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Significance of using electromagnetic (EM) method for groundwater investigation in Sedimentary and Basement terrains: a review

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Abstract: This review article briefly explores the significance of electromagnetic method among other methods used in groundwater investigation. Groundwater investigation can be carried out using various methods such as seismic, magnetic, electromagnetic (EM), electrical resistivity, gravity, remote sensing. Each with its peculiar implication. This paper discusses the effectiveness of EM in detail subsurface investigation for groundwater exploration through an extensive review of the literature. Relevant literatures within the last three years were considered to understand the groundwater features using the EM method over other techniques. Studies using other methods were also examined to compare their reliability in groundwater studies to EM method. This study discovered that the EM method is cheaper, faster and of higher precision in identifying groundwater bearing formation and possible structural control of which the rest technique do not possess such attribute. On this note, there should be a growing interest in the use of EM techniques for groundwater mapping, which gives credible and classification of structural features of both basement and sedimentary terrain groundwater characteristics.

Keywords: Geophysical Methods, Groundwater, Electromagnetic Method, Resistivity Methods

1. Introduction

The development of any society depends entirely on the availability of basic amenities such as water, good road network and electricity [1]. Water is essentials to life, and therefore its importance cannot be overemphasized [2]. The need for good quality water has been a source of concern in the world we live in today. The increase in population and industrialization, as well as contamination of surface water, is putting more and more pressure on water resources [3, 4]. Singh [4] discovered that there is more dependence on shallow dug wells and streams which are mostly seasonal and cannot be sustainable throughout the year.



Therefore, it is necessary to identify substitutes to complement surface water and the water, as mentioned above sources. The alternative is referring to a significant source of portable fresh water which lies beneath the earth surface popularly known as Groundwater. Researchers such as [5] have proven that groundwater is an alternative for man use. Due to its abundance, this leads to the increased pressure on groundwater to meet the daily demand for water supply [6].

As it is referred to as the water beneath the earth surface, it can be found both in sedimentary and basement terrain which forms the two broad geological terrains in Nigeria [7]. Exploration of groundwater in sedimentary terrain can be of little or no complexities. However, Adeyeye [8] observed that in crystalline basement terrains, the occurrence of groundwater is complex and erratic. Omeje [9] experienced a failure of groundwater investigation in basement terrain using resistivity method in 12 different locations within Gosa area of Abuja.

Seismic refraction techniques, long used in exploration for minerals and petroleum, can be effectively used in groundwater modeling studies. Groundwater aquifers in New England have large seismic velocity contrasts at major hydrologic boundaries; consequently, this technique can readily define the geometry of the aquifer but does not identify the groundwater bearing formation [10]. Sultan used total intensity map reduced to the pole to evaluate the detail subsurface features of magnetic anomaly and basement depth for groundwater potential [11]; it did not in any way indicate the possible groundwater depth or the exact position of the water bearing formation.

Groundwater is available at different proportion, in various rock types at various depths. It is also experiential that the use of the geophysical techniques is used in the exploration of this portable fresh water. Groundwater resource mapping and water quality evaluation is increased due to the rapid advances in EM methods [4]. There are several techniques employed in groundwater investigation, which include the seismic, magnetic, electrical resistivity, electromagnetic, gravity, remote sensing among others [4, 5]. Gravity and magnetic method are one of the oldest methods, electrical resistivity method is commonly used, and the seismic method involves the use of explosive as a source of the signal of which to estimate and classify the groundwater features in basement is sometimes difficult.

Hence, the aim of this study is to evaluate various techniques that have been used in investigating groundwater, while focusing on the significance of using an electromagnetic method.

2.0 Method

To review the geophysical applications in search for groundwater, several geophysical information used for this study were collected from previous literature published elsewhere within the last three years. Materials were sorted according to their relevance, aligned with the study aim. Data such as the lithological layers, thickness and depth of each layer's resistivity and velocity were extracted and collated from the materials sorted. During this review, the following methods can be identified, as shown in the table below

Table 1: Various methods used for groundwater investigation

Method(s)	Equipment	Basic mode of operation	Citation(s)
Electrical resistivity	Multi-electrodes resistivity meter	Electric current is injected into the subsurface using electrodes. Multi-electrodes are arranged using any suitable array (Wenner, Schlumberger, dipole etc) using	[2]

		preferred electrode spacing.	
Seismic	Seismogram	Artificial explosives (transmitter) are used in this technique. Geophones (receiver) are laid at a specific interval, connected to the seismogram using cables. The seismograph records the wave received from the geophone.	[3,12]
Magnetic	Magnetometer	Involves the use of magnetic spin which is an essential property of an atom. It has an angular momentum, without rotating physically, and its related magnetic moment.	[4]
Electromagnetic	Ground-penetrating radar EM-34, 55,	An electromagnetic pulse is emitted into the subsurface using a transmitting antenna and reflected from target. The reflected wave signal are detected by the receiving antenna.	[12]

3.0 Results and Discussion

3.1 Various Techniques for Groundwater Investigation

Table 2 shows the various techniques among many that have been used in groundwater investigation [7, 8, 1]. From previous experiments, it can be shown that the most widely used technique is the electrical resistivity method which gives information about the various lithological layers of the earth crust. The depth of each layers and the thickness of the layer and the electrical resistivity of the subsurface layers are revealed through probing of electrodes. Geophysical electrical resistivity techniques are based on the response of the earth to the flow of electrical current [4]. Through the interpretation of this information, the depth of water can be determined. Injection of electrodes into the subsurface is involved when dealing with electrical resistivity method. Whereas in the EM method, no galvanic coupling with the ground is required, less sensitive to non-unicity in the solution than the resistivity

The seismic method [3, 12] involves the use of both reflection and refraction method in determining the transverse path of waves. The distance in which the wave travels through different lithological units with respect to time can be related in terms of velocities [3]. However, this method is suitable for shallow geophysical exploration [4]. Magnetic resonance is also another geophysical application for determining aquifer properties such as porosity, permeability and water content. This gives information on the hydraulic subsurface aquifer properties [4].

Remote sensing involves the use of reflected electromagnetic energy by the sun or energy reflected emitted by a device such as radar. However, integration of various conventional methods with Remote sensing (RS) techniques and Geographical Information System (GIS) technology helps to increase the accuracy of results in the delineation of potential groundwater zone (Adeyeye et al., 2019). The ground-penetrating radar GPR is also an electromagnetic energy-based method. For GPR survey, an electromagnetic micro pulse is emitted into the earth by a transmitting antenna [12].

Among these methods, the electromagnetic method enables measurements to be collected rapidly and with a minimum number of field personnel. Most electromagnetic instrumentation commonly used has

the capability to electronically store data. This capability provides for a greater degree of accuracy than older analogue-readout instruments and also allows for faster data collection.

Furthermore, since electrodes are not used, EM surveys are faster and cheaper operation-wise, but the cost of equipment is relatively high than conventional resistivity method. Also, qualitative interpretation of EM anomalies is complex and penetration not very great if very conductive superficial layers are present.

Besides, most of the other geophysical instruments with features of a complex operation, heavyweight, too complex post-data processing, the users must be many-year experienced technicians. They have to be professionally trained before the operation of electricity exploration instrument. The EM method of natural Electric field geophysical exploration for groundwater detector is easy, the latest method as well as the output measurement data, curve graph and profile map by USB cable to the computer for analysis and making a geological conclusion as shown in Figure 4.

Table 2: Observation of the investigation of groundwater from different authors

Author (s)	Method	Location	Lithology	Depth of each layer (m)	Thickness (m)	Resistivity (Ω m)	Velocity (m/s)
[2]	Electrical resistivity method	Basement of kastina state Nigeria	1. Top layer 2. weathered layer 3. fractured layer 4. fresh basement layer.	13.2-36.6 0.406-20 0.19-111 0.366-2.23	6.06-17.3 0.0409-20 0.19-107 0.36-1.22	101-1573 2.36-3040 190-3194 26.3-896	-
[3]	Seismic refraction	Brunei Darussalam, located in the North of Borneo	1. braided river deposits. 2. weathered sandstone	-	-	-	1400 1800
[1]	Electrical method Vertical electrical sounding (VES)	Paggo, Minna.	1. Topsoil, 2. weathered layer, 3. fractured layer 4. and fresh basement layer			67.5–835.1 108.0-939.7 118.9–242.0 1041.0–9704.0	
[12]	Refraction seismic and GPR survey	Akamkpa area, Cross River State	1. weathered layer top soil 2. lateritic rocks 3. sand/sands to 4. granite	0.5 – 1.8 13.4 - 9.8 1.8 – 18.2 18.2 below.	- - - -	- - - -	300-380 624 – 746 1058- 1204 up to 1805

[4]	Ground magnetic resonance (GMR) and resistivity meter	Solanipura m and Paniyala India	1. Sand, clay, fresh water 2. Silty-sand, clay freshwater 3. Clayey sand 4. Sand and freshwater	0-5 5-10 10-15 15-20	-	-	-
[7]	electrical resistivity method	Basement Complex Rocks of Iseyinsakio yo state	1. Topsoil 2. lateritic layer 3. Weathered /fracture layer 4. Fresh rock	-	0.4 -3.6 4.5 – 20.7 7.7 – 55.2	55.5 -749.7 153.3- 862.0 15.6 – 698.9	-
[9]	electrical resistivity method	Basement Complex rock of Abuja, North Central Nigeria	1. Topsoil 2. lateritic layer 3. Weathered overburden /racture layer 4. Fresh rock	0 -0.5 0.5– 0.7 0.7- 3.4 3.4 – 16 16 - 42		83 438 63 2067	

3.2 Comparing Defferent Profiles Plots of Rsistivity and EM Methods for Groundwater Investigation from Previous and Current Studies

Figures 1, 2, 3, and 4 presents different profile plots to validate the robustness of EM over vertical electrical sounding (VES) of Schlumberger configuration which is said to be the best configuration for groundwater investigation in resistivity methods. In Figure 1, it can be observed that the depth to the aquifer is about 42.7 m with a resistivity value of 68.3 Ωm [9]. Figure 2 shows different VES profile plots for groundwater investigations in Abuja. In the study area, each report was carefully used to drill borehole which was unproductive with all the good water bearing formation features from the VES profile plots. The same VES values were used to create 2D cross-section as shown in Figure 3 to understand the detailed subsurface features that could be responsible for dry aquifers after pronouncing groundwater characteristics [13]. Without further integration of the data, it may not be possible to identify the cause of abortive borehole drilled to the estimated depth from the VES report. Figure 4 presents the Iso-contour map of the EM profile indicating the aquiferous zone with closures and the position of drilling with a clearer depth to the water bearing formation ranging from 270 to 300 m. It shows that the aquifer thickness is about 30 m. With these characteristics of high resolution of Iso-contour map from EM, clearer depth estimation and aquifer thickness, it has shown robust features to prove to be more detailed, easy interpretation than other techniques for groundwater investigation.

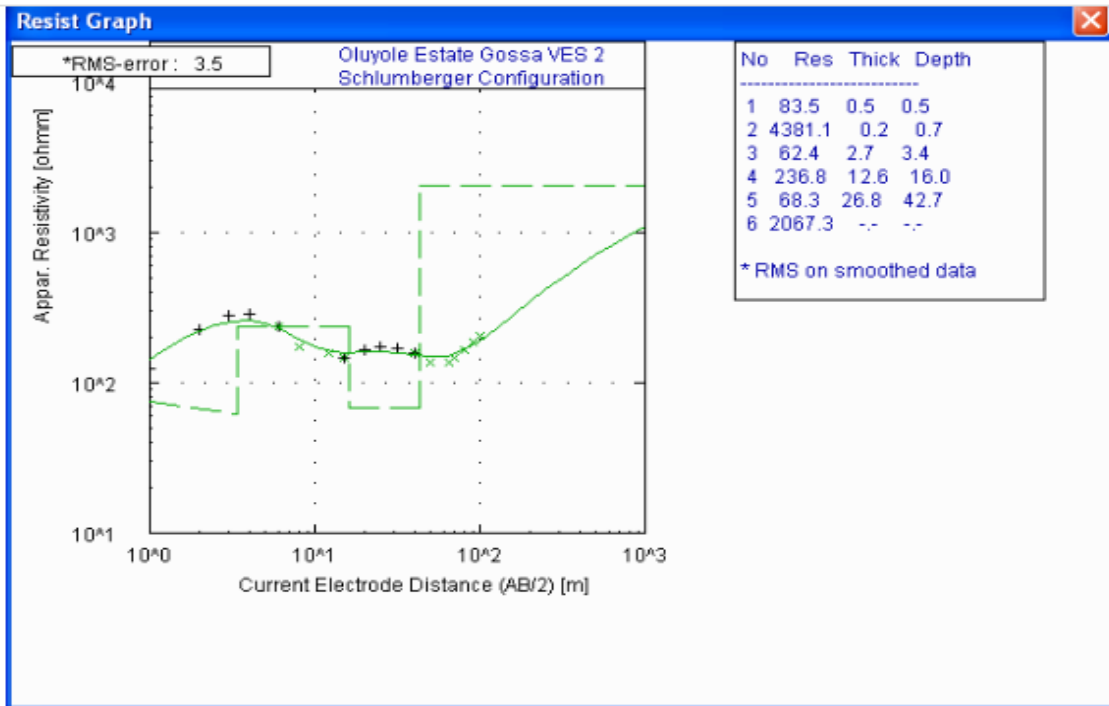


Figure 1: Vertical Electrical Sounding (VES) of Gosa Area of Abuja [9]

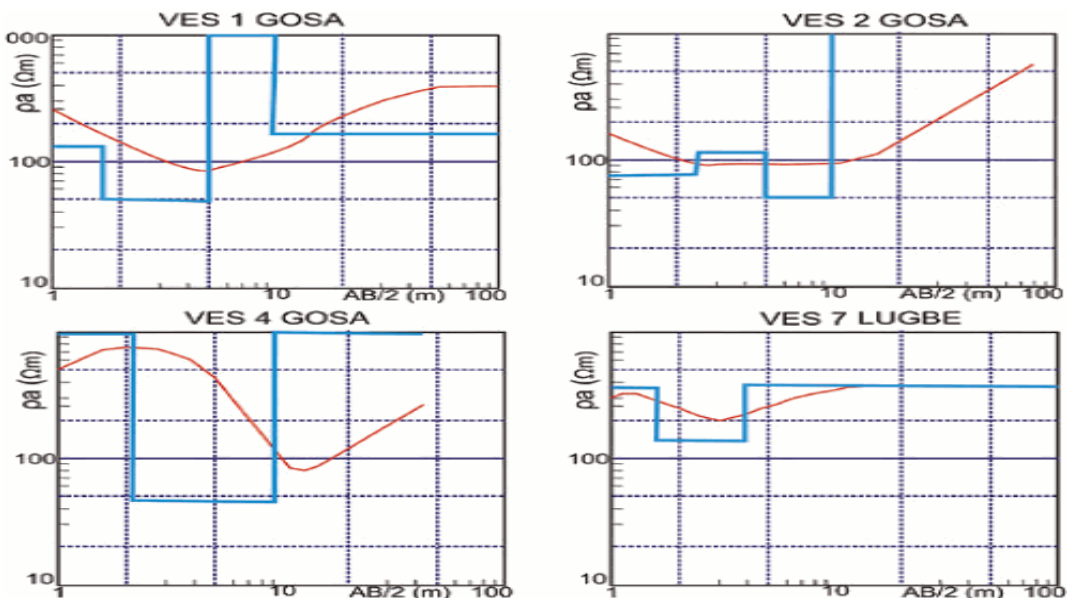


Figure 2: Vertical Electrical Sounding (VES) Showing Groundwater Features and Failed While Drilling to Recommended Depths [13]

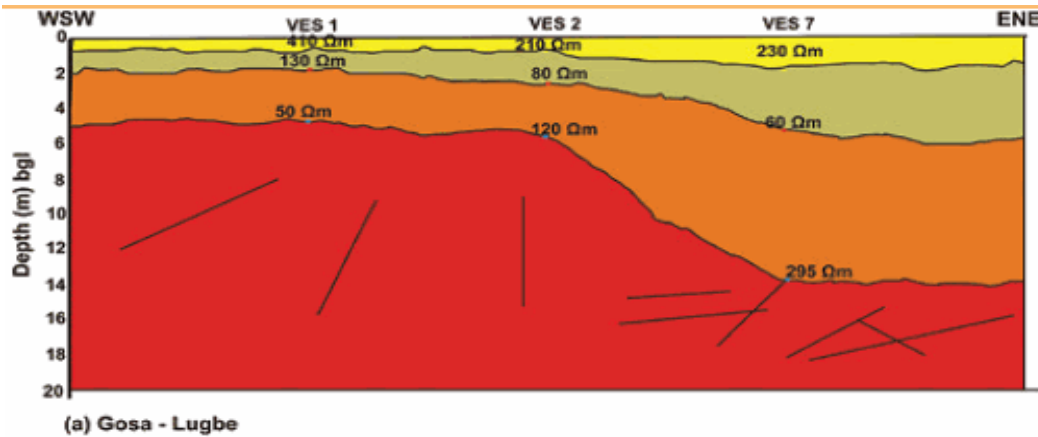


Figure 3: 2D Cross-Section of the Interpreted VES Layers to Identify the Possible Cause of Failed Resistivity Method of VES [13]

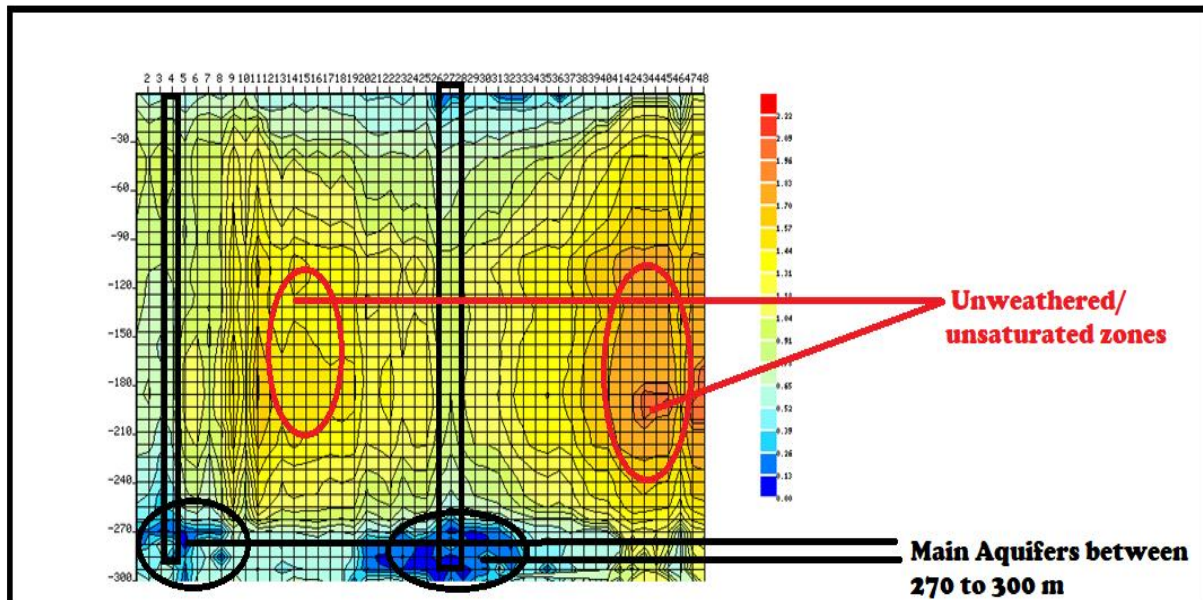


Figure 4: The Iso-Contour Map of Electromagnetic Method

4.0 Conclusion

All the methods of groundwater investigation offer an effective solution to water exploration, no doubt. However, in particular, the Electromagnetic method might have a better spatial resolution and a high degree of accuracy, nevertheless the cost implication of its equipment is low and cheap. The electromagnetic method is only emerging as a useful tool and not to displace other methods in the exploration of subsurface features that enhance the groundwater potentials. As EM usage is progressing, it increases the procedures or/and models that help prevent or simplify EM anomalies for straightforward interpretation of groundwater bearing formation. Inherently, the EM output measurement data, curve graph and profile map by USB cable to the computer for analysis and making geological conclusion is an added advantage compared to the rest of geophysical methods. As such, this method should be adopted

for smooth understanding of groundwater bearing formation and especially the high resolution of groundwater features that drillers that are not familiar with geophysical data interpretation can easily utilize the EM robustness.

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