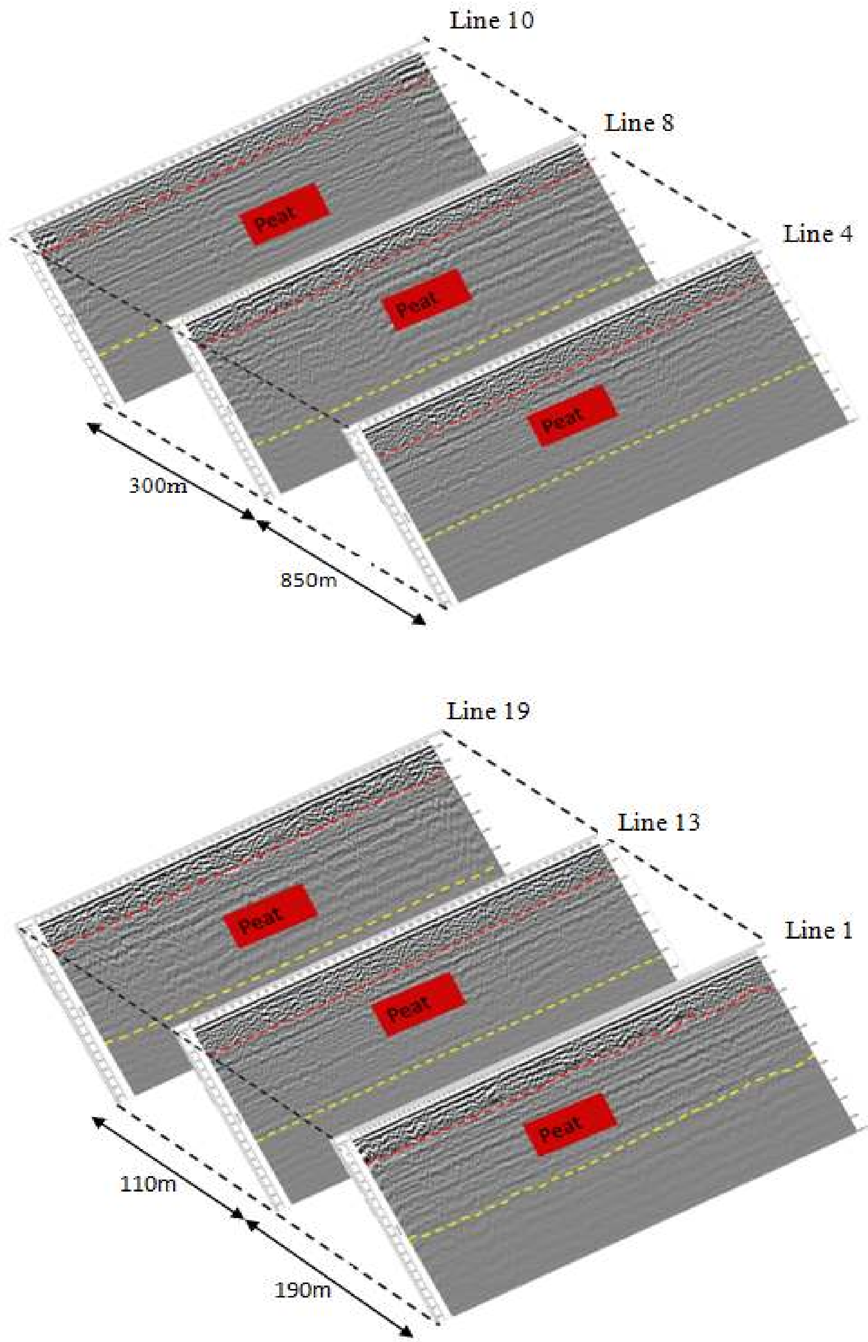

Figure 8: (a) Fence plot of the interpreted radar sections for parallel traverses 4, 8, and 10 within the study area (b) Fence plot of the interpreted radar sections for parallel traverses 1, 13, and 19 within the study area

Electrical Resistivity Results

The interpreted thirty-six sounding curve types indicate three distinct subsurface geologic layers. The layers are the topsoil, peat/clay and saturated sandy clay based on their resistivity values.

Geo-electric sections

The VES interpretation results were used to prepare 2-D geo-electric sections as shown in Figure 9(a-f). The sections generally identified three geo-electric/geologic subsurface layers comprising the topsoil, the peat/clay and the saturated sandy clay.

The resistivity of the topsoil varies from 20 to 225 Ωm and thickness ranging from 0.5 to 2 m which is composed of lateritic clay material; the peat and clay layer resistivity varies from 5 to 90 Ωm and thickness ranging from 4.0 to 29.0 m. The third layer has resistivity range of 36 to 366 Ωm and composed of saturated sandy clay. As observed from the geo-electric sections, the boundary of peat and clay could not be effectively defined as a result of the similarities in their conductivities or overlap in their resistivity value.

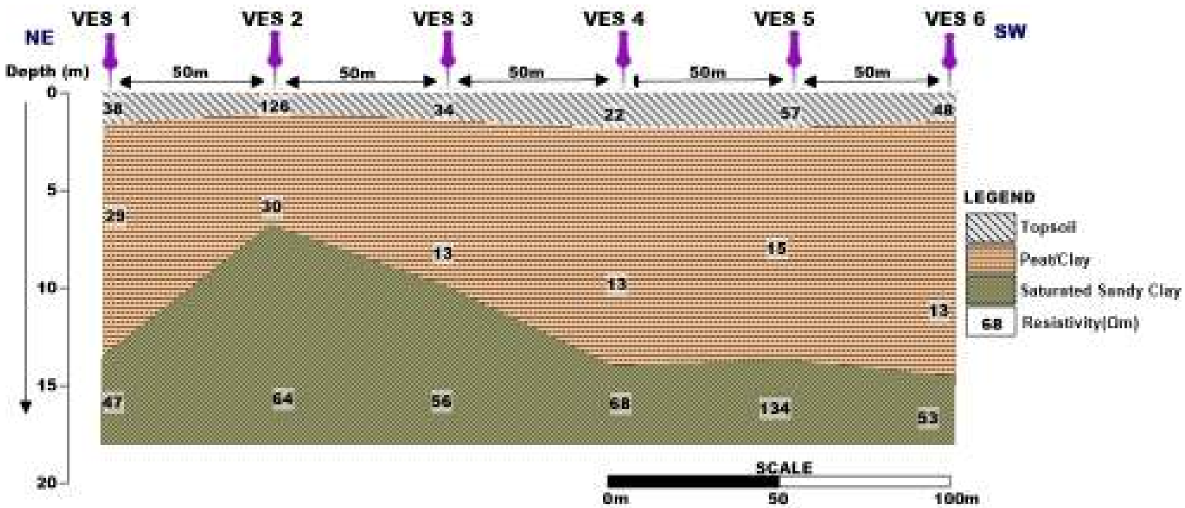

Figure 9a: Geo-electric section across VES 1 to VES 6

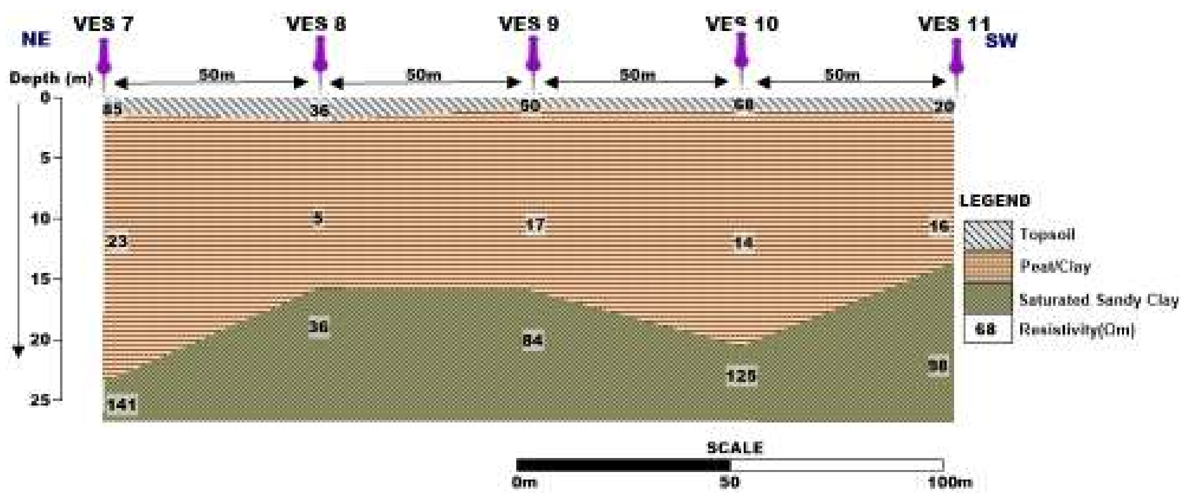

Figure 9b: Geo-electric section across VES 7 to VES 11

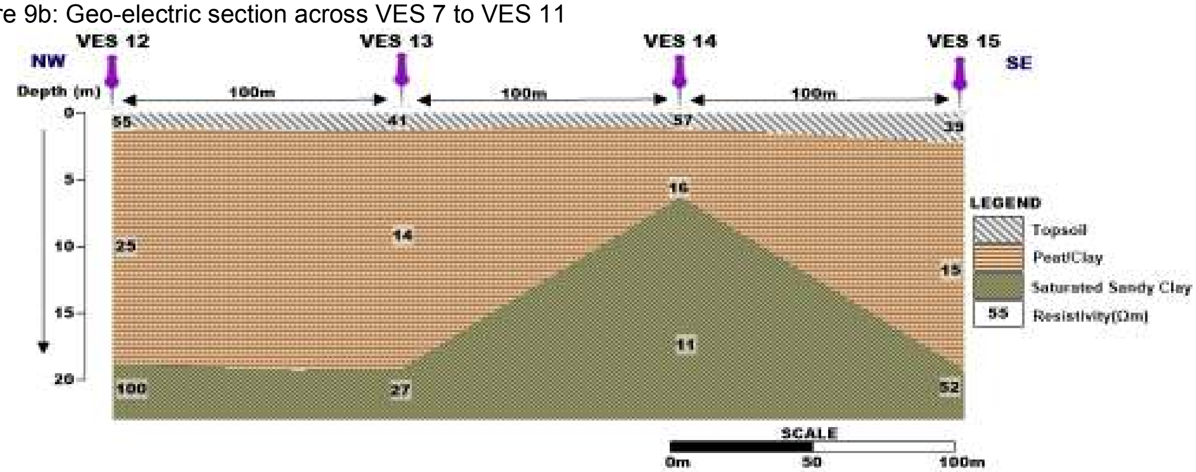

Figure 9c: Geo-electric section across VES 12 to VES 15

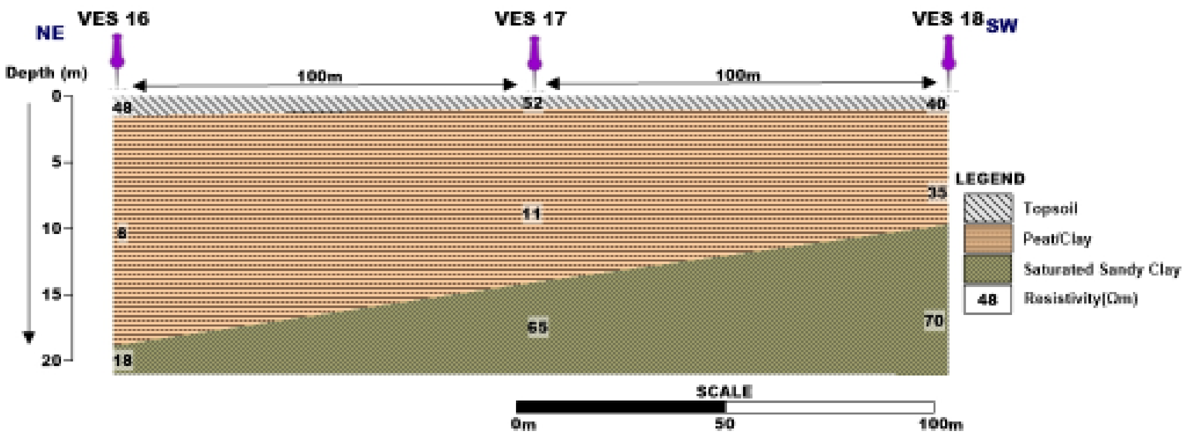

Figure 9d: Geo-electric section across VES 16 to VES 18

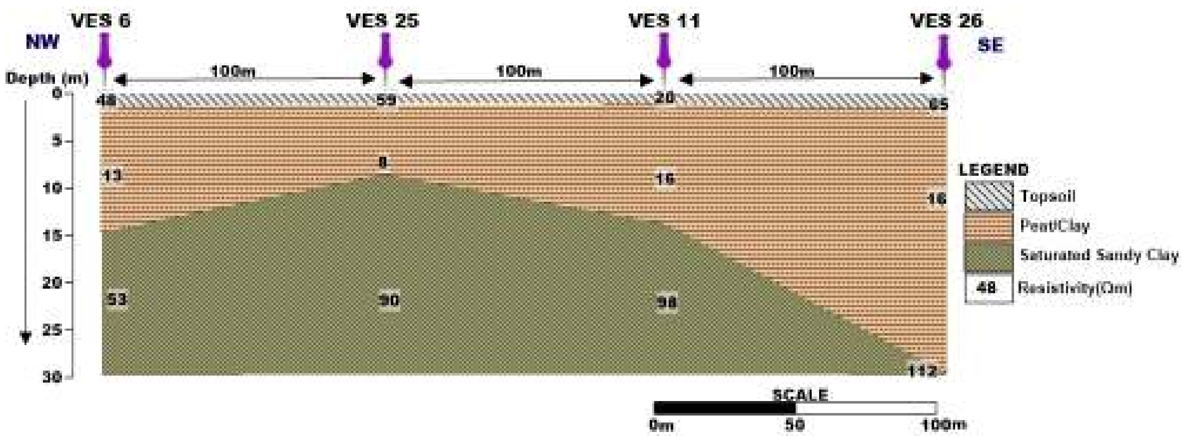

Figure 9e: Geo-electric section across VES 6, VES 25, VES 11 and VES 26

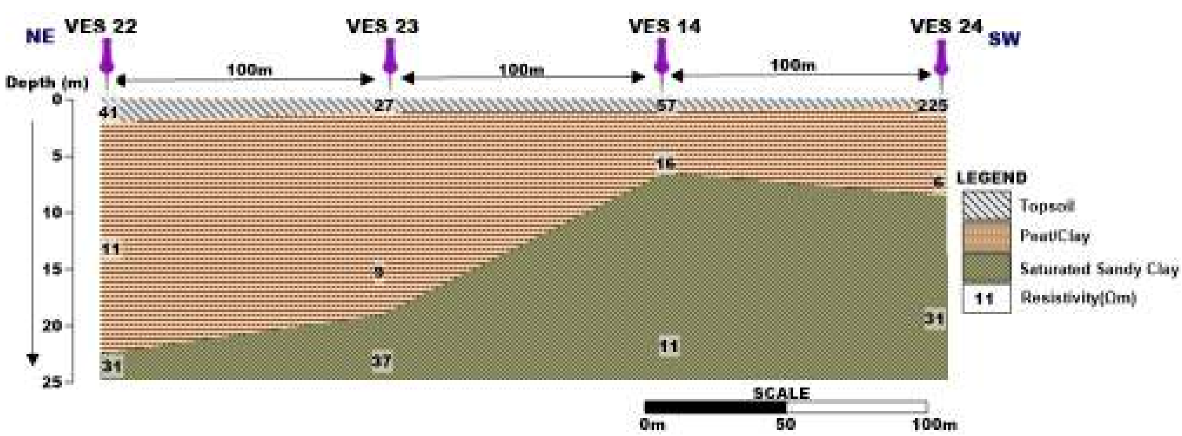

Figure 9f: Geo-electric section across VES 22, VES 23, VES 14 and VES 24

Residential buildings observed in the entire study area are marked with various degrees of distress, ranging from multiple cracks, sinking of building, and partial

Differential settlement or uneven settlement occurs when the soil beneath a structure cannot bear the weights imposed. It can also be as a result of variable highly compressible material adjacent to less compressible material. If the ground is extremely compressible by changes in water level, the building may sink below the surface of the surrounding ground or relative to adjacent structures that apply lesser or greater loads to the ground. Peat and clay which constitute near surface geologic materials in the study area are soft materials and are likely to compress if they are loaded by overlying structures, or if the groundwater level changes around them.

(a)

(b) (c)

Figure 10: (a) a residential building in the study area tilting to the left as a result of differential settlement as shown by the red and yellow arrows, (b) and (c) residential buildings with multiple cracks on the wall in the study area

SUMMARY AND CONCLUSIONS

Foundation failure in a building can be attributed to several things. The movement of expansive and highly plastic soils is a major causative factor of foundation failure. In this study, we utilized both the Ground Penetrating Radar (GPR) and Vertical Electrical Sounding (VES) techniques to investigate the liable causes of foundation failure in the area. Three different slithologies were prominent namely topsoil, peat and clay in which the stratigraphic unit of interest, peat, was revealed to having a thickness varying from 2.0 m to 8 m in the subsurface across all the traverses.

The results of the GPR data when correlated with the well logs obtained showed marked similarities in depth and thickness of the peat. The presence of peat and clay was adduced to be the cause of chronic differential settlements of some engineering structures within the area. Taking into account the soils appropriate for

designing a foundation, organic soils such as peat are difficult foundation materials because they exhibit very high compressibility compared with inorganic soils such as sand and gravel.
The study therefore gave a better image of the subsurface and provides room for better engineering design for the foundation of structure in the study area. Thus, GPR plays very important role for recognition of stratigraphy and could be used as a rapid preliminary assessment of a site.

RECOMMENDATIONS

Based on the results of the geophysical investigations, it is therefore advised that the Ground Penetrating Radar technique be incorporated in any engineering foundation design as a rapid preliminary site assessment.
For engineering construction purposes in the area, shallow foundations may not be feasible except some form of soil improvement is carried out in the study area. Deep foundation in terms of bored piles should be adopted.

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