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Engineering Geophysical Study of Adagbakuja Newtown Development Southwestern Nigeria

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Abstract: Geophysical investigation for engineering/environmental studies has been undertaken at Adagbakuja Newtown Southwestern Nigeria. The study is aimed at assisting in the planning and development process of the proposed new town. The proposed town is underlain by Dahomey Sedimentary Basin and proximal to the Atlantic Ocean shoreline. The electrical resistivity method utilizing the schlumberger electrodes configuration was adopted. Sixteen sounding locations were occupied on traverses established in the virgin area. Interpretation of the sounding curves showed that the site is underlain by mud/clay topsoil, organic clay substratum, silty clay and fine/medium grained sand. The entire geoelectric strata are characterized by very low resistivity values (0.4-1527.6 Ω-m) thus indicating high moisture content and high salinity. The bedrock materials are characterized by relatively high resistivity values (2.1-1527.6 Ω-m) that are characteristic of fine/medium grained sand with a possibility of relatively higher density and higher load bearing capacity. The depth to the upper silt/fine sand unit that can support foundation of small to medium size structures varies between 3 m on the northern flank to 11 m on the south with thickness varying between 8 and 11 m. The higher resistivity geoelectric units can presumably sustain foundations of large civil engineering structures. The sands occur at depths varying between 24 m in the north and 58 m on the southwestern edge close to Asisa and Abeotobo. Overburden protection capacity of the superficial deposits in the environment varies from 2.288 mhos (good) on the eastern flank of the area at VES 7 to 80.214 mhos (excellent) at the western end (VES 11). Thus, fresh groundwater protection within perched aquifers is envisaged while very deep aquifer units with thick overlying clay column are also likely to meet protection requirements. The soil resistivity at depths greater than 1.5 m (normal depth of burial of water and other utilities pipes) varies from 0.4-101.6 Ω-m in the environment. The degree of soil corrosivity within the Adagbakuja Newtown varies from moderately corrosive on the eastern flank to very strongly corrosive on the west. Corrosion prevention system should be considered at engineering design stages of steel/metal structures in the new town.

Key words: Resistivity, salinity, foundations, protection capacity, soil corrosivity

INTRODUCTION

The development of new towns generally requires a detailed evaluation of the virgin area so proposed. This involves the evaluation of the surface water resources, existing hydrogeologic setting, existing geotechnical parameters, geological setting, existing environmental setting and existing services (accessibility, telephone and proximity to national electricity grid). The use of geophysics for planning of new towns and estates is yet to be embraced. Recent studies have shown that adoption of geophysical studies can aid in appropriate allocation of spaces for residences, recreational facilities, buried utilities, educational institutions and industrial facilities. (Omosuyi *et al*., 2007; Oladapo and Akintorinwa, 2007; Oladapo *et al*., 2004; Ayolabi *et al*., 2004).

Coefficient of anisotropy (λ) which can be constructed from resistivity maps (Keller and Frischknecht, 1966) or from geoelectric azimuthal soundings (Olorunfemi and Opadokun, 1987) is useful for geologic boundary delineation within estates or new towns. Such delineated contacts can be avoided when locating massive masonry structures. Overburden thickness maps generated from seismic refraction studies or geoelectric soundings can guide the location of residential buildings, clinics, schools and recreational

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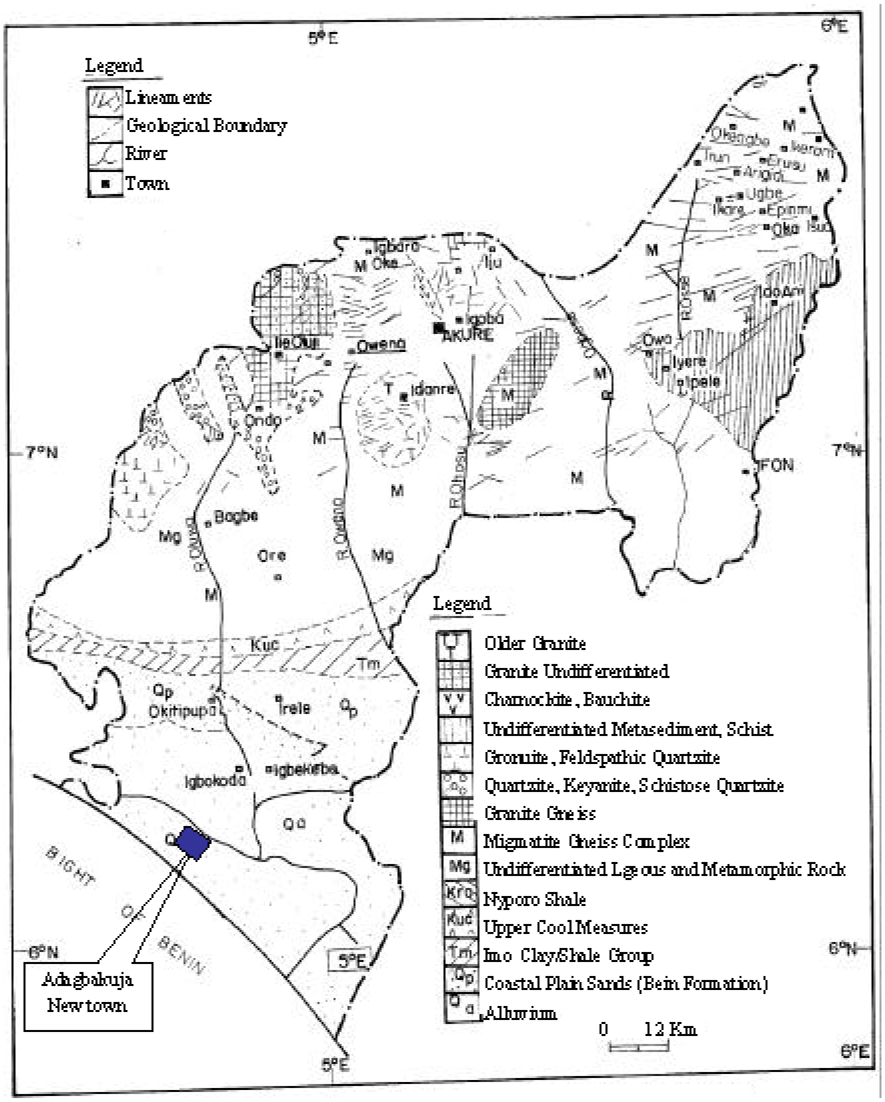

Fig. 1: Geological map of Ondo State, Nigeria showing the study area

facilities. Resistivity and Dar Zarrouk parameters (Zohdy *et al.*, 1974; Maillet, 1947) derived from geophysical studies in new towns and estates can guide the location of industrial facilities and burial of utilities.

The engineering geophysical investigation undertaken at Adagbakuja Newtown in this study is aimed at determining depth to competent stratum in the subsurface and identification of areas prone to subsidence or some form of instability. The study is also, aimed at evaluating the protective capacity of the superficial deposits overlying aquifer units in the area and to establish the degree of corrosivity of the subsoil from measured near-surface soil resistivity.

Study area description: Adagbakuja newtown is situated on the coastal margin of Ondo State on the southern flank of Nigeria. It is located at about 22 km south of Igbokoda (the headquarters of Ilaje Local Government Area of Ondo State) and situated west of Ugbo town (Fig. 1). Access to new town site is through Igbokoda-Ugbo roadway and Igbokoda-Mahin-Ugbonla waterway.

Geology/geomorphology of the area: The study area is underlain by the Dahomey Sedimentary Basin. The Dahomey Basin is one of the sedimentary basins on the continental margin of the Gulf of Guinea. The Basin extends from the Volta Delta Complex in southeastern

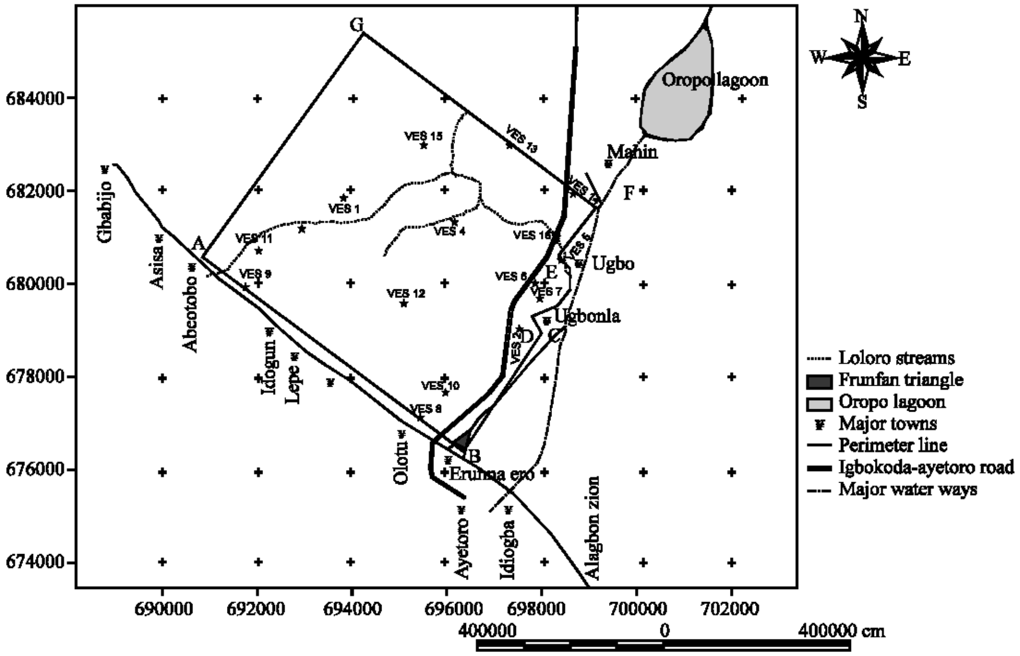

Fig. 2: Layout map of Adagbakuja Newtown showing geophysical data points

Ghana in the west through Republics of Togo and Benin to the west of the Niger Delta in Nigeria. The area of investigation is very close to the eastern limit of the basin which is marked by the Benin Hinge line, a major fault structure marking the western limit of the Niger Delta.

The sedimentary formations of the Dahomey Basin outcrop in an acuate belt, roughly parallel to the ancient coastline. The continental sediments that were deposited in a series of rapidly subsiding, fault-controlled depressions on the Basement Complex are progressively overlain by finer detrital sandstones, siltstones and shales of a transitional nature. The youngest Cretaceous strata on which the Adagbakuja Newtown development may be situated are marginal to fully marine sands and shales (Fig. 2).

Information on the geologic features and the structural setting of the Quaternary deposit of the Dahomey Basin is very scanty. Burke (1969) however, reported a Quaternary fault near Accra in Ghana. Similar faults may exist in the Quaternary deposits of the eastern part of Dahomey Basin.

There is noticeable presence of voids or cavities capable of precipitating subsidence. There is however, the risk of subsoil settlement (subsidence) arising from subsurface depression depressurization associated with new project construction activities within the area.

The terrain is generally flat (coastal plain) and characterized by a multiplicity of creeks and water channels with a net southeastern flow direction towards the sea. The location is situated about 2 km north of the Atlantic Ocean shore line. The area lies in the deciduous continental marginal forest with dense vegetation including marshes and related vegetations. The area is characterized by heavy annual rainfall averaging about 3,000 mm. The rainfall is distributed virtually over all the months of the year with the minima occurring between November and March.

The potential sources of water recharge in the study area include surface precipitation (rainfall) and recharges from the creeks and Oropo Lagoon situated northeast of the area and lateral groundwater movement. Discharge sources include seaward water movement at low tide and evapo-transpiration.

MATERIALS AND METHODS

ABEM SAS 1000 Terrameter complete with peripherals, manufactured by ABEM AB of Sweden were used for resistivity measurements. A minimum of 2 and maximum of 4 stacks measurement were adopted to ensure high signal/noise ratio. Sixteen Vertical Electrical Sounding Stations were occupied in the virgin land earmarked for the town. The geodetic system of coordinates was obtained using Garmin GPS 12 Global Positioning System. The Schlumberger current electrode separation (AB) was varied from a minimum of 2.0 m to a maximum of between 130 and 225 m at the VES locations.

RESULTS AND DISCUSSION

The field data acquired are presented as sounding curves. Qualitative interpretation of the curves involved evaluation for engineering/environmental geophysical characterization of the area. Quantitative interpretation of curves involved partial curve matching using 2-layer Schlumberger master curves and the auxiliary curves. Computer modelling was adopted for improving the interpretation.

The curve types obtained from the field data are 4-layer HA (VES 1, 3 and 4); 5-layer HKH (VES 2, 7 and 9); 4-layer QH (VES 5, 14 and 16); 6-layer KHKH (VES 6); 4-layer KH (VES 8); 7-layer QQHKH (VES 10); 6-layer HKHK (VES 12) and 5-layer QQH (VES 13 and 15). Typical sounding curves obtained from the study are shown in Fig. 3. The interpretation results and second order parameters (Dar-Zarrouk Parameters) are presented in Table 1 and 2.

The summaries of the interpretation results of Adagbakuja Newtown Development project site in terms of the geoelectric/geologic layering are the following (Fig. 4-6):

1st layer: Topsoil; the topsoil consists of soft vegetative materials and marshes

Layer resistivity: 0.4-198.6 Ω-m
Layer thickness: 0.6-2.7 m

2nd layer: The second layer consists of mud and peat.

Layer resistivity: 0.4-101.6 Ω-m
Layer thickness: 1.2-20.6 m

3rd layer: The third layer generally consists of clayey silts

Layer resistivity: 0.4-75.9 Ω-m
Layer thickness: 4.1-50.9 m

4th layer: The fourth layer consists of thick fairly resistive materials that is presumably related to consolidated sand units

Layer resistivity: 2.1-1527.6 Ω-m
Depth to layer: 18.4-68.3 m

Table 1: Interpretation summary

VES No.	Depths (m) $d_1/d_2/\ldots\ldots/d_{n-1}$	Resistivity (Ω-m) $\rho_1/\rho_2/\ldots\ldots/\rho_n$
1	0.8/4.6/55.6	1.1/0.6/0.9/5.9
2	1.3/8.0/33.0/56.6	1.2/0.6/1.3/0.7/3.6
3	0.6/10.5/30.4	1.4/0.7/0.9/18.0
4	1.0/8.2/51.2	0.9/0.6/0.9/7.4
5	0.8/6.0/18.4	198.6/29.3/1.5/66.1
6	0.8/2.7/9.9/22.1/61.7	37.6/101.6/1.3/18.7/2.9/100.8
7	2.7/8.2/19.4/48.1	157.9/9.3/75.9/18.6/1527.6
8	0.6/1.8/37.6	1.3/1.9/0.6/4.2
9	0.9/5.4/22.0/58.1	2.6/0.4/11.6/0.6/20.6
10	0.8/2.1/12.8/21.2/32.8/51.1	8.0/2.6/0.8/0.5/0.8/0.7/5.5
11	0.8/13.9/37.7	0.4/0.7/0.4/7.2
12	1.5/22.1/26.2/38.2/68.3	1.4/0.6/0.7/1.3/8.9/1.3
13	1.4/3.9/27.8/36.7	4.5/1.7/0.9/0.3/6.7
14	1.0/7.0/30.5	7.7/1.4/0.5/2.3
15	0.7/3.2/11.2/24.3	5.9/2.5/0.8/0.5/2.6
16	1.0/5.8/26.5	11.1/1.7/0.5/2.1

Table 2: Longitudinal conductance/protective capacity rating (Henriet, 1976; Oladapo *et al.*, 2004)

Longitudinal conductance (mhos)	Protective capacity rating
>10	Excellent
5-10	Very good
0.7-4.9	Good
0.2-0.69	Moderate
0.1-0.19	Weak
<0.1	Poor

Civil/geotechnical engineering implications of resistivity results: The resistivities of sediments are mostly influenced by the degree of fluid saturation and the chemistry (or salinity) i.e., quality of saturating fluid and the silicate framework of the rock matrix (Ward, 1990). Low resistivity values obtained from field measurements some times may indicate abundance of moisture. Extremely low values are usually associated with presence of saline water within the earth medium. Due to high ion exchange capacity of clay minerals, they are also associated with low resistivity field readings. In Adagbakuja area, the resistivities of upper geologic layers are generally low. It may be quite difficult in many cases to distinguish between sand layers saturated with saline water and clay/shale units. Thus, borings, SPT samplings and CPT measurements may be relied upon to resolve the problems of layer delineation for engineering designs. Experience of the authors on previous works in the area has shown that a low resistivity silt/fine sand substratum that can support foundation of small to medium size structures exist at depths of about 8-10 m in the environment. This has enabled the delineation of upper silt/fine sand stratum presented in Fig 7. These sand resistivity values are generally typical of brackish/saline sea water sand (Olorunfemi, 1985; Seara and Granda, 1987). The depth to the upper silt/fine sand unit varies between 3 m on the northern flank of the area to 11m on the south thus indicating that the stratum dips in the southern direction in the direction of the sea.

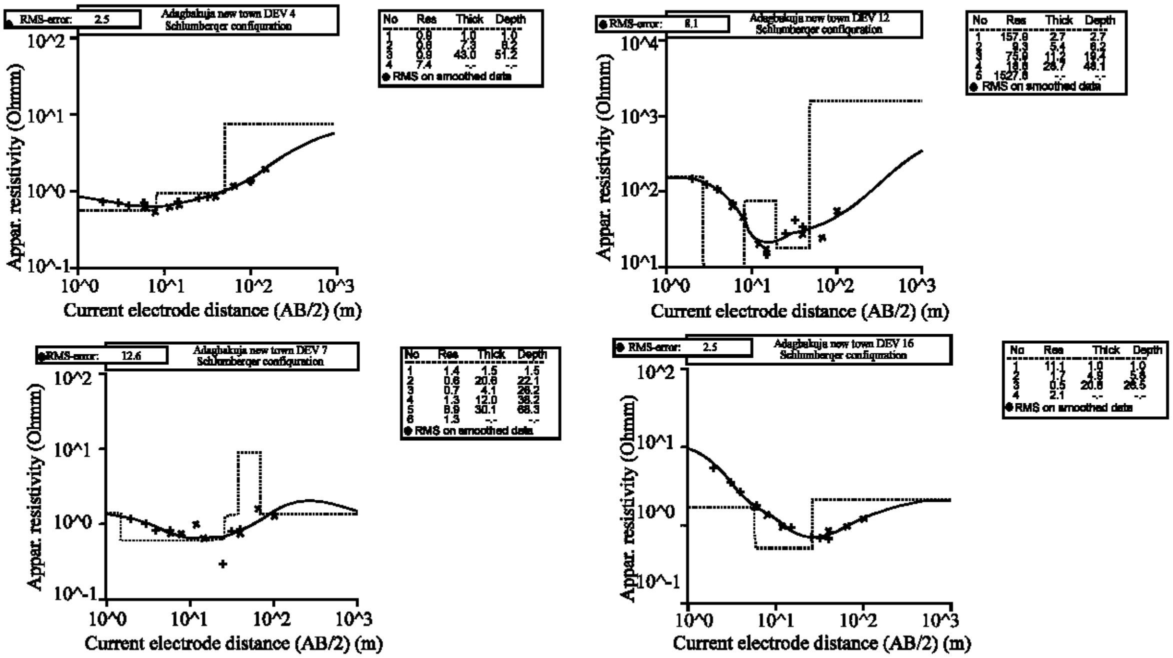

Fig. 3: Typical Geoelectric Sounding curves obtained from the study area

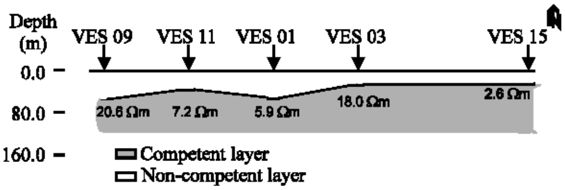

Fig. 4: Geoelectric Section Relating VES 9, VES 11, VES 1, VES 3 and VES 15, Adagbakuja Newtown Project

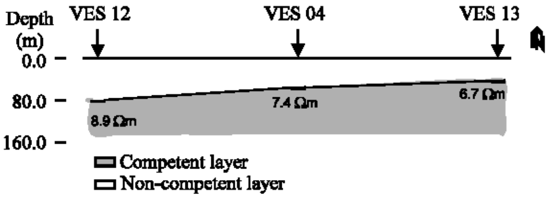

Fig. 5: Geoelectric Section Relating VES 12, VES 4 and VES 13, Adagbakuja Newtown Project

The high resistivity of the silicate framework of rock matrix controls the apparent resistivity field readings in environment of fresh water saturation. Thus, the bedrock in the area which is presumably medium-coarse grained sand aggregates are associated with higher resistivity geoelectric units obtained from the field readings. The higher resistivity geoelectric units are the consolidated higher load bearing sand units that can sustain foundations of large civil engineering structures. The map of depth to the consolidated layer is presented in Fig. 8. The map of Fig. 8 shows that the depth to the consolidated sand unit (bedrock) varies between 24 m in the north and 58 m on the southwestern edge of the area close to Asisa and Abeotobo. The depth to the consolidated sand unit is generally deep (excess of 40 m) on the entire southern flank of the Adagbakuja Newtown area.

Overburden protective capacity: The earth medium acts as a natural filter to percolating fluid (e.g., hydrocarbon spill). Its ability to retard and filter percolating fluid is a measure of its protective capacity. The protective capacity of an overburden overlying an aquifer is proportional to its hydraulic conductivity (Henriet, 1976). But high clay content generally corresponds with low resistivities and low hydraulic conductivities. Hence, the protective capacity of the overburden can be considered as being proportional to the longitudinal unit conductance (S) defined as the ratio of the overburden thickness to its resistivity. The higher the overburden longitudinal conductance, the higher is the protective capacity.

The protective capacity ratings (Table 2) adopted in this investigation are based on Henriet (1976) and modified by Oladapo *et al.* (2004). The underlying aquifer is overlain by very thick overburden (topsoil) whose longitudinal conductances are presented in Table 2. Overburden protection capacity of the superficial deposits in the environment varies from 2.288 mhos (good) on the eastern flank of the area at VES 7 to 80.214 mhos (excellent) at the western end (VES 11). Fresh

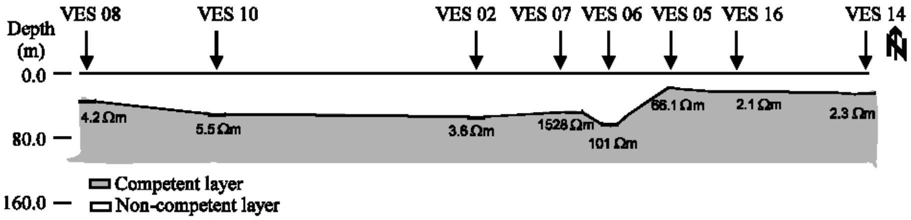

Fig. 6: Geoelectric section relating VES 8, VES 10, VES 2, VES 7, VES 6, VES 5, VES 16 and VES 14, Adagbakuja newtown project

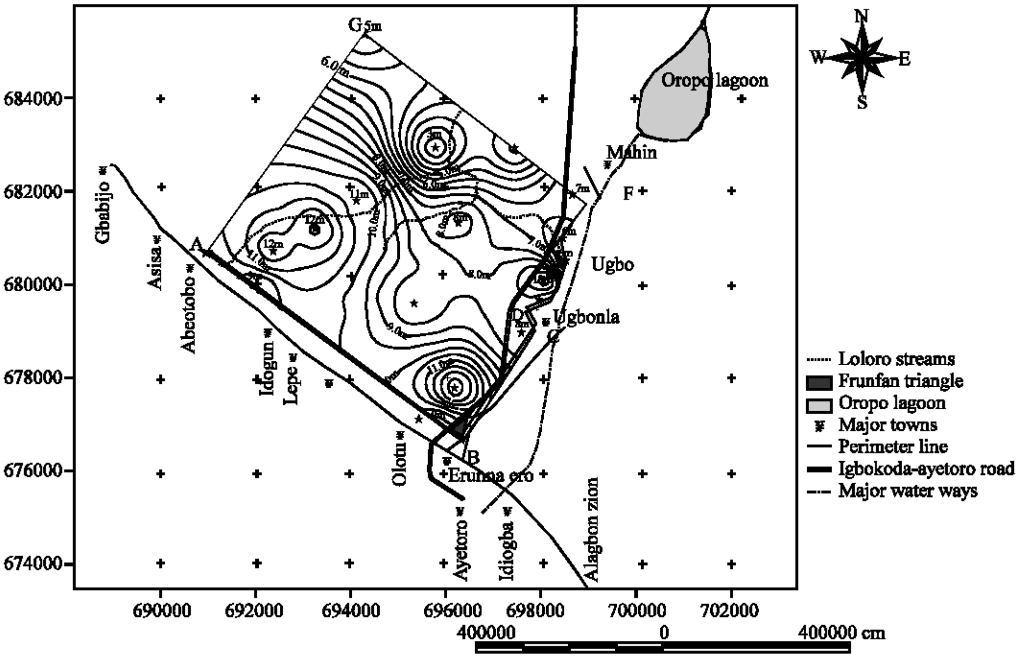

Fig. 7: Depth map of the substratum layer

groundwater protection within perched aquifers (if any exists in the environment) is envisaged while very deep aquifer units with thick overlying clay column are also likely to meet protection requirements.

Soil corrosivity: Soil corrosivity which can lead to severe corrosion failure is known to be associated with low resistivity. Low electrical resistivities are indicative of good electrical conducting paths arising from reduced aeration, increased electrolyte saturating or high concentration of dissolved salts in soil. Soil resistivity can therefore be classified in terms of the degree of soil corrosivity as shown in Table 3.

Topsoil resistivity map is presented in Fig. 9 where areas vulnerable to corrosion are hatched. The degree of soil corrosivity within the Adagbakuja Newtown varies from slightly corrosive (101.6 Ω-m) on the eastern flank to very strongly corrosive (0.3 Ω-m) on the west. Engineering design of steel/metal structures in the Adagbakuja Newtown project implementation should consider the incorporation of corrosion prevention system.

Possible environmental impacts: Possible environmental impact that could arise from site preparation/construction (excavation and sand fill) at Adagbakuja Newtown project may include: Surface depressurization (unloading or relieving of the subsurface of lithostatic pressure) due to excavation/dredging works that can precipitate geological instability such as ground subsidence, temporary increase in the turbidity of the creek/canal water dueto excavation/ dredging works, reloading or increase of lithostatic

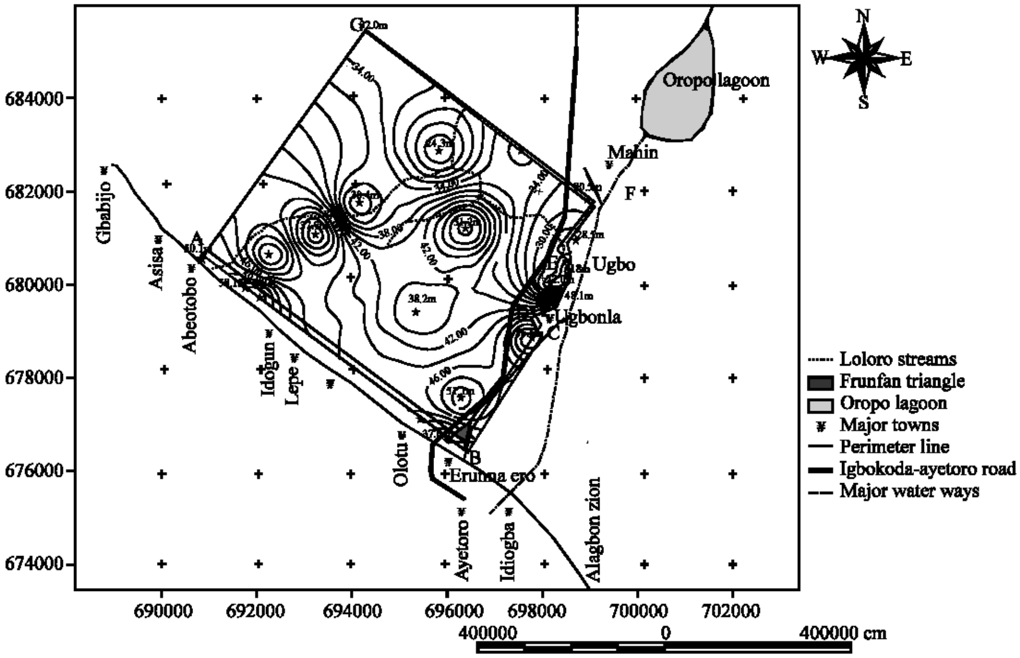

Fig. 8: Depth map of the consolodated layer

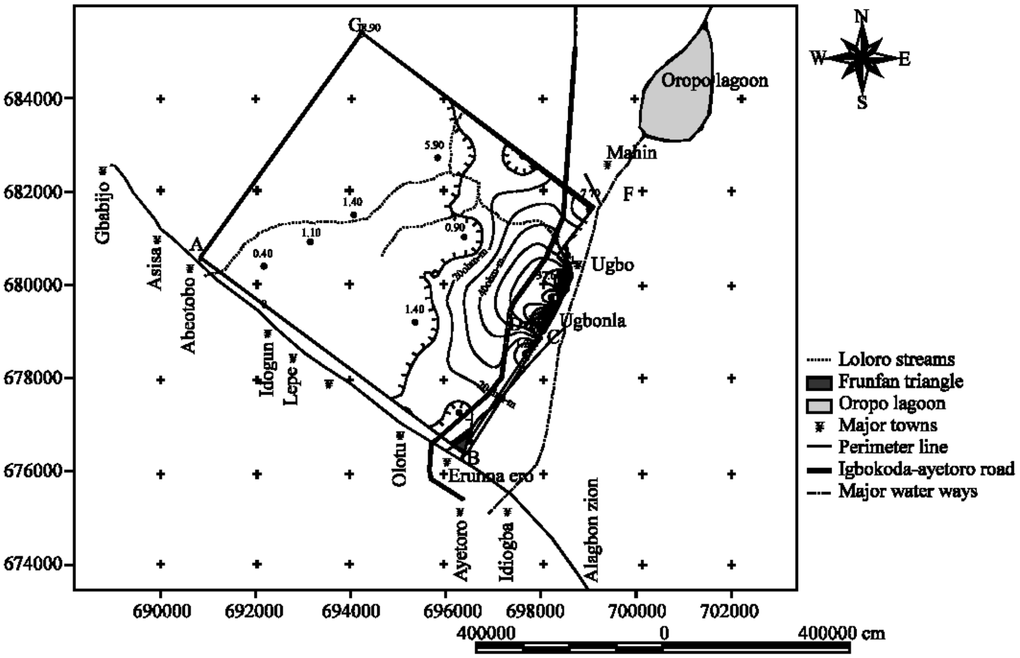

Fig. 9: Topsoil resistivity map with high corrosion zone hatched

pressure due to sand filling may lead to compaction/settlement of the subsoil and precipitation of surface/near-surface water outflow that may cause temporary change in local water level and or groundwater flow direction, corrosion of buried oil metal pipes in the moderately to strongly corrosive saline water saturated

Table 3: Classification of soil resistivity in terms of the corrosivity (Baeckmann and Schweak, 1975; Agunloye, 1984)

Soil resistivity (ohm-m)	Soil corrosivity
Up-10	Very Strongly Corrosive (VSC)
10-60	Moderate Corrosive (MC)
60-180	Slightly Corrosive (SC)
180 and above	Practically Non-Corrosive (PNC)

Table 4: Classification of potential Environmental impact (Rau, 1990)

Potential Impact	1	2	3	4	5	6
I Excavation/dredging						
Subsurface depressurerization						
-Geological instability	*		*			*
Surface water						
-Water turbidity	*		*		*	
Groundwater						
-Groundwater level	*		*		*	
-Groundwater flow direction	*		*		*	
II Sandfilling						
Subsurface loading						
-Compaction/settlement	*		*			*
Groundwater						
-Groundwater level	*		*		*	
-Groundwater flow direction	*		*		*	

Note: 1 = Short Term; 2 = Long Term; 3 = Mild; 4 = Severe; 5 = Reversible; 6 = Irreversible

subsoil and failure of unprotected oil/chemical metal pipes leading to pollution of the surface and groundwater through porous and permeable sand layers.

The assessment of the enumerated potential environmental impact is based on template of Rau (1990) "ad hoc method". The potential environmental impacts are classified as shown in Table 4.

CONCLUSION

The results of engineering geophysics study of proposed Adagbakuja Newtown have shown that the project area is underlain by geoelectric/geologic sequence consisting of vegetative marshes, mud/shale/peat, silts/fine grained sand, clay/shale and medium/coarse grained sands units. The upper vegetative marshes and mud/shale/peat layers are apparently poor foundation support soil units.

The silt/fine grained sand units delineated are situated at depths ranging between 3 and 11 m and have thickness varying between 8 and 13 m. The silt/fine sand unit presents characteristics indicative of fairly good foundation support rock materials. The unit may possibly support medium to moderately large engineering structures with special foundation designs to ensure that its allowable load bearing capacity is not exceeded. The low resistivity shallow soil units above the silt/fine grained sand in the area may only safely sustain raft foundation types for residential buildings, institutional buildings (e.g., schools, hospitals, clinics, office buildings e.t.c.).

The bedrock in the study area is generally characterized by high resistivity values indicative of medium to coarse grained sand bodies. The high resistivity values recorded is an indicative of the influence of the resistive silicate framework of rock matrix within the stratum despite the presence of saline/brackish water. The depth to the presumably consolidated layer varies from 24 m on the northern flank to 58 m on the southwestern edge of the project area. The higher resistivity characteristics of the bedrock are indicative of higher load bearing sustainability. Foundations of large civil engineering structures within Adagbakuja Newtown area should be safely anchored in form of piles on the bedrock at deep depths in excess of 30 m.

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