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AN APPRAISAL OF GROUNDWATER SURVEY EMPLOYING THE ELECTRICAL RESISTIVITY METHOD

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ABSTRACT— The electrical resistivity method (ERM) of the geophysical prospecting favoured by geoscientists, has become one of the most often used methods in hydrogeological and engineering geophysics. The ERM is a geophysical approach that provides a highly appealing method for characterizing subsurface formation over a vast region. Moreover, ERM is used to generate complete and persuasive results that are cost-effective, time-efficient, and data-rich which has been used in groundwater investigations in a variety of ways. ERM can also be applied in general stratigraphic mapping, well logging, seawater intrusion, groundwater pollutants, and estimation of overburden thickness This paper present a ranging review to highlight the usage of the ERM for groundwater investigation. The ERM results regularly give additional data to experts on numerous geophysical issues, for example, data on groundwater defilement, leachate, protective possibilities, and also to water supply sources within the environment.

KEYWORDS: Geophysical investigation, Groundwater, Electrical resistivity, Environmental studies, Stratigraphic mapping.

1. INTRODUCTION

In recent years, there has been a surge in interest concerning studies on subsurface sources, prompting greater in-depth research on both quantitative and qualitative features of underground beds that yield groundwater. Groundwater is an absolutely essential resource for water. Globally, population expansion and contemporary developments have increased the demand for water resources [1] and in most places of the world, groundwater characterizes the principal source of potable water quality [2]. [3] reported that in both rural and municipal parts of Nigeria, groundwater serves as a significant supply of drinking water. It is still the greatest accessible basis of fresh water, making it a critical link in the water supply chain. [4] reported that water is essential for every life on the planet. It is vital to our health, economy, food production, and environmental well-being. [5] emphasized that groundwater quality is crucial to groundwater safety, particularly for the purpose of water supply. Water, despite its importance, is a limited natural resource. It is impossible to construct. The hydrologic cycle is the process through which water is recycled through the atmosphere. Subsurface water that fills soil pores and fractures of rock formations is referred to as groundwater [6], which provides around 95% of total water [7]. The presence of dual-porosity circumstances, in which groundwater flow is characterized by volumetrically small but high-permeability flow features such as fracture systems, was described by [8]. Furthermore, hydrogeological engineers employ geophysics, a branch of physics, which examines the earth by making measurements near/or on its surface, to determine the precise location of the groundwater zone in the subsurface layer [9]. As a result of their widespread usage in geotechnical and geoenvironmental studies, geophysical methods are widely considered the most suited instruments for groundwater research. One of the ancient and most extensively utilized geophysical exploration techniques is the resistivity survey [10]. More also, for many years, geophysics has played an important role in such studies, helping to improve equipment and create new ones to get better results and expand their applications. [11] reported that over the years, geophysical technologies are increasingly being used to monitor groundwater resources and water quality, particularly in third-world nations where individuals are responsible for providing water for their daily activities. The ERM is a kind of geophysical strategy utilized as the primary phase of groundwater investigation. For a long time, electrical resistivity has been used to dissect layered media thickness and guide the land climate of existing springs. [12] carried out a groundwater exploration in hard rock terrains in Mount Betung Western Bandar Lampung using an integrated geophysics method in order to study the effects of basement and hard rock on groundwater prospects. Geoelectric Vertical Electrical Soundings (VES) and gravity survey were both used. Gravity survey and Geoelectric Vertical Electrical Soundings (VES) were used. This discovery demonstrates that the fractures are dispersed at random and responsible for a number of worked-well failures. In addition, the cracks in the hard rock at Mount Betung's base serve as conduits for water to go from recharging at the mountain to the aquifer beneath the Bandar Lampung Basin. In view of the strategy's effortlessness, proficiency, and nondestructive execution in giving subsurface imaging, it has been really utilized for groundwater [13]. Furthermore, accurate information on groundwater and the location of subsurface layers may be acquired using the core borehole data and profile picture generated by this approach. As a result, this paper provides a brief overview of the electrical resistivity method's application in groundwater studies.

2. The Theory of Electrical Resistivity Method

ERM is utilized to ascertain and plan the resistivity of subsurface properties [14]. This also refers to an inquiry that uses a variety of technologies to conduct an electrical current and measure the voltage to create an image of the subsurface's electrical properties [15]. Electrical resistivity approach is established on the earth's response to electrical current flow, as shown in Figure 1.

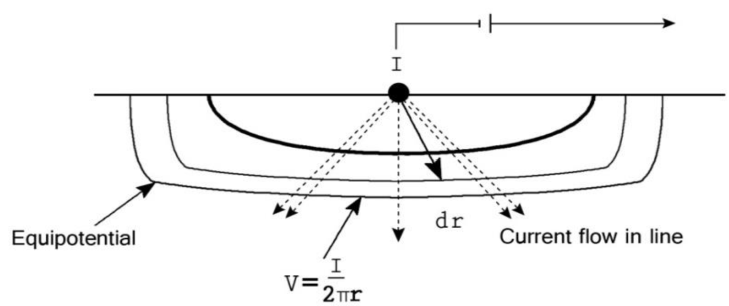

Figure 1. A single surface electrode's current flow [16]

It's delicate to changes in the subsurface's electrical resistivity, which is estimated in Ohm meters [17]. As displayed in Figure 2, resistivity is estimated by actuating an electric flow into the ground through two current electrodes (C1/C2) and estimating the subsequent voltage at two possible terminals (P1/P2).

Figure 2. Simple Distribution of Current/Potential Electrodes

NOTE: CI = Current-electrode 1; C2 = Current-electrode 2
P1 = Potential-electrode 1; P2 = Potential-electrode 2

The likely distinction across the shell can be assessed by characterizing the opposition R concerning the resistivity and the region of the shell (equipotential surface) from Figure 1.

$$dV = i(R) = I\left(\rho \frac{dr}{2\pi r^2}\right) = I\left(\rho \frac{L}{A}\right) \qquad 1$$

V denote the voltage/electrical potential, I denote the flow, r denote the span of the equipotential surface, and R is the resistivity. By combining the aforementioned requirements, one may reduce the potential at endlessness to zero. A good ways off R from the source, the electric potential is given by:

$$V = \frac{\rho I}{2\pi R} \qquad 2$$

The unit of resistance is Ohm.m, which should not be confused with the unit of resistance, which is ohms. Therefore, the resistivity of a material is characterized as:

$$\rho = \frac{RA}{L} \qquad 3$$

R is the material's opposition, A is the sectional region through which current flow and L is the material's length. The potential has been determined in view of a solitary current source. The objective of resistivity studies is to sort out how current going through two current electrodes causes a distinction is possible between two focuses. The potential at every terminal is represented by the current sources:

$$VP_1 = \frac{I\rho}{2\pi r_1} - \frac{I\rho}{2\pi r_2} \qquad 4$$

$$VP_2 = \frac{I\rho}{2\pi r_3} - \frac{I\rho}{2\pi r_4} \qquad 5$$

The potential difference $V = VP_1 - VP_2$ which simplifies to:

$$\Delta V = \frac{I\rho}{2\pi}\left(\frac{1}{r_1} - \frac{1}{r_2} - \frac{1}{r_3} + \frac{1}{r_4}\right) \qquad 6$$

3. The Theory of Apparent Resistivity

The most well-known issue experienced in resistivity sounding method is high contact opposition at the current electrodes. Huge contact protection (>2 k) limits the most elevated current that might be applied utilizing the meter's result voltage, regardless of the way that this significantly affects the deliberate opposition (normally 300 - 400 V). To overcome high protection, terminals can be watered with a soaked salt arrangement or set in a pit loaded up with betonies or mud slurry [18]. Figure 3 shows the distance between anode readings.

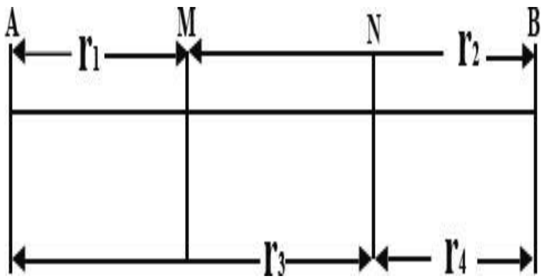

Figure 3. The distance between the electrode measurements [18]

A and B are current electrodes
M and N are potential electrodes
After the introduction of current, the potential is then calculated:

$$V = \frac{I\rho}{2\pi x} \qquad 7$$

The Total Potential at M and N is given by V_M and V_N
The Potential at M is given calculated as:

$$V_M = Vr_1 - Vr_2 \qquad 8$$

$$Vr_1 = \frac{I\rho}{2\pi r_1}, Vr_2 = \frac{I\rho}{2\pi r_2} \qquad 9$$

$$V_M = \frac{I\rho}{2\pi r_1} - \frac{I\rho}{2\pi r_2} = \frac{I\rho}{2\pi}\left(\frac{1}{r_1} - \frac{1}{r_2}\right) \qquad 10$$

Also, the potential at N is then calculated as:

$$V_N = Vr_3 - Vr_4 \qquad 11$$

$$Vr_3 = \frac{I\rho}{2\pi r_3}, Vr_4 = \frac{I\rho}{2\pi r_4} \qquad 12$$

$$V_N = \frac{I\rho}{2\pi r_3} - \frac{I\rho}{2\pi r_4} = \frac{I\rho}{2\pi}\left(\frac{1}{r_3} - \frac{1}{r_4}\right) \qquad 13$$

Then the Potential Difference between M and N is then calculated as:

$$V = V_M - V_N \qquad 14$$

$$V = \frac{I\rho}{2\pi}\left(\frac{1}{r_1} - \frac{1}{r_2} - \frac{1}{r_3} + \frac{1}{r_4}\right) \qquad 15$$

$$\rho_a = \frac{2\pi V}{I}\left[\frac{1}{\frac{1}{r_1} - \frac{1}{r_2} - \frac{1}{r_3} + \frac{1}{r_4}}\right] \qquad 16$$

ρ_a is the apparent resistivity

Also, in homogenous area $\rho_a = \rho$ true

ρ true is the inversion of the measured apparent resistivity

The geometry factor k is the quantity $2\pi\left[\frac{1}{r_1}-\frac{1}{r_2}-\frac{1}{r_3}+\frac{1}{r_4}\right]$

$$\rho_a = K.\frac{V}{I} \quad (17)$$

$$\rho_a = K.R \quad (18)$$

The configuration of four electrodes determines the geometric factor k. The imaging depth of the electrical resistivity method is determined by the distance between electrodes. Greater depth is possible due to increased electrode spacing. The electrode array's full length contributes to the greater imaging depth. The overall subsurface resistivity significantly affects the imaging profundity, with more safe terrain having a tendency to bring down the profundity after reversal. Groundwater resistivity levels range from 10 - 100 ohm-m, as reported by [19], contingent upon the extent of broken-down salts as shown in Table 1.

Table 1. Showing the Resistivity value of some type of Water Respectively [19]

Types of Water	**Resistivity (Ωm)**
Precipitation	30 – 1000
Igneous Rock	
Surface water	30 – 500
Groundwater	30 – 150
Sedimentary Rock	
Surface water	10 – 100
Groundwater	> 1
Water	
Freshwater	10 – 100
Seawater	0.2
Maximum Salt Content	
Drinking water	> 1.8
Water for Irrigation	> 0.65

4. Electrode Configuration in Electrical Resistivity Method

The electrode design, or array, utilized in electrical resistivity surveys is responsible for high resolution, reliability, and great imaging. Several studies on the performance of various arrays have been conducted [20]. Arrays come in a variety of shapes and sizes, and they can be used to collect data in a variety of ways. Figure 4a-e shows the arrays used to explore the subsurface layer: Wenner, Schlumberger, Dipole-dipole, Pole-dipole, and Pole-pole [21].

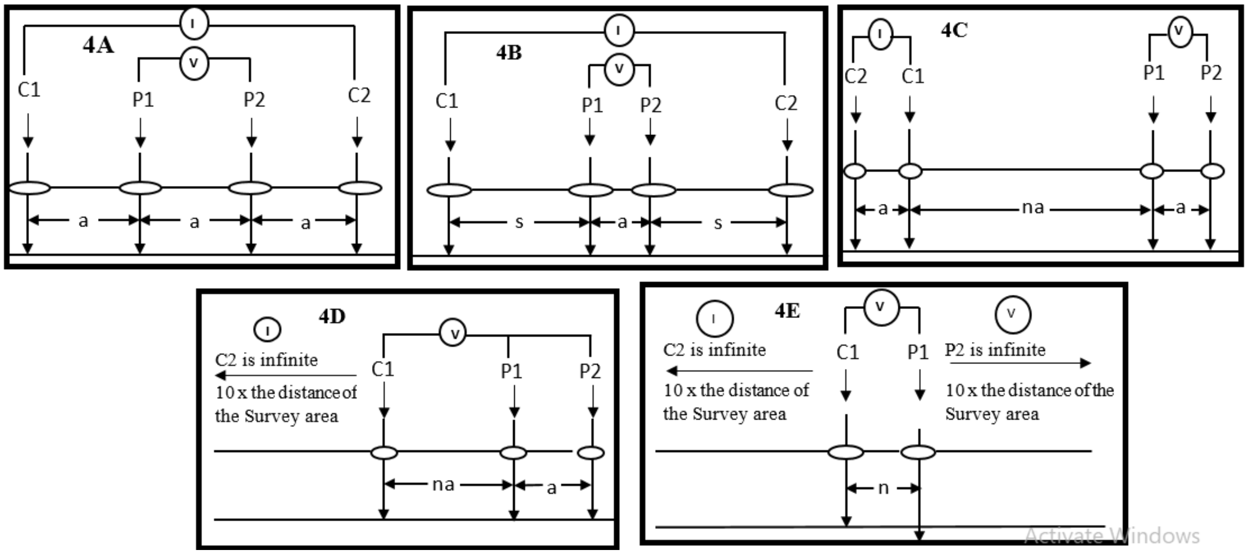

Figure 4. Showing the Array Configuration: (A) Wenner, (B) Schlumberger, (C) Dipole-dipole, (D) Pole-dipole and (E) Pole-pole

With regards to aversion to horizontal and vertical heterogeneities, the profundity of exploration, flat information inclusion, and sign force, the array configuration impacts goal, awareness, and profundity of study. According to [22], Table 2 shows the representation of each array configuration.

Table 2. Showing the Major Representation of the Array Configuration

Description	Wenner	Schlumberger	Dipole-Dipole	Pole-Pole	Pole-Dipole
The Sensitivity of Array Horizontal Structure	E	G	W	G	G
The Sensitivity of Array Vertical Structure	W	G	E	G	W
Depth of Investigation	W	G	VG	E	VG
Horizontal Data Coverage	W	G	VG	E	VG
Signal Strength	E	VG	W	E	G

NOTE: W = Weak; G = Good; VG = Very Good; E = Excellent. All represent the sensitivity of the different Array Configuration.

Each array comes with its own set of benefits and drawbacks. The depth of the object, the kind of heterogeneity to be planned, horizontal and vertical variations in the subsurface, and signal strength are elements to consider while picking an array. The purpose of the survey, on the other hand, is the most crucial factor to consider. According to the author [21], the practice of several configurations can advance the subsurface's distinct analysis properties and prime to an enhanced analysis in particular cases.

5. Factors that affect the Electrical Resistivity values

The idea of electrical resistivity is that the earth substance being examined behaves like a resistor in a circuit. The capacity of a material to resist current was tested after an electrical current was produced into the ground. Because diverse earth materials display features of resistivity value, this application may be used to discriminate between them. The resistivity levels of earth materials were affected by several variables. Moisture content, density, particle size fraction, void ratio, porosity, and the temperature of the subsurface environment are all elements that influence the ground resistivity value [23]. The electrical resistivity method may detect water-saturated clay, which has a lower resistivity zone, and image local variations in apparent resistance with depth [24]. Resistivity techniques can be utilized successfully for groundwater study when there is a good electrical resistivity difference between the water-bearing formation and the underlying rocks, according to [25]. As a result, the resistivity value will change or remain constant depending on the amount of water in the materials. The degree of fracture, according to [26] is one of the most common factors in resistivity measurements. Fractures are usually filled with groundwater. The resistivity of the rock layer diminishes as the number of cracks increases. The granite resistivity, which varies between 5,000 and 10,000 m in wet and dry conditions, is a good example of this assumption. The resistivity of these rocks will be low to direct when soaked with water, going from a couple of m to under 100 m, as depicted by [19]. Above the water table, soils are drier and have a higher resistivity value, ranging from hundreds to thousands of meters. The resistivity of soils below the water table, on the other hand, is less than 100 m.

6. The Electrical Resistivity Method in Groundwater Exploration

The geophysical approach was first established for the oil and mineral exploration, but as water has become more treasured and scarce, it has also been applied to groundwater exploration, resulting in a better understanding of groundwater resources and a better understanding of the underground groundwater system. The electrical resistivity method has been established to be the most active approach for mapping of groundwater resources because the groundwater flow and presence are typically limited and difficult to establish [27]. Supporting borehole data and interpretation of the resistivity imaging acquired can be used to offer reliable groundwater information. Nowadays, it is common to utilize an electrical resistivity imaging approach to locate groundwater. In Nigeria, the electrical resistivity method has been used as an alternative method to handle a variety of challenges, particularly in the disciplines of hydrogeological engineering and research [3]. Groundwater plays a significant role as a source of drinkable water, according to [3]. It remains the most readily available source of fresh water, making it an important part of the water delivery system. The most widely recognized issues in the field were subsurface contamination and destruction. Hydrogeological engineers had the option to distinguish the wellsprings of disappointment in the subsurface, forestall harm to the encompassing structures, and guide the break zone in the subsurface and material under assessment because of the fruitful sending of these devices [24], [20]. The presence of groundwater is determined by the geologic subsurface formation, which is impacted by fluid forces in the pores, fractures, and fissures of rocks [28]. Groundwater requires recharging, not only because of the little or high storage capacity but also because a better understanding of the processes and amounts involved provides knowledge of its occurrence and potential. The major source of groundwater recharge could be precipitation, which eventually infiltrates water discharged from streams, lakes, and reservoirs, as well as infiltration from irrigation canals and water used for specialized applications to enhance groundwater supplies. The electrical resistivity technique, then again, is the most remarkable and practical strategy in groundwater research. This is due to a well-established link between the aquifer's hydrogeological characteristics and its electrical properties. Many Nigerian and foreign researchers have used geophysical techniques, particularly the electrical resistivity method, to explore groundwater. [29] studied groundwater potential and aquifer protective capacity using an electrical resistivity method using Schlumberger electrode configuration. The findings revealed a significant clay concentration in the overburden, implying a low groundwater potential rating but a favourable boost of the overburden protective potential. [30] also, play emphasizes to the use of the electrical resistivity method employing Schlumberger electrode configuration to investigate the impact assessment of solid waste on groundwater and reported that vertical electrical sounding data revealed the presence of leachate plumes. Furthermore, [20] conducted a groundwater investigation using vertical electrical resistivity using a Schlumberger electrode arrangement, concluding that resistivity sounding is effective for aquifer characterization and groundwater exploration. [31] carried out groundwater prospecting using a vertical electrical sounding method employing the dipole-dipole electrode configuration. The method is said to be useful for geological surveys and can locate fracture zones with strong prospects for groundwater detection. In addition, [32] used pole-dipole and pole-pole to research hydrogeology and geophysical studies for deeper groundwater resources in the hard rock ridge. This was used to look at high signal strength data for groundwater in the tectonically distributed hard rock ridge region.

7. Conclusion

The review study reported that the use of the electrical resistivity method has aided hydrogeological engineers in mapping a variety of subsurface hydrogeological interests and issues within the subsurface, particularly during the preliminary stages of groundwater research. Furthermore, this approach is resourceful in terms of rate, period, and data analysis where groundwater ranging from 1-100 Ωm may be easily recognized with borehole data and geochemical information. The electrical resistivity method can also be applied in general stratigraphic mapping, well logging, seawater intrusion, and estimation of overburden thickness. Conclusively, the array configurations employed during data acquisition are critical in generating exact results depending on the study's principal goal. Therefore, since geophysicists are experts in this discipline, the provision of direction and assistance to increase knowledge of this application is guaranteed. Thus, researching the theory and application of the resistivity approach in detail is highly significant to acquire reliable information within the environment.

8. References

[1] Ibrahim, K., et al., Physico-Chemical Evaluation of Groundwater in Kuje, Federal Capital Territory, Abuja, Nigeria. Nigerian Journal of Technological Development, 2015. 12(1): p. 1-5.

[2] Hasan, M.A., S. Ahmad, and T. Mohammed, Groundwater Contamination by Hazardous Wastes. Arabian Journal for Science and Engineering, 2021. 46(5): p. 4191-4212.

[3] Olatunji, J., et al., Assessment of groundwater quality of Ilorin metropolis using water quality index approach. Nigerian journal of technological development, 2015. 12(1): p. 18-21.

[4] Adeoti, L., et al., Geoelectrical assessment of groundwater potential at Ewuloja and its environs in Simawa Area, southwestern Nigeria. Nigerian Journal of Technological Development, 2018. 15(2): p. 39-49.

[5] Adeniji, A., et al., Combined Geoelectrical and Statistical Approach in Subsurface Structural Mapping for Groundwater Prospect at Oke-Odo, Iwo, Southwestern Nigeria. Technology Reports of Kanai University, 2020. 62(7): p. 3411-3425.

[6] Muchingami, I., et al., Electrical resistivity survey for groundwater investigations and shallow subsurface evaluation of the basaltic-greenstone formation of the urban Bulawayo aquifer. Physics and Chemistry of the Earth, Parts A/B/C, 2012. 50: p. 44-51.

[7] Haider, H., I.S. Al-Salamah, and A.R. Ghumman, Development of groundwater quality index using fuzzy-based multicriteria analysis for Buraydah, Qassim, Saudi Arabia. Arabian Journal for Science and Engineering, 2017. 42(9): p. 4033-4051.

[8] Maliva, R.G., et al., Aquifer storage and recovery of treated sewage effluent in the Middle East. Arabian Journal for Science and Engineering, 2011. 36(1): p. 63-74.

[9] Nazri, M.A.A., et al., Authentication relation between surface-groundwater in kerian irrigation canal system, perak using integrated geophysical, water balance and isotope method. Procedia Engineering, 2012(50): p. 284-296.

[10] Reynolds, J.M., An introduction to applied and environmental geophysics. 2011: John Wiley & Sons.

[11] Raji, W., Review of electrical and gravity methods of near-surface exploration for groundwater. Nigerian Journal of Technological Development, 2014. 11(2): p. 31-38.

[12] Rustadi, R., et al., Groundwater exploration using integrated geophysics method in hard rock terrains in Mount Betung Western Bandar Lampung, Indonesi. Journal of Groundwater Science and Engineering, 2022. 10(1): p. 10-18.

[13] Dor, N., et al., Verification of surface-groundwater connectivity in an irrigation canal using geophysical, water balance and stable isotope approaches. Water resources management, 2011. 25(11): p. 2837-2853.

[14] Asry, Z., et al., Groundwater exploration using 2-D geoelectrical resistivity imaging technique at Sungai. Udang, Melaka. Journal of Earth Science and Engineering, 2012. 2(10): p. 624.

[15] Abidin, M.H.Z., et al. Application of geophysical methods in Civil engineering. in Malaysian Technical Universities International Conference on Engineering and Technology. 2011.

[16] Alagbe, O., Integration of Electrical Resistivity Techniques and Lineament analysis in Hydrogeological investigation of parts of Ogbomoso, South–Western Nigeria. M. Tech Thesis, Ladoke Akintola University of Technology, Ogbomoso, Nigeria, 2005.

[17] Grant, F., Introduction to electrical methods. Interpretation theory in applied geophysics, 1965: p. 385-401.

[18] Bakhtiar, Q., Note on Introduction to Electrical Resistivity. University of Sulaimani, Iraq, 2010.

[19] Keller, G.V. and F.C. Frischknecht, Electrical methods in geophysical prospecting. 1966.

[20] Adagunodo, T.A., et al., Groundwater exploration in Aaba residential area of Akure, Nigeria. Frontiers in Earth Science, 2018. 6: p. 66.

[21] Loke, M.H., Electrical imaging surveys for environmental and engineering studies. A practical guide to, 1999. 2: p. 70.

[22] Samouëlian, A., et al., Electrical resistivity survey in soil science: a review. Soil and Tillage research, 2005. 83(2): p. 173-193.

[23] Koefoed, O., Resistivity Sounding measurements, Elsevier Scientific Publishing Company. Geosounding principles, 1979. 1: p. 19-27.

[24] Sunmonu, L.A., et al., Geoimaging of subsurface fabric in Awgbagba, Southwestern Nigeria using geomagnetic and geoelectrical techniques. Malaysian Journal of Fundamental and Applied Sciences, 2018. 14(2): p. 312-324.

[25] Zohdy, A.A., Total field resistivity mapping and sounding over horizontally layered media.

Geophysics, 1978. 43(4): p. 748-766.

[26] Briški, M., et al., Characterization of aquifers in metamorphic rocks by combined use of electrical resistivity tomography and monitoring of spring hydrodynamics. geosciences, 2020. 10(4): p. 137.

[27] Sunmonu, L., et al., Geoelectric delineation of aquifer pattern in crystalline bedrock. Open Transactions on Geosciences, 2015. 2(1): p. 1-16.

[28] Adeniji, A., et al., Combined Geoelectrical and Statistical Approach in Subsurface Structural Mapping for Groundwater Prospect at Oke-Odo, Iwo, Southwestern Nigeria. 2020.

[29] Abiola, O., P. Enikanselu, and M. Oladapo, Groundwater potential and aquifer protective capacity of overburden units in Ado-Ekiti, southwestern Nigeria. International Journal of Physical Sciences, 2009. 4(3): p. 120-132.

[30] Olafisoye, E.R., et al., Impact Assessment of Solid Waste on Groundwater: a Case Study of Aarada Dumpsite, Nigeria. ARPN Journal of Earth Sciences, 2013. 2(2): p. 45-53.

[31] Mumuni, A. and J. Bayor, Groundwater prospecting using the dipole-dipole configuration for vertical electrical sounding: prediction of major aquifer depth in the Tolon-Kumbungu district of Northern Ghana. Journal of Science and Technology (Ghana), 2017. 37(2): p. 43-58.

[32] Kumar, D., V.A. Rao, and V. Sarma, Hydrogeological and geophysical study for deeper groundwater resource in quartzitic hard rock ridge region from 2D resistivity data. Journal of Earth System Science, 2014. 123(3): p. 531-543.