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Integrated Geophysical Investigation of Aquifer and Its Groundwater Potential in Camic Garden Estate, Ilorin Metropolis North-Central Basement Complex of Nigeria

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Abstract: *This paper presents a geophysical study for ground water evaluation in a typical crystalline basement complex terrain of Camic garden estate in Ilorin metropolis, North central basement complex of Nigeria. Very Low Frequency-Electromagnetic (VLF-EM) and Ground Magnetics (GM) were used for structural evaluation/delineation combined with Electrical Resistivity Method (ERM) using the Vertical Electrical Sounding (VES) Technique. Eight (8) VLF-EM and GM profiles covering a distance range of 70 to 300 m were established, VLF-EM at a measuring intervals of 10 m each, while six (6) VES were carried out based on quantitative, semi-quantitative of the VLF-EM and GM, a correlation was also carried out between the VLF-EM and the GM results of conductive zones and zones of low magnetic susceptibility that may be diagnostic of fault, fracture/weathered material. The six (6) VES were carried out using Schlumberger configuration, with AB/2 varying from 1.00 m to 225.00 m, with the predominant curve being of the HA type* representing three-layer earth model *i.e. the top soil, the clayey/weathered layer, and the fresh basement for most of the curves obtained, the clayey/weathered layer constitutes the major auriferous unit in the area, and are characterised by moderately low resistivity value which ranged between 23.00 and 200.00 Ωm while the thickness varies 13.2 to 61.0 m. The study reveals that 83% of the study area may be of low water bearing/yield owing to the thick clayey column that characterised the weathered layer without fractured basement. Therefore, there is a critical need for elaborate ground water study in the entire area, to be able to site boreholes with a reasonable yield in an environment where fractured basement/bedrock is rare to find.*

Keywords: *Aquifer, Basement Complex, Borehole yield, Geophysical investigation, Groundwater.*

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I. Introduction

Geological media capable of accumulating groundwater have always been the target of groundwater Explorationist in any environment [1].The search may prove to be more challenging, especially in hard crystalline basement complex environment, were availability of fresh water is dependent on fractured crystalline bedrock and other favourable parameters, porosity, permeability, transmissivity and all the rest given the heterogeneous and anisotropic nature of basement rocks formations [2]. Therefore, extensive groundwater exploration in the basement complex region recognised the fractured bedrock and thick-weathered regolith as the two major prolific formations from which water can be extracted. These were the target in Camic garden estate, Ilorin metropolis of Kwara state, north central basement complex region of Nigeria. According to [3], ground water means the water occupying all the empty spaces with a geologic rock units or stratum. [4], identified porosity and permeability as important factors that could affect the quantity of water stored in fractured/weathered crystalline rock. Therefore, borehole yields may depend significantly on the quantity of water stored in superficial materials that can leak downwards into bedrock, and on periodic replenishment by recharge. Various factors have been used as indices for groundwater development in different areas; most of these factors are often evaluated by a number of experts using different approaches.

However, the degree of contribution of one or more factors on groundwater potential is not the same, and this may vary from one location to the other. In addition, all the important factors that can influence the ground water potential in an area must be integrated to be able to make a reliable groundwater potential estimate /evaluation. The use of multi-techniques geophysical approach has proved to be a veritable tool in detecting the availability, quality and quantity of groundwater for many years, especially in a typical basement complex terrain as employed by [5, 6, 7, 8].

Multi-technique geophysical approach may be adopted, especially, in the delineation of structures in the search of groundwater in a basement complex terrain. The application of Electromagnetic (EM) and magnetic methods [7] as a reconnaissance tool in delineating conductive and low susceptibility zones respectively may be diagnostic of fracture/faults; fissures, cracks; joints and deep saturated fractured bedrocks in basements terrains. These play a vital role in delineating a host to ground water occurrence/ accumulation. The development of potable water is crucial to the resident of Camic garden, especially given a situation of many failed/abortive boreholes in an ever increasing population in a metropolitan city of Ilorin with a steady and ever increasing demand for potable water, the need for an elaborate groundwater search becomes imperative. More also, these methods are faster and cost effective compared to other geophysical methods. In addition, electrical resistivity method was adopted to provide information on horizontal beddings and subsurface layer parameters. This method is considered as a comprehensive means by estimating apparent resistivity, depth and thickness of the subsurface layers with a view of defining conductive zones. [9], proved that resistivity of rocks are controlled by the bulk resistivity eB of the sub-surface rocks and that of the formation water, ⅇW, that filled the pores spaces given by equation

$$F = ⅇB/ⅇW \quad (1)$$

Where f is the formation factor, ⅇB is the bulk resistivity of the subsurface rock and ⅇW is the resistivity of water within the pore space, making the choice of electrical resistivity method very relevant in this study.

This study presents the use of geophysical methods in the delineation of bedrock structures, and identification of lithological units, required in the determining the possible nature of the auriferous units that are critical to the ground water bearing in the area. More so, that the area is characterised by many cases of abandoned/failed boreholes, Hence, a detailed understanding of the geologic and hydro geologic characteristics of the crystalline bedrock, as well as the regional tectonic setting, which are very essential in siting a highly productive borehole [10], to be able to meet both the domestic as well as industrial water needs of the people of this area. Prior to this research work, the study area is noted for common cases of failed\abortive and boreholes with extremely low yield, with no previous existing literature. Therefore the current effort is directed at unveiling the situation with a view to find a lasting solution to the problem of providing viable, potable and sustainable water for the people of this area.

II. Location and Geology of the Study Area

The area of study is within Camic garden, Ilorin, Kwara State. Its geographical coordinates are 671000-671400N and 944500-945100E of the Universal Traverse Mercator UTM (Figure 1a), it is accessible by trunk ‘C’ roads via Ilorin and Sobi Barrack road, the area is situated on an elevated terrain (270 - 300 m) above the sea level and the topography is gentle. Vegetation is sparsely distributed, while part of it has been cleared for physical development. There are visible presence of well and boreholes within the area but often with low yield and many a time abortive. The use of borehole is desirable for the use of the people in the area especially for their domestic use. The rock exposure and laboratory analysis revealed extensively weathered granite/banded gneiss, intruded by pegmatite sills. Mineralogical, quartz at 45% feldspar at 30%, and biotite at 20%, with 5% of other minerals making up the mineralogy of the gneiss, while quartz at 50%, feldspar at 35% and biotite at 15% makes up the pegmatite. The trend is 150°, 88° while the width ≅ 30 cm and traceable over 3 mm length. The gneiss strike/dips are 152/18°W, 156/22°N, 056/14°W with joint direction of 006°, 078°. The angle of quartz crystals stretch along east-west direction, which corresponds to the foliation plane. The other has remained relatively unaffected. The dimension respectively, are 3.5×2 cm, 3×3.5 cm, the thickness of foliation plane varies from 1mm to 30 mm, locally the strike/dip is of 078/18°SW and fracture line of 164°, 140°, 184° and 82°.

The study area is situated in the tropical/humid rain forest region, with a climate characterised by wet and dry seasons. The wet season usually occurs from March to October and is dominated by a heavy thunderstorm. The dry season occurs from November to march when the area is under the influence of north-easterly winds. The annual rainfall ranges between/about 1000 and 1500 mm. the annual temperature varied from about 18 ℃ for a very cold day and 34 ℃ for very hot day [11]. The geology of the study area is characterized mainly by the presence of older granite and undifferentiated basement complex [12]. There are no visible outcrops in the study area. Locally, granitic and gneissic basement rocks overlain by relatively thick covering of weathered materials underlie the area.

III. Material and Methods

Both the VLF-EM and magnetics profiles were carried out using ABEM WADI instrument and proton-precision magnetometer G.19T respectively. Measurements were carried out at interval of 10m long along eight traverses with length ranging from 70 to 300 m. The traverses were established in the south-west, north-east (SW-NE) and east to west (E-W) direction. A total of 149 stations were occupied, utilising a frequency of 27.2 kHz for the EM equipment. The ABEM WAD1 (receiver) rely on the electromagnetic field generated military navigation radio (transmitter) working in the VLF frequency band (15-30 KHz) as the principal electromagnetic field. [13] reported that radio waves are very low frequency could be applied to prospect for conductive mineral deposits. This has brought about the wide range use of VLF transmitter at various locations around the world being employed in prospecting for conductive near surface structure, which may be associated with fault, fracture, crack, joints and weathered materials. The equipment was developed based on a principle of induction i.e. an inductive survey technique. The receiver measures the secondary electromagnetic effect resulting from the transmitter, primary field as amplitude and face of geologic subsurface structure. The raw real/ or filtered real, R (in phase) and the raw of filtered imaginary I (quadrature) as a reflection of the secondary field component resulting from the sub-surface geology of the study area. The equipment is very sensitive to the ground conductivity. The raw real VLF records were processed with the aid of an inbuilt filtering program provided in the ABEM WAD1 equipment, as well as the software package, Karous-Hjelt and Fraser filtering (KHF) which was applied to the very low frequency EM geophysical data. By the filtering process, real data anomaly inflections appear as peak positive anomalies and false VLF anomaly inflection points as negative anomalies [14].

The primary field of very low frequency EM generated by the radio transmitter has an horizontal magnetic component Hy and a vertical electrical component Ez; the two are perpendicular to the direction of propagation (x). The earth resistivity discrepancy created horizontal component Ex of the electric field, thereby modifies the horizontal magnetic component Hy [15]. The measurements of both Hy and Ex constitute the VLF resistivity which uses similar principles as the natural magneto telluric method. The earth's impedance is therefore defined as [16];

$$Z = Ex/Hy \tag{2}$$

ABEM 4000 Resistivity meter was used for the vertical electrical resistivity using Schlumberger array configuration with AB/2 ranging from 1.00 m to a maximum of 225.00 m.

The magnetic measurements were obtained using the G.I9T proton precession total field magnetometer over 149 stations at 10m measuring intervals. The data were subjected to diurnal and drift correction. The regional was removed from the corrected to obtain the residual upon which the susceptibility map of the study area was generated using the Oasis Montaj software package.

IV. Data acquisition and processing

The geophysical investigation involved the use of Magnetic profiling, VLF-EM profiling and Electrical Resistivity Sounding (ERS). Eight traverses of length ranging from about 70 – 300 m were established in the E-W direction. The Magnetic and VLF-EM profiling used station separation of 10m. Six (6) VES using Schlumberger configuration were carried out as obtained from the VLF-EM results. The Schlumberger arrangement is such that the electrode spacing 'AB/2' is at least five times greater than the potential electrodes and of the current electrodes is located at the infinity. The electrode spread begins from 'AB/2' = 1.00 m to a maximum spread (AB/2) of 225 m.

The field magnetic data were subjected to the diurnal and drift correction. The regional was removed from the corrected data so as to emphasize the residual. The residual data represents, presumably effects of the intermediate zone of interest after near surface noise and the regional have been removed. This correction removes the background effect. The VLF-EM data were processed by applying Fraser and Karous-Hjert filter. The [17] filtering on the in-phase component to removes complex patterns before interpretation. The Karous-Hjert a statistical linear filter, this filter provides an apparent depth profile from the current density which is derived from the magnitude of the vertical component of the magnetic field a specific location. The apparent resistivity data obtained from the VES survey were presented as depth sounding curves. These data were processed using a partial curve matching, the result of the curve matching was fed into the computer as a stating model in an iterative forward modeling technique, upon which Subsurface geoelectric model were generated and presented as layer resistivity and thickness.

V. Results and Discussion

EM profiles and magnetic susceptibility map

The VLF profiles: profile 1, (fig. 1i) this covers a distance of 220 m from which an inflection of positive anomaly was obtained at three stations i.e. 160.00 m, 165.00 m and 190.00 m. Profile 2, (fig. 1ii) had three positive peaks / inflection points, i.e. at 80.00 m, 170.00 m and 250.00 m. Profile 3, (fig.1iii) had one point of interest which was observed at 20.00 m, which also coincides with the same station on profile 4 (fig. 1iv). At profile 5, (fig.1v) the positive peak / inflection points between the raw real and the filtered real anomaly occurred at 120.00 m, 160.00 m, and 190.00 m. while it was obtained at 130.00 m and 190.00 m on profile 6 (fig. 1vi). The positive inflection point (positive peak anomaly) occurred at 20.00 m, 40.00 m, 50.00 m, 110.00 m and 150.00 m on profile 7,(fig. 1vii) while it occurred at 110.00 m and 180.00 m respectively on profile 8 (fig. 1viii). The most profound point of interest, with respect to the signature, nature / extent of anomaly within the study location occurred on profile five and six within 120 and 190 m, it has a trend extending for about 60 to 70 m and a width extent of about 100 m.

The representative results of the raw real, Fraser filtered data plot as well as karous-Hjelt 2-D pseudo-section for profile 1 to 8 are shown in fig 1 (i) to 1 (viii). The interpretation of the profiles, the pseudo-section and susceptibility map were qualitative or semi-quantitative. The inflection of the raw real with the Fraser filter i.e. the positive peaks are mapped as linear features. These points correspond to the conductive zones and are promising in ground water occurrence/exploration as they often correspond to zones with high conductivity, characteristics of water bearing formation in fractured/faults, cracks, and regolith in basement complex terrain [18, 19]. The asymmetry of conductive structures is dipping. Anomalies suggest that the varying amplitude exhibited by the anomalies are mostly controlled by fig. 1(i)-1(viii) corresponds to the K-H filter, 2-D inversion current density and change in conductivity as a function of depth.

Qualitatively, the pseudo-section enables possible discrimination between conductive and resistive features which are depicted in the section with color codes, where high positive value corresponds to conductive sub-surface structure and low negative values are related to resistive structures with fractures / conductive features are mapped independently on the respective profiles. The mapping of conductive zones (structures) enabled the identification /delineation of points of EM anomaly upon which six vertical electrical were established, after a reasonable degree of correlation had been made with magnetic susceptibility map of the study area (Figure 2).

Magnetic susceptibility map of the study area was characterised by low susceptibility zones at about 80 m and 160 m on profile1. Observed at about 20 m, 120 m and 185 m on profile 2 with similar trend extending to other profiles. The major zones of low magnetic susceptibility occurred at profiles 1,4,5 and 6 extending to transverse seven, which occur between 80 m and 170 m, i.e. lateral extent of 90 m and width extent of about 100 m; here a fairly reasonable weathered layer thickness was obtained from the result of vertical electrical sounding in the study area.

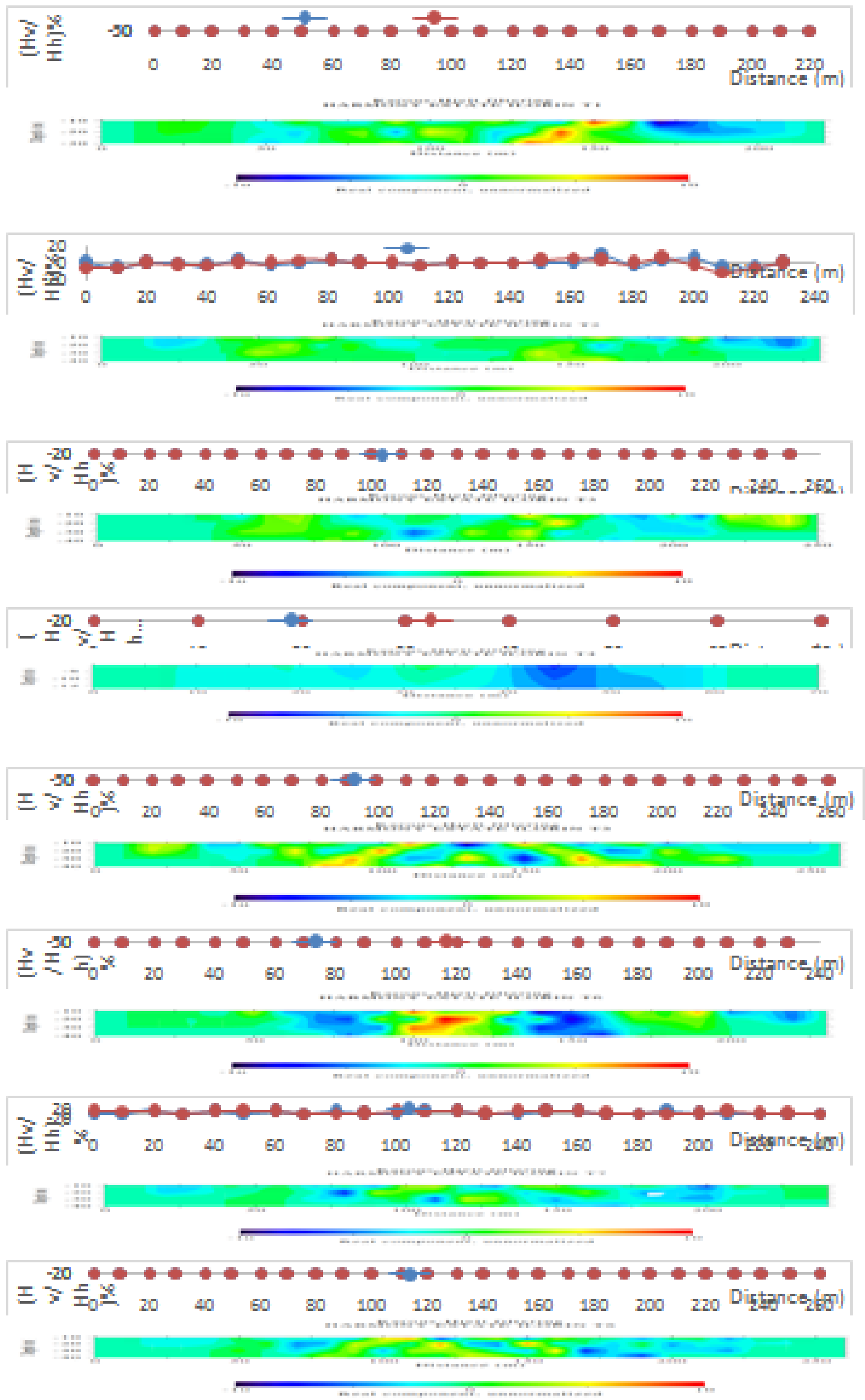

Figure 1: (i-viii): shows the VLF-EM profile and Section along Traverses i to viii

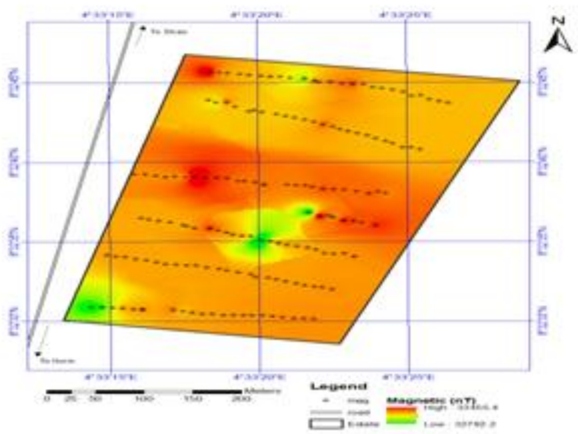

Figure 2: Magnetic Susceptibility Map of the study area.

Vertical Electrical Sounding Curves

The curve type obtained in the study area was similar in nature, and seemed indicate the nature of the auriferous zones in the study location. The curve type obtained is the HA curve, ($\rho_1 > \rho_2 < \rho_3 < \rho_4$) representing three-layer earth model, with moderately thick clayey sand and thick weathered basement with no noticeable fractured basement and hence may be partly responsible for many case of low borehole yield/abortive boreholes that exists in the area. Figure 3 shows the typical VES sounding HA curves obtained from the data interpreted in the study area and this is shown in table 1.

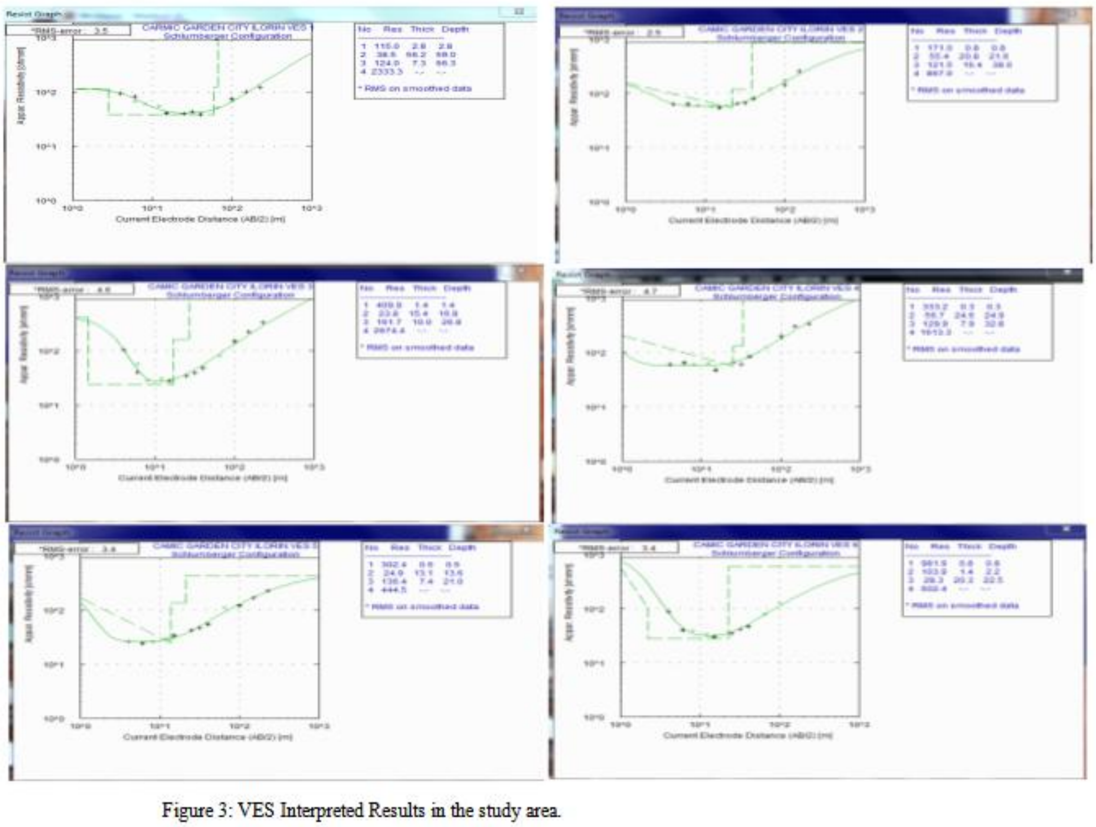

Figure 3: VES Interpreted Results in the study area.

Table 1: Summary of VES results.

VES Station	Layer	Resistivity (Ωm)	Layer thickness (m)	Depth (m)	Curve type	Infer Lithology
VES1	ρ_1	115.0	2.8	2.8	HA	Topsoil (Clayey sand)
	ρ_2	38.5	56.2	59.0		Weathered basement
	ρ_3	124.0	7.3	66.3		
	ρ_4	2333.3	-	-		Fresh basement
VES2	ρ_1	171.0	0.8	0.8	HA	Topsoil (Clayey sand)
	ρ_2	55.4	20.8	21.6		Weathered basement
	ρ_3	121.5	16.4	38.0		
	ρ_4	867.0	-	-		Fresh basement
VES3	ρ_1	409.9	1.4	1.4	HA	Topsoil (lateritic hard pan)
	ρ_2	23.8	15.4	16.8		Weathered basement
	ρ_3	161.7	10.0	26.8		
	ρ_4	2674.4	-	-		Fresh basement
VES4	ρ_1	333.2	0.3	0.3	HA	Topsoil (Clayey sand)
	ρ_2	56.7	24.6	24.9		Weathered basement
	ρ_3	129.9	7.9	32.8		
	ρ_4	1613.3	-	-		Fresh bedrock
VES5	ρ_1	302.4	0.5	0.5	HA	Topsoil (Clayey sand)
	ρ_2	24.9	13.1	13.6		Weathered basement
	ρ_3	136.4	7.4	21.0		
	ρ_4	444.5	-	-		Fresh basement
VES6	ρ_1	981.9	0.8	0.8	HA	Topsoil (lateritic hard pan)
	ρ_2	103.9	1.4	2.2		Weathered basement
	ρ_3	28.3	20.3	22.5		
	ρ_4	602.4	-	-		Fresh basement

Table 1 shows the variations of resistivity and thickness values of the sub-surface layers within the study area. Two sections were constructed in the survey area along E-W (VES1 – VES4) and NE-SW (VES5 – VES6). The section generally revealed the detail of three sub-surface layers; the top soil, the weathered layer, and the fresh basement. The top soil is relatively thin characterised by resistivity values that ranged from 115.0 – 981.9 Ωm and layer thickness of between 0.3 - 2.8 m. It can be deduced that the top soil is made up of clayey sand to the lateritic hard pan, based on the resistivity values of the top soil. The weathered layer beneath the topsoil is characterised by moderately low resistivity values that varied from 23.8 – 161.7 Ωm and thickness of 1.4 and 56.2 m. This layer was considered to be the major aquifer unit of the study area as it reflects moderately low resistivity and appreciable layer thickness, considered fairly good enough to be of hydrogeological significant in the study area. However, the basement terrain of Camic garden is characterised by high resistivity that varied from 444.5 to 2,674.4 Ωm.

VI. Conclusion

This study successfully integrated geophysical techniques involving Very Low Frequency-Electromagnetic (VLF-EM), magnetics, and Electrical Resistivity (ER) for the purpose of delineating conductive/zones of weakness material within the crystalline basement complex environment of Camic garden in Ilorin Metropolitan City North Central basement Complex region of Nigeria.

The results/interpretation of the VLF-EM profiles, and corresponding 2D model combined with magnetics, identified fracture/conductive/ weak zones, which were further investigated using VES. The geoelectric parameters obtained from the vertical electrical sounding data were used to generate geoelectric sections that were relied upon in the assessment of the hydrogeological parameters of the subsurface of Harmony Estate

Area.

The study revealed that the weathered layer constitutes the major conductive unit, rather than fractured Basement and also accounts for the aquifer unit in the study area; with depth to the basement greater than 21 m. The geoelectrical parameters and the geoelectric section obtained were used to evaluate the groundwater potential in the study area. In addition, the weathered layer material accounts for the high VLF-EM anomalous response, rather that fractured Basement as depicted by the VLF and magnetics response (s). The VES employed for this study clearly recognised and identified these conductive zones and layer sequence as delineated in the result obtained. Therefore the use of multi-technique geophysical method becomes very necessary as a result of the complex nature of the North Central Nigeria Precambrian Basement.

Conflicts of interest

The author declares no conflicts of interest regarding the publication of this paper.

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