Hydrogeophysical Investigation of Kusa Mining Hill, Ijero-Ekiti Nigeria, Using Geo-Electrical and Electromagnetic Methods

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Abstract
An integrated electromagnetic and geo-electric study was carried out in some parts of Kusa Mountain, Ijero Ekiti, Southwest Nigeria. Very Low Frequency Electromagnetic (VLF-EM) profiling was measured along eight traverses from which conductive (fractured) zones were established. This enabled the location of 10 points at prominent fractured zones where vertical electrical sounding (VES) were conducted to further reveal the geo-electric parameters. The electromagnetic and geo-electric parameters were analysed, processed and modeled with relevant software in order to obtain the spatial distribution of the groundwater. From the groundwater potential map, the study area was rated as low, moderate and high groundwater potential. This study showed that central to eastern region fell within high groundwater zone. The region around VES 8 and 9 (northeastern flank) was rated as moderate while the remaining part is rated as having low groundwater potential. It is recommended that future exploration and exploitation work for groundwater resources should be concentrated around region rated as having high groundwater potential.

Keywords: Hydrogeology, Electromagnetic, Geo-electric, Resistivity, Groundwater, Curve type

1.0 Introduction

Electrical and electromagnetic techniques have been extensively used in groundwater geophysical investigations because of the correlation that often exist between electrical properties, geologic formations and their fluid content [1- 6]. Groundwater is described as water which exists below the earth surface within saturated layers of sand, gravel and pore spaces in sedimentary as well as crystalline rocks [7]. Ground resistivity is related to various geological parameters such as the mineral and fluid content, porosity and degree of water saturation in the rock. Electrical resistivity surveys have been used for many decades in hydrogeological, mining, geotechnical, environmental and even hydrocarbon exploration [8]. Electromagnetic prospecting has been found useful for reconnaissance survey in groundwater exploration [9], [10], [11].

The knowledge of aquifer parameters is essential for the management of groundwater resources. The parameters which describe the dynamics of aquifers include geometry of the pore space, geometry of the rock particles themselves, secondary geologic processes such as faulting as well as folding and secondary deposition. All these parameters jointly affect the rate and pattern of groundwater flow [12]. Hydrogeophysics has emerged over the years as one of the dominant sub-disciplines in near surface geophysics [13].

In recent years, there has been an increased awareness that subsurface characterization using standard drilling methods which offers a point measurement does not provide information to accurately evaluate the true distribution of geologic parameters beneath ground surface at many sites [14]. The need to tap groundwater wherever possible has therefore increased especially with population growth. The occurrence of groundwater in recoverable quantity as well as its circulation is controlled by geological factors [15, 16]. Therefore, the objective of the present study is to employ surface geophysical techniques involving electrical resistivity and electromagnetic methods for hydrogeophysical investigations.

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2.0 Materials and Methods

2.1 Geology and description of the study area

The study area falls within the basement complex of southwestern Nigeria corresponding to Latitudes $7^o49^I50^{II}$ N to $7^o45^I50^{II}$ N and Longitudes 5^o03^I E to 5^o07^I E (Figure 1) of the Greenwich meridian. It is characterized by the abundance of pegmatites which harbors minerals such as gem-stones and rare earth metals as well as metallic-ores such as lepidolite among other minerals (Figure 2).

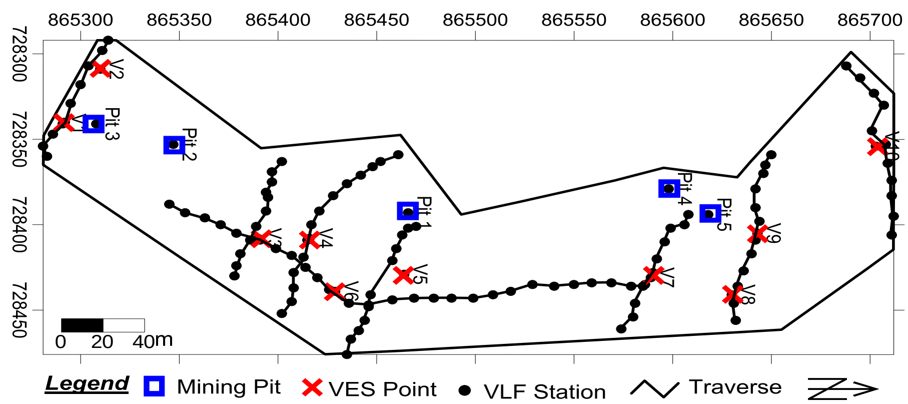

Figure 1: Location map of the study area

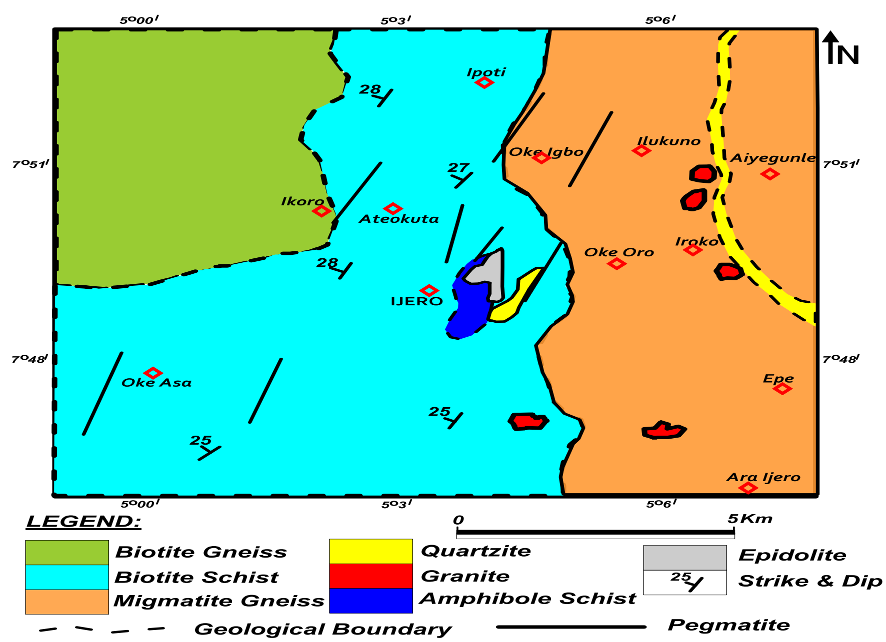

Figure 2: Geological map of Ijero, Ara and Epe towns (After [17])

The basement complex rocks of Nigeria forms a part of the African crystalline shield which occurs within the Pan African mobile belt that lies between the West African and Congo Cratons and South of the Tuareg Shield [18] (Figure 3). It is a polycyclic terrain which suffered its most pronounced deformation and mobilization during the Pan-African age (600 Ma). Grant [19] established an orogenic belt of similar age in the Ghana-Togo-Dahomey area in the Eastern margin of the Craton. Thereafter, it was observed that majority of the radiometric ages obtained fell in the range of 600 Ma, which corresponds to the Pan-African thermo-tectonic event. The basement complex are precambrian rocks occupying about half the landmass of the country and consisting predominantly of folded gneisses, schist and quartzite into which have been emplaced granitic and to a lesser extent, more basic material. They are intruded by the Mesozoic calc-alkaline ring complexes (Younger Granites) of the Jos Plateau and is unconformably overlain by Cretaceous and younger sediments.

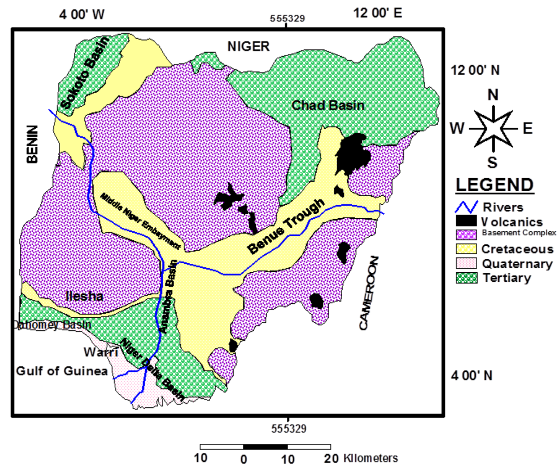

Figure 3: Simplified geological Map of Nigeria (Modified after [20])

Several workers have proposed different lithologic classifications for the basement complex terrain [18, 21]. Three principal subdivisions are recognizable within the basement complex namely the ancient migmatite-gneiss complex, Schist belts and the Pan African plutonic series [22]. The Migmatite-gneiss-complex is the oldest, most widespread and abundant rock type in the Basement [23]. It is of Archean-Proterozoic and possibly undergone polycyclic evolutionary histories. The Nigerian Schist belts comprise of low-grade metasediments and metamorphosed pelitic and psammitic assemblages that outcrop in a series of N-S trending synformal troughs infolded into the crystalline complex of migmatite gneiss. The Pan-African Granites referred to as Older Granite include rocks of wide range of composition varying from tonalite, granodiorite, granite and syenite [24]. The pegmatite from Ijero area form an intrusion into the older rock of biotite gneiss that occupies the central part of the area, covering about three quarter of the total land mass (Figure 3).

2.2 Electromagnetic VLF-EM Survey

The Electromagnetic response was measured using the ABEM WADI Very Low Electromagnetic instrument which measures the in-phase (Real) and quadrature (Imaginary) components of the induced vertical magnetic field as a percentage of the horizontal primary field along the eight profiles. The preliminary survey of the area entails studying of rock outcrops and their distribution on the study area, road networks and major features so as to come up with a location map of the study area in order to establish geophysical traverses. Measurements were taken at 10 m intervals along each of the profiles lines in the West-East direction with lengths ranging from 250 to 350 m (Figure 1). The EM data was interpreted and inverted into a 2-D section using the Karous-Hjelt filtering [25]. The EM profiles were interpreted quantitatively by matching with geophysical models [26, 27]. The quantitative analysis enabled the identification of profiles where positive amplitude of filtered real and/or crossover/inflection point of the raw real as points of anomaly for vertical electrical sounding [28]. The VLF-EM data were presented as maps by plotting filtered real values as contour maps using Surfer 10 software.

2.3 Electrical Resistivity Survey

The equipment employed for the resistivity field data measurements is the resistivity Meter – Model-SSR-MP1. Ten (10) vertical electrical soundings were conducted, using the conventional Schlumberger technique, with half electrode spacing (AB/2) varying from 1 to 65 m. The VES were conducted at selected locations based on the results obtained from the VLF surveys. The apparent resistivity values obtained from the VES were plotted against electrode spacing on a bi-log paper. Quantitatively, the sounding curves were interpreted by partial curve matching technique [29] using a 2-layer master curves and the corresponding auxiliary curves. Layers parameters from this manual interpretation were inverted with the aid of computer aided iteration curve matching techniques using Resist Version 1.0 [30]. The final VES interpretation results were used for aquifer identification and aquifer geoelectric parameter determination from where Isopac map, longitudinal unit conductance map, Basement relief map and Groundwater potential map were generated. In particular, field curve types were examined to identify if the aquifer types show distinct geoelectric characteristics.

3.0 Results and Discussion

3.1 VLF-EM Profiles and Map

Filtered real component readings were plotted as profile, 2D section (Figure 4) and contour map (Figure 5) of the study area. VLF-EM anomalies were delineated as fairly-conductive, conductive, highly-conductive, fairly-resistive and resistive responses at different locations across the study area. The map is characterized with zone of positive and negative anomalies with readings ranging between – 9.9 to + 7.0 %. Positive anomaly is indicative of steeply-dipping linear features such as fractures which are prominent around the central and the northern flank. These features serve as channels for migrating fluids and minerals.

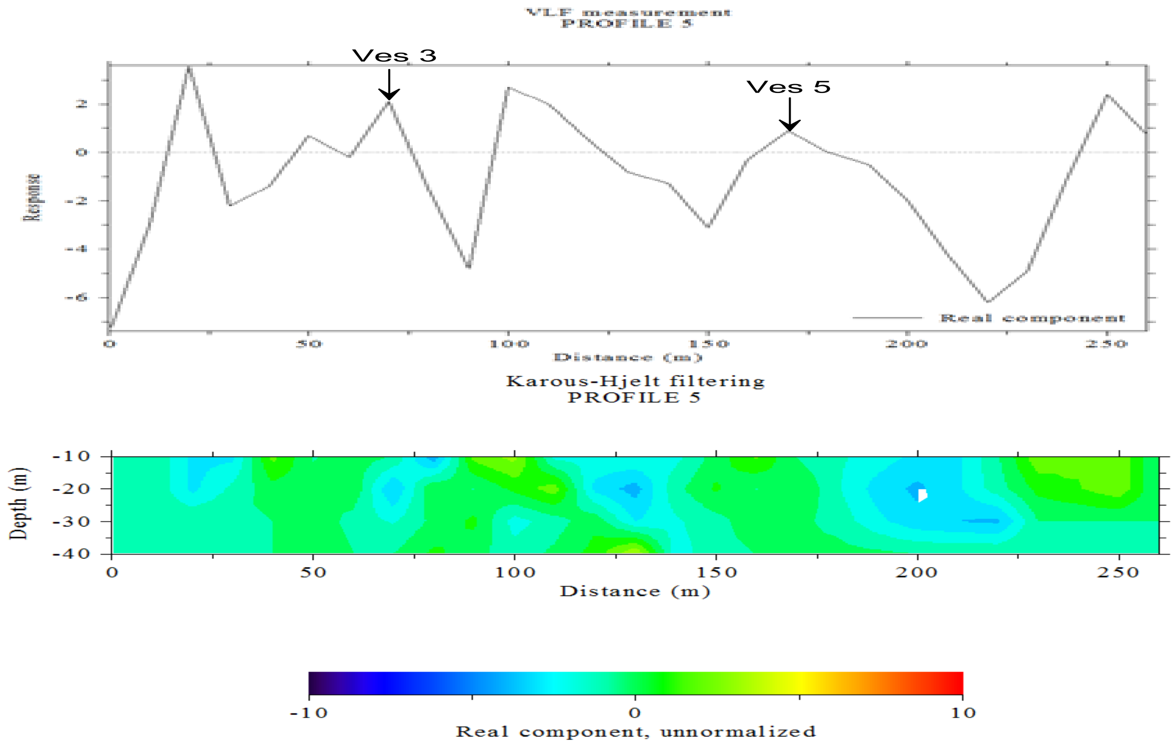

Figure 4: VLF profile and section along traverse 5

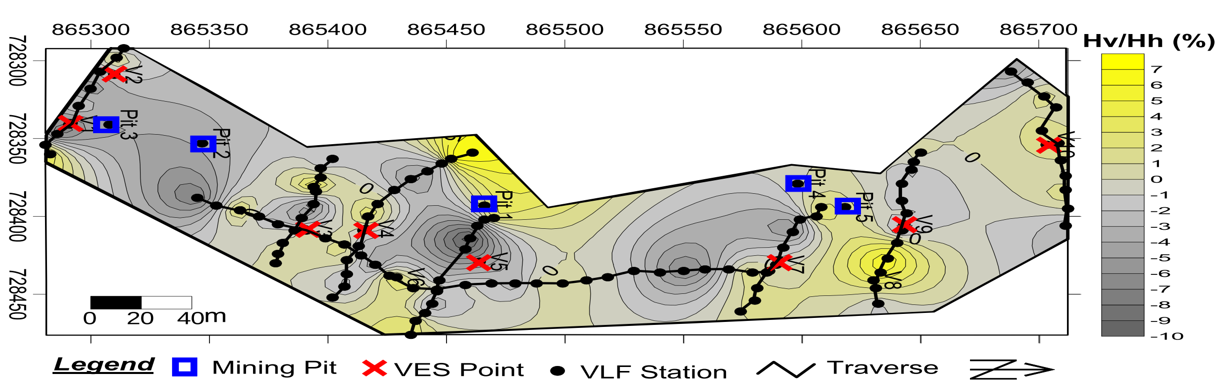

Figure 5: Filtered real component map of the study area.

3.2 Resistivity Sounding Curves and Geoelectric Sections

Curve types identified are H, K, HK, HKH, and AH (Table 1). HKH curve type (Figure 6) has 20%, while each of HK, AH and K curve types have 10% respectively. The predominant curve type is the H curve type (Figure 7) having percentage frequency of 50%. The H and KH curves which are often associated with groundwater possibilities [31] are prominent within the study area. Visual inspection of these curves gave qualitative interpretation of the subsurface resistivity variations. The results of the quantitative interpretation of the VES data are summarized in Table 1.

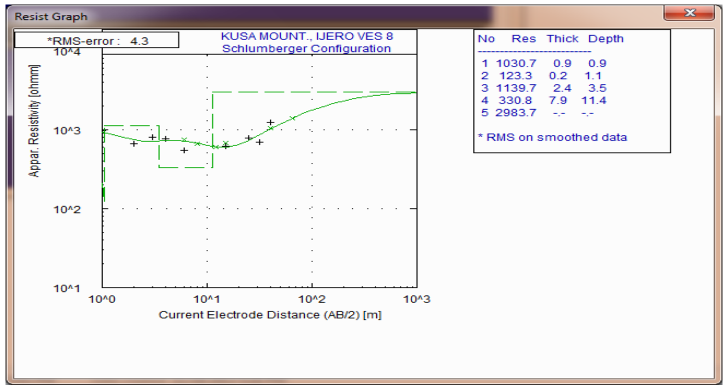

Figure 6: Typical Vertical Sounding HKH-type curve from the study area

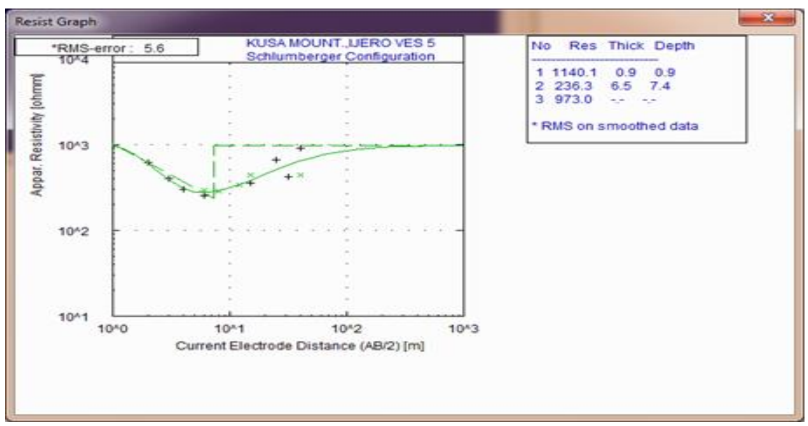

Figure 7: Typical Vertical Sounding H-type curve from the study area

Table 1: Summarized VES result for the study area

VES No.	ρ_1	ρ_2	ρ_3	ρ_4	ρ_5	h_1	h_2	h_3	h_4	Curve Type	Northing	Easting
1	668.4	571	128.5	600.9	-	1	2	1.4	-	H	728341	865291
2	1447.6	415.3	696.4	-	-	0.4	3.1	-	-	H	728309	865310
3	613.1	188.6	1590	350.8	-	0.6	1.3	7	-	HK	728408	865390
4	208.4	362.7	4392.7	248.7	856.8	1.3	6.6	7.8	5.1	AH	728408	865416
5	1140.1	236.3	973	-	-	0.9	6.5	-	-	H	728429	865464
6	424.9	288.7	661.9	168.6	9489.4	0.7	0.5	5.9	4.7	HKH	728439	865429
7	756.3	286.5	1957.7	-	-	0.4	9.7	-	-	H	728431	865589
8	1030.7	123.3	1139.7	330.8	2983.7	0.9	0.2	2.4	7.9	HKH	728441	865630
9	692.2	342.5	1850.7	-	-	0.7	0.9	-	-	H	728405	865643
10	183.3	3906.5	1085.9	-	-	0.5	1.3	-	-	K	728354	865703

Electrical resistivity methods primarily reflect variations in ground resistivity [32]. These variations are due to observable contrast between geo-electric boundaries within the subsurface. Figure 8 is a geo-electric section generated in approximately S - N direction showing the result of VES conducted within Kusa Mining Hill in Ijero-Ekiti. The geo-electric section (Figure 8) shows the variations of resistivity and thickness of geo-electric layers below VES 4, 5, 7 and 8 in that order. The geo-electric sections revealed between three to five subsurface geo-electric layers consisting of topsoil, clay/lateritic soil, mineralized layer, weathered/fractured layer and fresh basement.

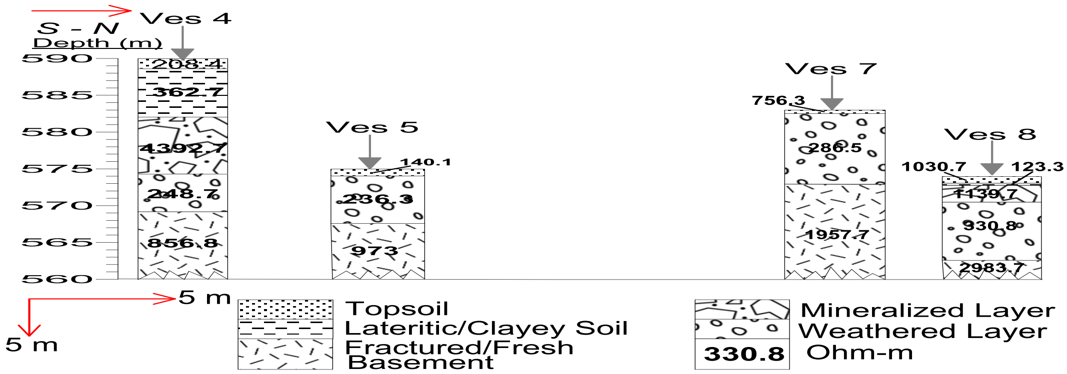

Figure 8: Geo-section of the study area beneath VES 4, 5, 7 and 8

The topsoil which is relatively thin has thickness ranging between 0.4 and 1.3 m while the resistivity values range from 183.3-1447.6 Ω-m. The resistivity values obtained within this layer indicates that the topsoil is composed of lateritic soil and in most part covered by superficial materials. The second layer has thickness ranging from 0.2 – 6.6 m and resistivity values range from 123.3 to 571 Ω-m. This layer predominantly composed of clayey soil.

3.2.1 Geoelectric Characteristics

3.2.1.1 Isopach map of the weathered layer

The weathered/fractured layer has thickness ranging from 0.9 – 9.7 m (Figure 9) and the resistivity values range from 128.5-3906.5 Ω-m. This contains weathered and fractured rocks that are partially saturated with water. This layer forms the major aquifer unit within this study area. Overlying the fresh basement is a layer of highly resistive and mineralized layer with thickness values ranging from 2.4 to 7.8 m while the resistivity values range from 661.9 to 4392.7 Ω-m.

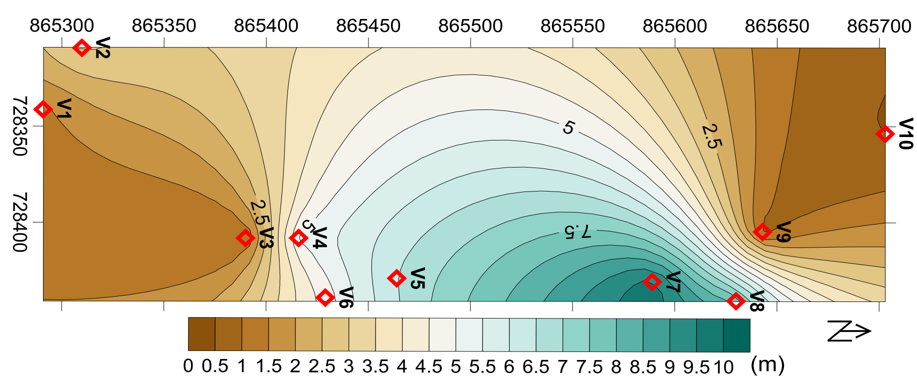

Figure 9: Isopach map of the weathered layer

3.2.1.2 Bedrock Relief map

The bedrock relief map of the study area was produced by removing the overburden thickness contour values from the elevation iso-contour values (Figure 10). The map reflects the topography the bedrock underlying the area. The map shows that the basement structures in the area include both basement ridges and depressions. The basement resistivity values range between 600.9 and 9489.4 Ω-m, it is partially fractured under VES 1, 2 and 5 but very fresh under VES 3, 4, 6, 7, 8, 9 and 10. The bedrock also form basement ridges under VES 1 and 2 with a depression which underlain VES 3, 4, 5 and 6. The depth to bedrock within this study area ranges between 1.6 and 20.8 m.

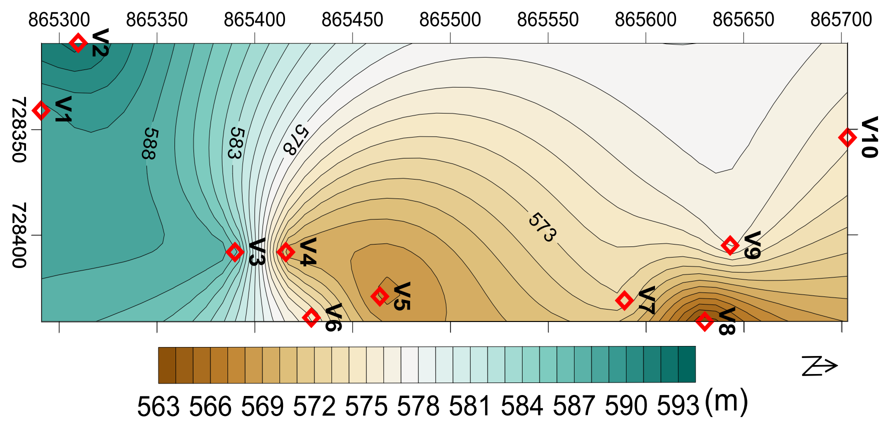

Figure 10: Bedrock relief map of the study

3.2.1.3 Groundwater Evaluation

A horizon is regarded as significant with respect to its water-bearing potential, if it is relatively thick and has low resistivity values which suggest a saturated condition [33].

The groundwater potential of the study area was classified into high, moderate and low potentials. Zones where the overburden is relatively thick (7.4 – 20.8 m) with longitudinal conductance values ranging from 0.01 to 0.028 mhos (Figure 11), significantly thick weathered layer of resistivity values between 169 and 249 Ω-m are classified as high groundwater potentials.

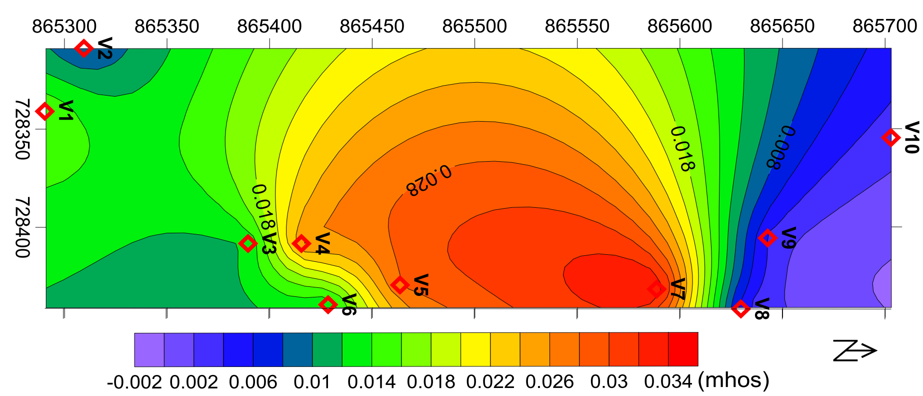

Figure 11: Longitudinal Unit Conductance map of the study area

Zones with thin overburden (thickness between 1.6 and 11.4 m), shallow basement depression, thin weathered layer with resistivity value between 330 and 343 Ω-m and low values of total longitudinal conductance (0.0036 – 0.0046 mhos) are considered to have moderate groundwater potential. Lastly, zones with thin overburden (thickness between 1.8 and 8.9 m), near-surface basement, thin weathered layer with resistivity value between 189 and 415 Ω-m and low values of total longitudinal conductance (0.00306 – 0.0158 mhos) are considered to have low groundwater potential.

The groundwater potential map (Figure 12) shows that about 49% of the entire study area falls within zone rated as having high groundwater potential, while about 43% of the study area constitutes the low groundwater potential rating and the remaining 8% has moderate groundwater potential rating. The aquifer in this area occurs within a basement depression, highly localized and is protected against infiltration of polluting fluid.

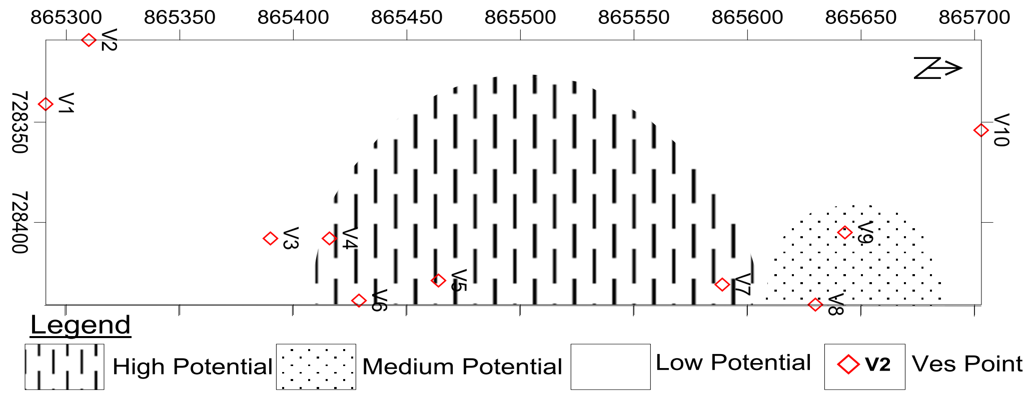

Figure 12**:** Groundwater potential map of the study area

4.0 Conclusion

Integrated geophysical technique has proved very successful and cost effective in delineating structures suspected to have favoured the accumulation of groundwater within the study area. The VLF-EM results revealed fractures (positive anomalies) which are suspected to have served as migration path for percolating fliud. VLF-EM and geo-electric methods jointly reveal potential aquifers within the study area which enable its classification into low, moderate and high groundwater potential zones. Groundwater accumulation is structurally controlled and highly localized. Therefore, future exploration and exploitation programme should be restricted to the high groundwater potential zone while scrupulous geophysical survey should be carried out prior to drilling.

5.0 Conflict of Interest

The authors report no conflict of interest in the publication of this article. The authors alone are responsible for the content and writing of the paper.

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