Integrated Electromagnetic and Magnetic Survey for Hydrogeophysical Characterization of Ijapo Housing Estate, Akure.

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ABSTRACT

Very Low Frequency Electromagnetic (VLF-EM) and Ground Magnetic studies were carried out in Ijapo Housing Estate, Akure, with the aim of delineating hydrogeologic associated structures. The area is underlain by the Precambrian Basement Complex rocks of southwestern Nigeria. The VLF-EM profiling was undertaken along 19 traverses with eight traverses aligned NW – SE and eleven aligned SW – NE. The traverse lengths varied from 180 to 1,200 m. The Ground Magnetic data were acquired along 35 traverses of lengths ranging from 120 to 1,060 m. Nine of the traverses were oriented E – W, thirteen traverses NE – SW while the remaining thirteen were oriented NW – SE. The VLF-EM readings vary from – 110.3 to + 99.9 % in the filtered real and imaginary components. Areas with positive peak anomalies are considered as probable fracture zones. The VLF-EM depth-structure map enables the classification of the area into zones of shallow and deep fractures. The western and eastern flanks are situated within zones of deep fractures. The relative magnetic values vary from -1290.38 to +835.38 nT. The low magnetic readings are presumably indicative of concealed linear features. The depths to the top of structures delineated vary between 14.5 and 46.6 m. The magnetic depth-structure map enabled the classification of the study area into shallow and deep fracture zones. The integrated result of the VLF-EM and the magnetic methods show that the deep structures delineated with the VLF-EM method coincides fairly well with zones where deep fractures were delineated with the magnetic method.

Keywords: *Electromagnetic, Magnetic, Hydrogeology, Structures, Depths*

1. INTRODUCTION

The successful exploration and exploitation of groundwater requires a proper understanding of its hydrogeological characteristics [12]. Careful studies that are supported by improved drilling techniques yield very favorable results even in the problematic areas of the basement complex [7]. Geophysical methods are important in investigating near surface formations and modeling of aquifer units for groundwater development. Notable among the methods are the Electric resistivity, Electromagnetic, Seismic refraction and Magnetic methods [3].

The aquifer in the basement terrain is not only inhomogeneous but also localized hence; the description of aquifer parameters in this geological terrain may be difficult [6]. In such terrain therefore, a thorough geophysical investigation must be carried out for optimum siting of viable boreholes for groundwater development.

EM method is more relevant in the delineation of near surface fractures than in the estimation of overburden thickness, because their anomalies aremore influenced by the conductivity of the overburden (weathered layer) than the thickness [9].

Therefore, the VLF-EM was adopted as a fast reconnaissance tool to map possible linear fractures such as faults and fractures zones while the magnetic method was used to investigate prominent magnetic anomalies andprovide a structural image of the concealed structures.

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Research work has been previously carried out in Ijapo Estate Akure to establish geoeletric parameters, the groundwater potential and susceptibility to environmental pollutions [1], [8]. In both studies 30 vertical electrical soundings were carried out across the entire estate. However, in this survey the VLF-EM and the magnetic methods were adopted.

1.1 Geology of the Study Area

The geology of the study area can be explained within the context of the geology of the Precambrian basement Complex of southwestern Nigeria which form a part of the basement complex of Nigeria[11] (Fig. 2).Ijapo Estate is situated on a gently undulating terrain with elevation between 330 and 364 m above mean sea level. The area lies in the tropical rain forest with mean annual rainfall of about 1300mm. The annual mean temperature is between 18 and 33℃. River Osisi cut across the estate at the central part and flows south into River Ala.Ijapo Estate as at the time of this study is the largest residential estate in OndoState. It is located northeast of Akure town within longitudes 5°12.307' E and 5°16.552' E and latitudes 7°15.859' N and 7°16.552' N. The estate h osts some commercial centers such as petroleum products sales outlets, hotels and guesthouses and shopping malls.Residents in the estate, depend largely on hand-dug wells and motorized boreholes for domestic and commercial water supply (Fig. 1). Hence, there is need to investigate the area in order to evolve the hydrogeologic setting within the estate. In this survey, the electromagnetic (VLF-EM) and the Ground Magnetic methods were therefore adopted.

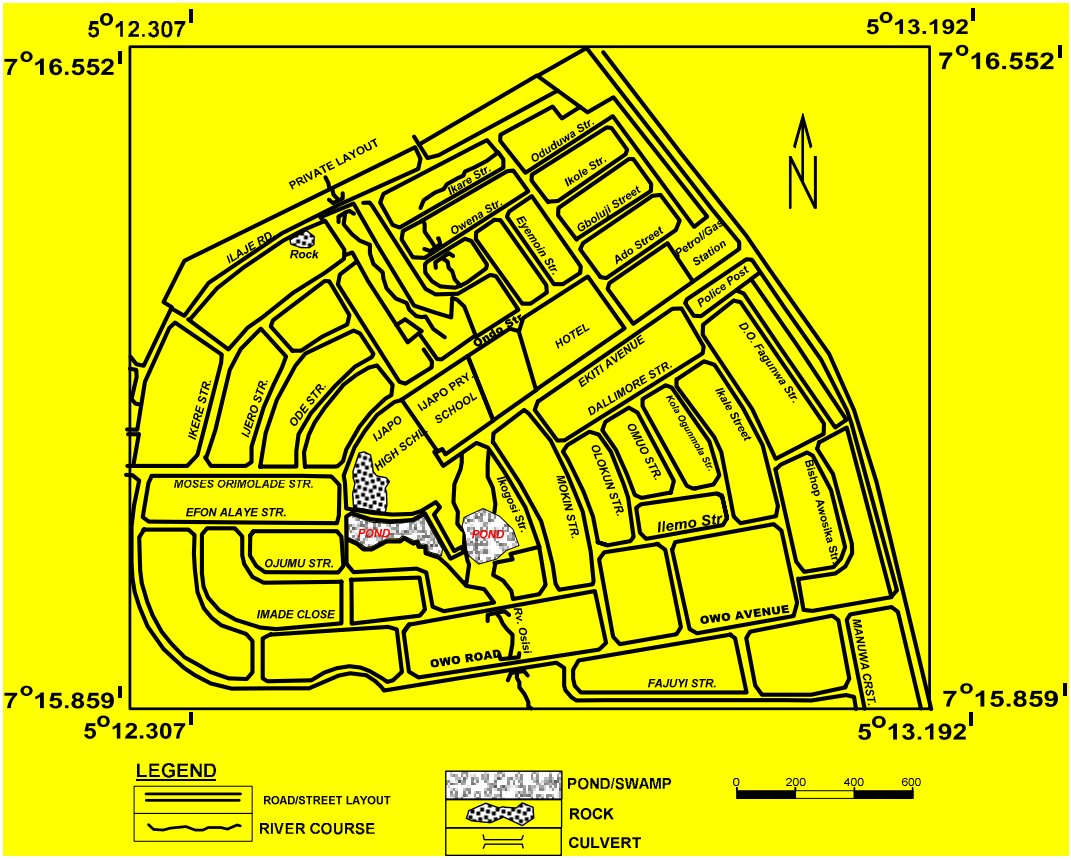

Fig. 1: Base map of the study area showing the street layouts.

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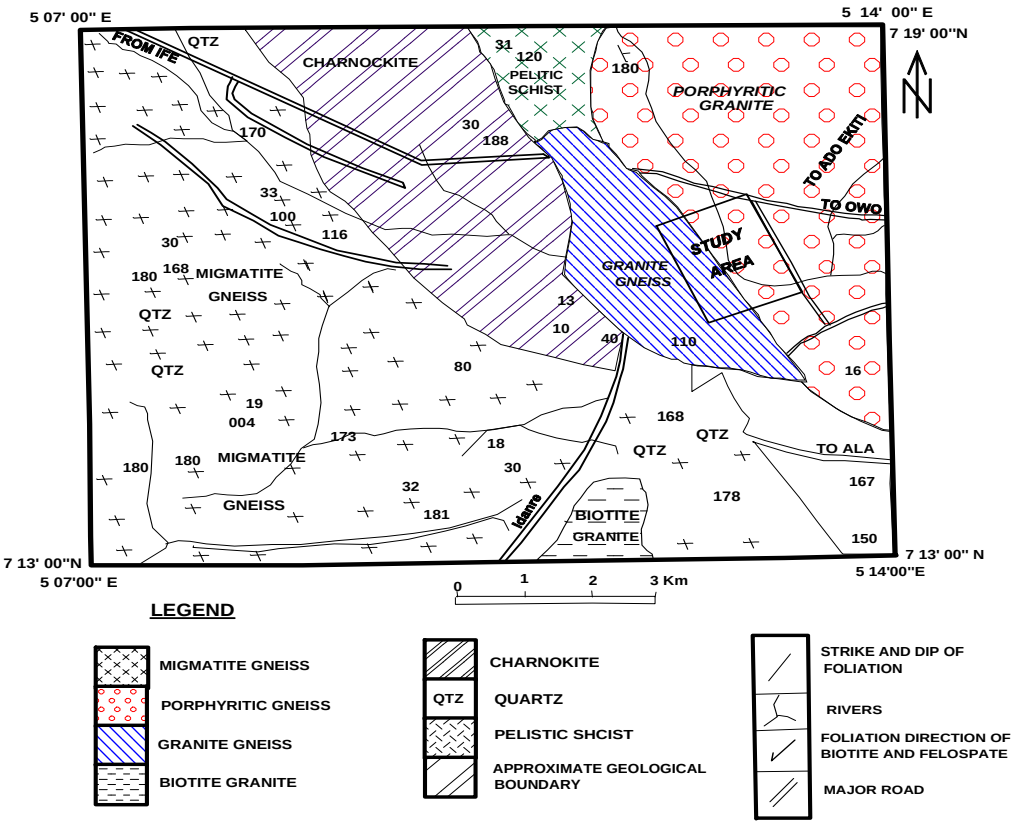

Fig. 2: A generalized geological map of Akure (after Owoyemi, 1996)

2. MATERIAL AND METHOD OF STUDY

The VLF-EM profiling was undertaken at 25 m station interval on 19 traverses. The traverses lengths vary from 180 to 1,200 m. The Ground Magnetic data were acquired on 35 traverses of lengths ranging from 120 to 1,060 m at 20 m station intervals. ABEM-WADI VLF instrument was utilized for Electromagnetic data acquisition while Proton Precision Magnetometer was used for magnetic data acquisition. 2-D filtering operation was carried out on VLF-EM data, while the Magnetic data were interpreted quantitatively using deconvolution process. The generated profiles, sections and maps enabled the delineation of concealed structures.The integration of the results of VLF-EM and Ground Magnetic survey enabled the hydrogeophysical characterization of the study area.

3. RESULTS AND DISCUSSION

3.1 Filtered Real Component Map

WADI VLF-EM detect the ratio (in %) between the vertical and the horizontal components. This is an indication of the degree of inhomogeneity of the subsurface. The real component readings were plotted as a contour map of the study area (Fig. 3a). The map was characterized with zone of positive and negative anomaly, the readings range between - 50 to +35 %. The zones with positive anomaly occur as patches and are more prominent around the western part, also around the central region and the northern flank. VLF-EM anomalies were delineated at twenty-nine (29) locations within the study area.This indicates that these areas have concealed geological structures suspected to be linear steeply-dipping fractures that favoursgroundwater accumulate.

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Fig. 3a: Filtered real component map of the study area

3.1.1 VLF-EM Depth-Structure Map

This map was obtained by computing the depths and locations of fractures delineated by VLF-EM methods across the entire study area. The map enables the classification of the study area into two, based on the depth of the delineated fractures i.e. the shallow-seated and the deep-seated fractures (Fig. 3b). The western and eastern flanks of the study area are classified as shallow-seated fracture zone; it covers Ikere, Ijero and Ode Street on the western flank and Dallimore, D.O. Fagunwa and Ikale and Kola Ogunmola Streets on the eastern flank. The central part is classified as moderately deep-fracture zone; it covers Ondo Road, Mokin Street, Ilemo Street, EfonAlaye Street and Ode Street. The northern and southern flanks are classified as deep-fracture zone. Most of the deep fractures delineated fall within the central region.

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Fig. 3b: VLF-EM depth-structure map of Ijapo Housing Estate, Akure

3.2. Magnetic Depth-Structure Map

This map was obtained by computing the depth and location of source of magnetic anomalies across the entire study area. Close observations of the map enable the characterization of the study area based on the depth of occurrence of the identified structures. Low magnetic intensity zones were delineated by the freeware eulerdeconvolution software producing a steeply dipping interface and are classified as the probable fracture zones for groundwater accumulation. The zone with concealed shallow features covers a major part of the study area, underlining Ojumu Crescent, EfonAlaye Street, Akoko Avenue, D.O. Fagunwa Street, Owo Avenue, Ondo Road, Mokin Street, Henry Fajemirokun 1, Ekiti Avenue, Eyemoin Street and Olokun Street. The remaining part of the study area i.e. region around Owo Avenue, Fajuyi Crescent, Henry Fajemirokun Street 2, Ilaje Road, parts of Imade Street, Moses Orimolade Street, Ondo Road, Ode Street, Ikole Street, Dallimore Street, Ikale Street and Owena and northern part of Ondo Road are all classified as zones with deep-fractures (Fig. 4). Magnetic anomalies were delineated at one hundred and seventy-one (171) locations from the ground magnetic profiles.The deep structures are oriented NW – SE.

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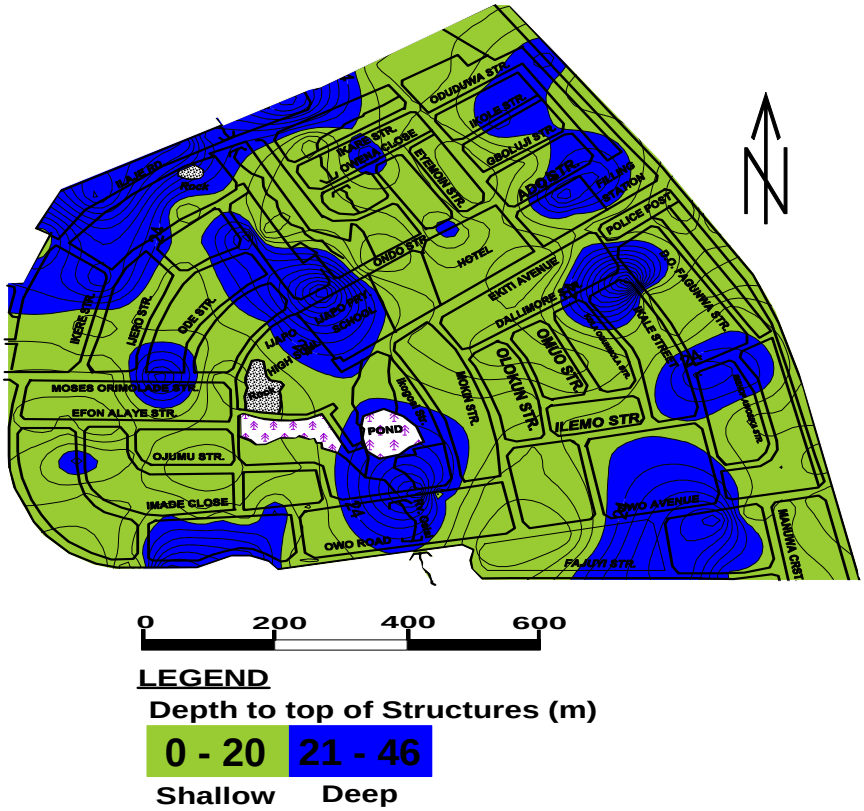

Fig. 4: Magnetic depth-structure map of the study area.

3.3. Typical profile and sections of ground magnetic and VLF-EM

Ground magnetic profiles, geomagnetic sections, VLF-EM profiles and 2D-sections were produced from the data acquired through the Ground Magnetic and VLF-EM methods respectively.
The qualitative interpretation of the ground magnetic and VLF-EM profiles reveals that the varying amplitude of the anomaly signature as well as the positive peak filtered real values and cross-over points suggest possible fracture zonesbelieved to be zones of groundwater accumulation.Quantitatively, the magnetic profiles were interpreted one by one using the automated freeware eulerdeconvolution techniques. Quantitative interpretation of the VLF-EM data involve the generation of the VLF-EM sections with the use of KarousHjelt(KH) filtering software which allows for the estimation of fracture length within the zone.Detailed descriptions of typical profiles and sections generated along a selected traverse are given below.

Figure 5 (a – c) is a typical profile and sections of ground magnetic and VLF-EM surveys along Imade Street. The traverse length is about 1,000 m and is oriented W – E. Low magnetic intensity values are observed at distance ranging from 5 to about 100 m and then from 300 to 800 m. Magnetic intensity contrast are observed between + 29.1 and – 14.5 nTat distance between 150 and 220 m, - 25.1 and + 13.5 nT at distance ranging from 250 to 280 m and + 29.1 and – 29.1 nT at distance between 850 and 950 m respectively. These identified zones of low magnetic intensities and magnetic intensity contrast are the probable fracture zonesbelieved to accumulate groundwater. The geomagnetic sections produced from the depth estimated by the automated freeware eulerdeconvolution technique enabled the delineation of five probable fracture zones with estimated depth of 19 m at distance 250 m, 20 m at distance 400 m, 20 m at distance 425 m, 20 m at distance 700 m and 21 m at distance 900 m respectively. The probable fracture zones all occurred within the granite gneiss.
The VLF-EM profile shows positive peak filtered real values at 100 m, 400 m and 600 m and cross-over points at distance 50 m, 360 m, 700 m and 850 m which represent the conductive zones along the traverse. The corresponding 2D-section reveals conductive zones at distance ranging from 60 m to 100

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m, 320 m to 400 m and 620 m to 780 m respectively. The depth to the top and bottom of the conductive/fracture zones obtained from the 2D-section is between 20 m and 75 m corresponding to fracture lengths of 45 m, 20 m to 100 m corresponding to fracture length of 80 m and also 20 m to 100 m corresponding to fracture length of 80 m respectively.The 2D-inverse models reveal the depth to sources of anomalies which ranges between 37.5 and 100 m.

The interpretation of the different sections and profiles produced from the processing of results obtained from the ground magnetic and VLF-EM reveal high degree of fracturing along this profilesuggesting zoneof high groundwater potential.

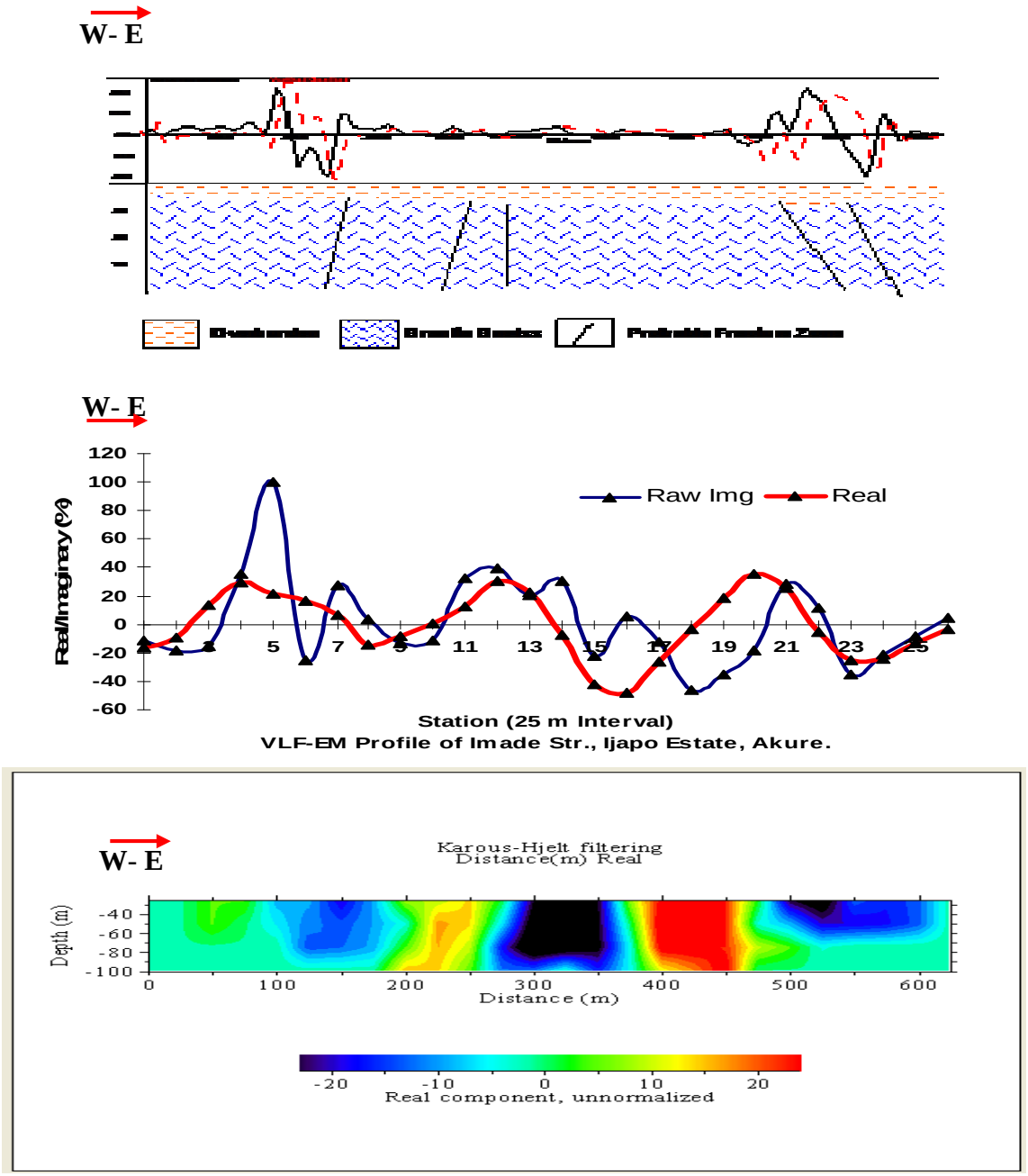

Fig. 5:(a)Ground Magnetic profile and Geosection (b) VLF-EM Profile and (c) 2D-inverse model of Imade Street, Ijapo Estate, Akure.

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3.4.Magnetic and Electromagnetic Synthetic Map

The integration of results of VLF-EM and Ground Magnetic surveys enabled the hydrogeophysical characterization of the study area. The VLF-EM depth-structure map is characterized by zones of shallow and deep-seated fractures, thus classified as the low and moderately-high water bearing potential zones. The western and the eastern flanks are marked with high altitudes which also coincide with zones of shallow-seated fractures. The depth to top of structures within these zones is below 40 m. The shallow buried structures may be due to the presence of ridges or/and thin overburden layers which may not favour groundwater accumulation within these zones. On the other hand, the northern, southern and the central regions are characterized by low altitude and deep-seated structures and relatively thick overburden, thus forming the groundwater collection center within the study area.
The ground magnetic depth-structure map is characterized by zones of high and low water bearing potential as a result of the deep and shallow fractures delineated within the study area (Fig. 6). The deep structures are oriented NW – SE coinciding with the trend of the water course within the study area (Fig. 1). The shallow structures are buried within 20 m below the ground surface while structures buried within 21 – 46 m are classified as deep-seated structures. The deep structures occur at regions with depression, thick-overburden and river course thereby forming groundwater collection centers of the study area.
It can be concluded that the structures delineated occurred at the basement-overburden interface. The VLF-EM serves as a good reconnaissance tool for the Ground Magnetic survey. Most of the deep structures delineated with the Magnetic method fall within zones classified as deep-fractured from the VLF-EM method.

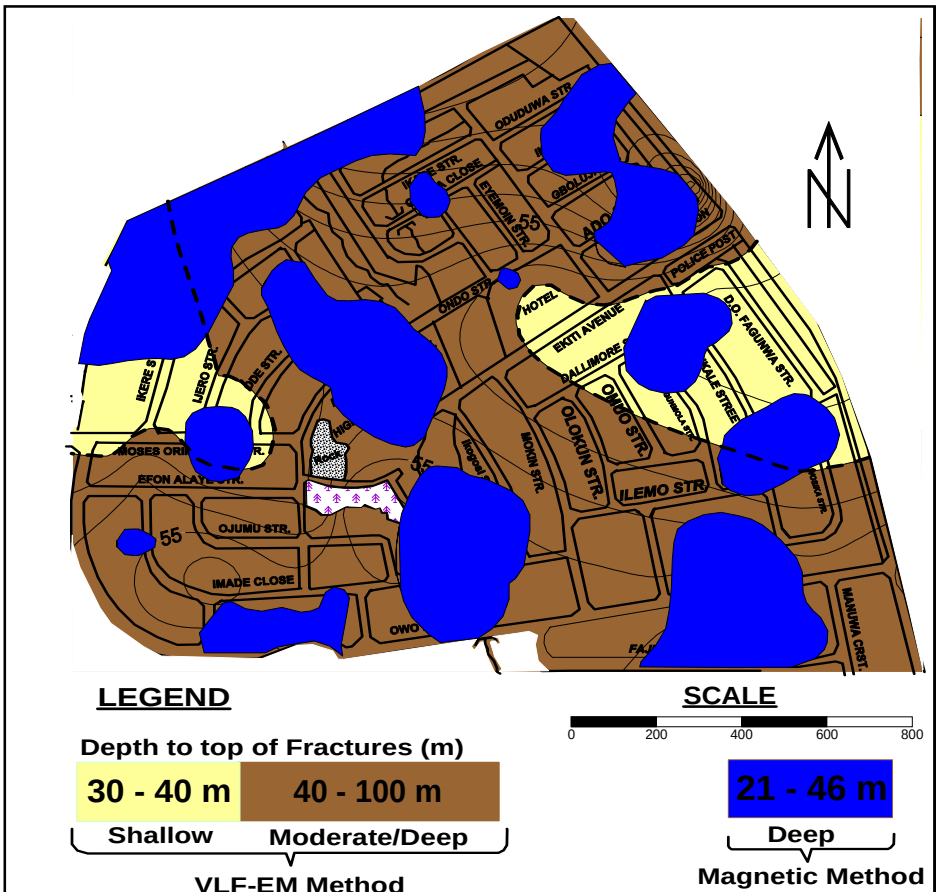

Fig. 6: Magnetic and Electromagnetic Synthetic map of the study area

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Table 1: Summary of integrated ground magnetic and VLF-EM results

Traverses	Traverse Length (m)	Traverse Orientation	Geophysical Method Adopted	Location of Fracture (m)	Depth Top of Fracture (m)	Geology of the area
Dallimore Street	375	SW – NE	Ground Magnetic	75*	25	Porphyritic Gneiss
				245	30	
				275	25	
				360	19	
			VLF-EM	75*	25	
				275*	25	
Imade Street	1,000	W – E	Ground Magnetic	250	19	Granite Gneiss
				400*	20	
				425	20	
				700*	20	
				900	21	
			VLF-EM	100	20	
				400*	20	
				700*	20	
				850	20	
Fajuyi Street	450	W – E	Ground Magnetic	100*	25	Porphyritic Gneiss
				225	30	
				275	25	
				405*	25	
			VLF-EM	105*	25	
				300	25	
				420*	25	
Owo Avenue	1,100	W – E	Ground Magnetic	260	15	Granite Gneiss & Porphyritic Gneiss
				550	24	
				620*	26	
				660	30	
				885	19	
				975	16	
			VLF-EM	325	25	
				625*	25	
				875	25	
				1,025	25	
Ondo Road	900	SW – NE	Ground Magnetic	50*	15	Granite Gneiss & Porphyritic Gneiss
				200*	14.5	
				410*	41.6	
				480	16.7	
				650	23.5	
				700	23.5	
				775	16.7	
			VLF-EM	50*	25	
				200*	25	
				400*	25	
				775	25	

Note: ***The asterisk values are locations where fractures are delineated by the two methods.***

4. CONCLUSION AND RECOMMENDATIONS

Geophysical techniques have proved very successful and cost effective in delineating fractures or weathered zones within zones underlain by Crystalline Basement Complex rocks. The VLF-EM and Ground Magnetic methods enabled the delineation of dipping and steeply dipping linear conductors that are suspected to be fractures of varying length within the study area.Profiles, sections and maps were generated to delineate concealed structureswhich harborgroundwater resources within the study

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area.Alinear filter - Karous and Hjelt Filter (KHF) was used to interpret the VLF-EM data toproduce 2D-inverse model which serves as a useful tool for estimating the depth to source of anomaly.The 2D-inverse models reveal the depth to sources of anomalies which ranges between 37.5 and 100 m. Structures less than 40 m are grouped as near-surface structures while those above 40 m are grouped as deep-seated structures, most of which occurred within the near-surface structures zone.Freeware Euler Deconvolution software was used to analyze magnetic data obtained within the study area. The magnetic profiles give an estimate of depth to magnetic sources ranging between 14.32 and 46.54 m. Zones with fractures of length less than 21 m are classified as near-surface structure zone while areas with fractures longer than 21 m are classified as deep-seated structure zone. The Magnetic depth-structure map enables the classification of the groundwater potential of the study area based on the depths of the identified structures.Ijapo is a highly fractured area as revealed by the results obtained from the two geophysical techniques employed for the research. The trends of the identified fracture zones are mostly in the NW-SE, the orientation of the structures agree with the physical trend of the river course as shown on thebase map of the study area(Fig. 1). Groundwater occurrence can therefore be said to be structurally controlled. In conclusion, the results of these two techniques correlate with one another; they are complimentary and the integration produced a better resolution.

It is recommended that pre-drilling geophysical survey be carried out prior to sitting of water boreholes.Groundwater development programme should be limited to deep-fractured zones of the study area i.e. the high groundwater potential zone.Where necessary, confirmatory drill-holes should be sited at some selected locations e.g. conductive zones, deep-fracture zones, e.t.c.It is therefore pertinent to sink boreholes beyond the regolith layerfor optimum yield of groundwater.

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