International Journal of Water Resources and Environmental Engineering Vol. 3(4), pp. 77-86, May 2011
Available online at http://www.academicjournals.org/IJWREE
ISSN 1991-637X ©2011 Academic Journals

Full Length Research Paper

Geophysical evaluation of rock type impact on aquifer characterization in the basement complex areas of Ondo State, Southwestern Nigeria: Geo-electric assessment and Geographic Information Systems (GIS) approach

Mogaji K. A.*, Olayanju G. M. and Oladapo M. I.

Federal University of Technology, Akure, Ondo State, Nigeria.

Accepted 27 May, 2011

Geoelectrical survey and Geographic Information Systems (GIS) analysis were conducted in the hard-rock terrain areas of Ondo State, Southwestern Nigeria, with the view to determine impact of rock types on the variability of aquifer characteristics and their influence on the hydro geologic systems. The interpretation of the 414 sounding data indicates occurrence of 17 curve types which were used to infer subsurface lithology and geologic structures. A correlation of sounding curves and rock types revealed that two major aquifers: confined and unconfined aquifers occur mostly on the migmatite, pegmatite, Charnokite and undifferentiated fine-grained quartzite/schists. The third, leaky aquifers, occur predominantly on the biotites gneiss where occurrence of fracture is minimal. Confined aquifers are mostly associated with varying degree of fracturing of crystalline rocks. Estimated average hydraulic conductivity for the aquifer units are 4.43, 0.96 and 4.58 m/day, while their mean transmissivity values are 13.0, 8.71 and 60.18 m^2/day respectively. From this work, it is evident that most aquiferous zones have poor to moderate permeability, which revealed why most wells in the area usually have low yield. While moderately permeable unconfined aquifer might be prone to contamination, the leaky or weathered/fractured aquifers can be tapped for groundwater development in the area.

Key words: Geo-electric, Geographic Information Systems, aquifer, transimissivity, hydrogeological.

INTRODUCTION

In most places within the basement terrain of Ondo State, there is a major problem of acute shortage of potable water for domestic and industrial uses. Sources of water in the region are through shallow wells in the urban areas and mostly through streams and springs in the rural communities. This shortage is aggravated by collapse of many public water systems in most cities and increase in rural to urban migration of people. Most boreholes drilled in the area have high spate of failure rate which could be attributed to underlying complex geology and inadequate geophysical information prior to sitting and development of boreholes in the area. Besides, borehole yield is frequently low in the basement complex area during the dry season and, during this period, water supplies from boreholes do not have long-term sustainability, so it is imperative to locate boreholes on aquiferous zones: a lithological formation that is characterized by fractures, shear, joints, fissures and/or faulted basement rocks.

The accurate and complete evaluation of groundwater resources can only be achieved by application of appropriate state-of-the-art for the aquifer characterization/modelling. This is because the differing properties of various rock types by nature of their origin, lithology, and structure do influence the geoelectrical parameters of a particular site (Seidel and Lange, 2008). The aquifer is any mass of permeable rock material from

---

*Corresponding author. E-mail: mogakeh@yahoo.com

which a significant amount of water can be recovered. Aquifers differ in properties, because these properties are function of rock types constituting them. Different lithologic materials constitute the basement complex and sedimentary aquifers. In hard rock terrain, aquifers are fractured rocks and weathered in-situ materials, while the sedimentary aquifers consist of sands and sandstones. The existence of fracture zone in a geologic medium can assist in creating groundwater conduit medium and aids groundwater accumulation (Hazell et al., 1988).

Groundwater distribution in Basement Complex areas varies from place to place due to the localized nature of basement aquifers (Satpathy and Kanungo, 1976). The spatial variation of the aquifer parameters such as porosity, permeability, transmissivity and conductivity can be attributed to, among other causes, tectonic set-up and degree of weathering of near-surface rocks (Barker et al., 2001). Therefore, mapping and characterization of aquifer types in lieu of evaluating the hydro geologic conditions will enhanced the groundwater development in the study area. A thorough knowledge of the rock types underlying the area and their geologic history is essential to efficiently map and regionally characterise the aquifer types.

The basement aquifers in the study area are fractured rocks and the weathered *in-situ* materials, while the sedimentary aquifers consist of sands and sandstones. In the basement area, aquifers occurs in the saprolite (*in-situ* weathered materials) overlying the fresh rock and in the fractured basement (Idowu and Ajayi, 1998).

The methods of groundwater exploration can be grouped under four subheadings: surface geological, subsurface geological, surface geophysical and subsurface geophysical methods (Olorunfemi et al., 2001; Hazell et al., 1988). The electrical resistivity method is majorly the geophysical application in hydro geologic investigation which is directed towards aquifer characterisation and groundwater quality studies (Olayinka and Mbachi, 1992; Ismailmohamaden, 2005; Asfahani, 2006; Bello and Makinde, 2007). High resistivity contrasts usually occur between solid rocks and saturated fracture zones (Leroux et al., 2007).

Recent development in aquifer characterization and evaluation of hydrogelogic systems of an area based on the subsurface geology involves the integration of methodologies involving geophysical method and GIS approach in selecting groundwater well (Kovar and Nachtnebel, 1993; Khitam et al., 2003).

This work focuses on the influence of the rock types on geo-electrical and hydro-geological characteristics of the aquifers, as well as the relation between the vertical electrical sounding (VES) curves and aquifer potential in the study area. In carrying out this study surface geology, geophysical (Electrical resistivity) and GIS methods were employed in the characterisation and evaluation of groundwater systems within the basement terrain. Correlation of measured geophysical data with the types within the basement terrain was conducted using rock geospatial data analysis.

PHYSIOGRAPHY, GEOLOGY AND HYDROGEOLOGY

The study area lies within the basement complex area of Ondo State in the Southwest of Nigeria and lies within latitudes 6° 00' and 8° 45' North and longitudes 5° 30' and 6° East (Figure 1). In the area the proliferation of many small river channels characterize the drainage system. The vegetation is dense and made up of broad-leaved trees that are mostly evergreen.

The study area is underlain by rocks of the Precambrian basement complex of Nigeria (Jone and Hockey, 1964; Rahaman and Ocan, 1978; Rahaman, 1988), while the lithological units include majorly, Undiferentiated gneiss, granites gneiss, biotite gneiss, quartzite and Charnokite (Figure 2).

In the area, weathering processes create superficial layers, with varying degree of porosity and permeability. The regolith and fractured bedrock generally occur in typical basement terrain (Odusanya and Amadi, 1990). Studies have shown that the unconsolidated overburden could constitute reliable aquifer, if significantly thick (Satpathy and Kanungo, 1976; Dan-Hassan and Olorunfemi, 1999; Bala and Ike, 2001).

In addition, the concealed basement rocks may contain highly faulted and tightly folded area, incipient joint and fracture system derived from multiple tectonic events they have experienced. These structures may house abundant groundwater in a typical basement setting. The detection and delineation of such structural features may facilitate the location of groundwater prospect zones in the study area.

MATERIALS AND METHODS

The vertical electrical resistivity soundings carried out involved acquisition of four hundred and fourteen (414) sounding data through surface measurement of electrical resistance of the subsurface to the induced currents using the Ohmega resistivity meter.

Measured earth resistance values were presented in terms of the subsurface apparent electric resistivity distribution beneath the sounding locations. Electrode current spread length (AB) for the adopted Schlumberger array was varied between 2 and 200 m, while the spacing between the potential electrodes (MN) were intermittently varied between 0.5 and 10 m in order to achieve suitable current penetration and depth of investigation that will enable proper delineation of the bedrock relief and allow good estimate of aquifer parameters.

The geographic coordinates of the 414 VES points were determined with the aid of GERMAIN -12 Global positioning system (GPS).

WinRESIST inversion program was used for the automated 1-D inversion of the sounding curves obtained from the field data. Spatial qualitative and quantitative interpretations of geophysical data in relation with the rock types were made with the aids of ArcGIS software, version 9.3.

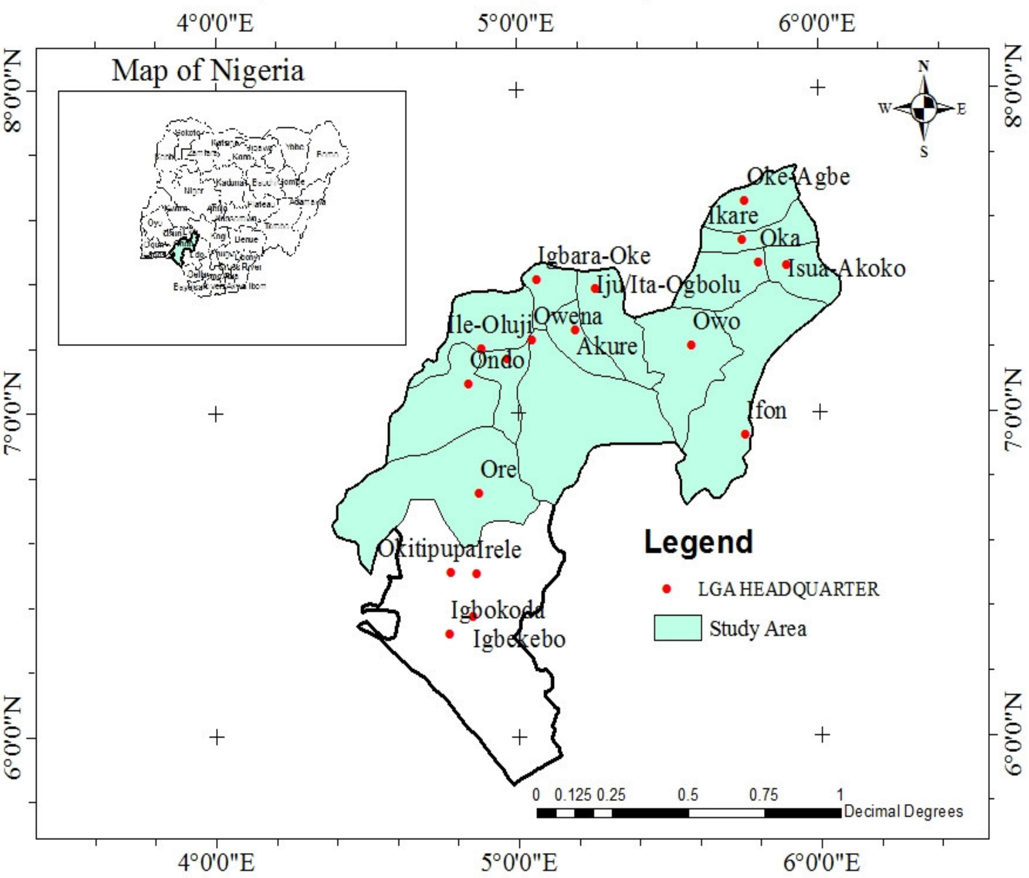

Figure 1. Location Map of the study area (Inset: map of Nigeria).

Inverted electrical sounding curves were interpreted in form of the earth models displaying subsurface structure and stratigraphy on the basis of the distribution of effective resistivity values. The GIS database was populated with the derived geoelectrical parameters and analyzed using the GIS spatial analysis applications to evaluate the impact of rock types on the aquifer properties and determine their influence on the hydrogeologic system of the state, using 95% confidence limit.

The 3D analysis tools of the ArcGIS programs were used to generate composite map from spatial aquifer distribution map and geologic rock types. The composite map was derived based on statistical estimates of spatial join, union, symmetric difference and intersection between the classified aquifer types and geologic rock units in the study area.

Embedded geostatistical tools available in ArcGIS include tools for prediction of values at a single location using interpolation method (Z-value calculation); prediction of unmeasured values or validation of a measured value at a location using geostatistical layer to point or grid or contour (GA layer to point/grid/contour); Gaussian geostat simulation tool for both conditional and unconditional geostatistical simulation based on simple kriging model; Semi-variogram sensitivity tools used for spatial sensitivity analysis.

The frequency distribution of the obtained sounding curve types is shown in Figure 3, while distribution of the identified aquifer types over the underlain rock types on the basis of the obtained geo-electric parameters (layer resistivity and thickness values) in the area are shown in Figures 4, 5 and 6. Spatial location of the delineated aquifer types from the interpreted sounding curves were used to generate aquifer classification map of the study area as shown in the Figure 7. Interrelationship between the aquifer type and subsurface geology is reflected in the overlay of the aquifer type distribution on the associated geology (Figure 8).

In Figure 3, seventeen (17) curve types were identified ranging from the simple 3-layer case to the combinations of these, as 4-layer or 5-layer stratigraphic units, with the dominant 3-layer H-type curves (43.48%) followed by the A-type (11.59%). K- and Q-types occur least. The type-H curves revealed greatly different degree of weathering in the area and stratigraphic unit: typified by a topsoil-weathered layer-fresh bedrock sequence. The type-A curves symbolize high resistance and low permeability in the subsurface geology. High percentage of these curve types demonstrated that there is significantly low rate of development of secondary porosity in most of the rocks, thus low groundwater potential due to low permeability and porosity of the underlying fresh bedrock.

The combination curve types in form of AA, HA, QH, HK and KH are diagnostic of four-layer cases, with varying geologic characteristics. AA- and QH-types are diagnostic of un-protective media highly susceptible to pollution; KH-type is diagnostic of stratigraphy with fairly protective overburden; while AK- and HK-types may be associated with relatively deep fractured bedrock with development of poor secondary porosity in AK-type or fairly developed secondary porosity in the HK-type.

The 5-layer case HKH is diagnostic of possible high level of development of secondary porosity arising from fractured bedrock, which is favourable for high groundwater yield. The significance

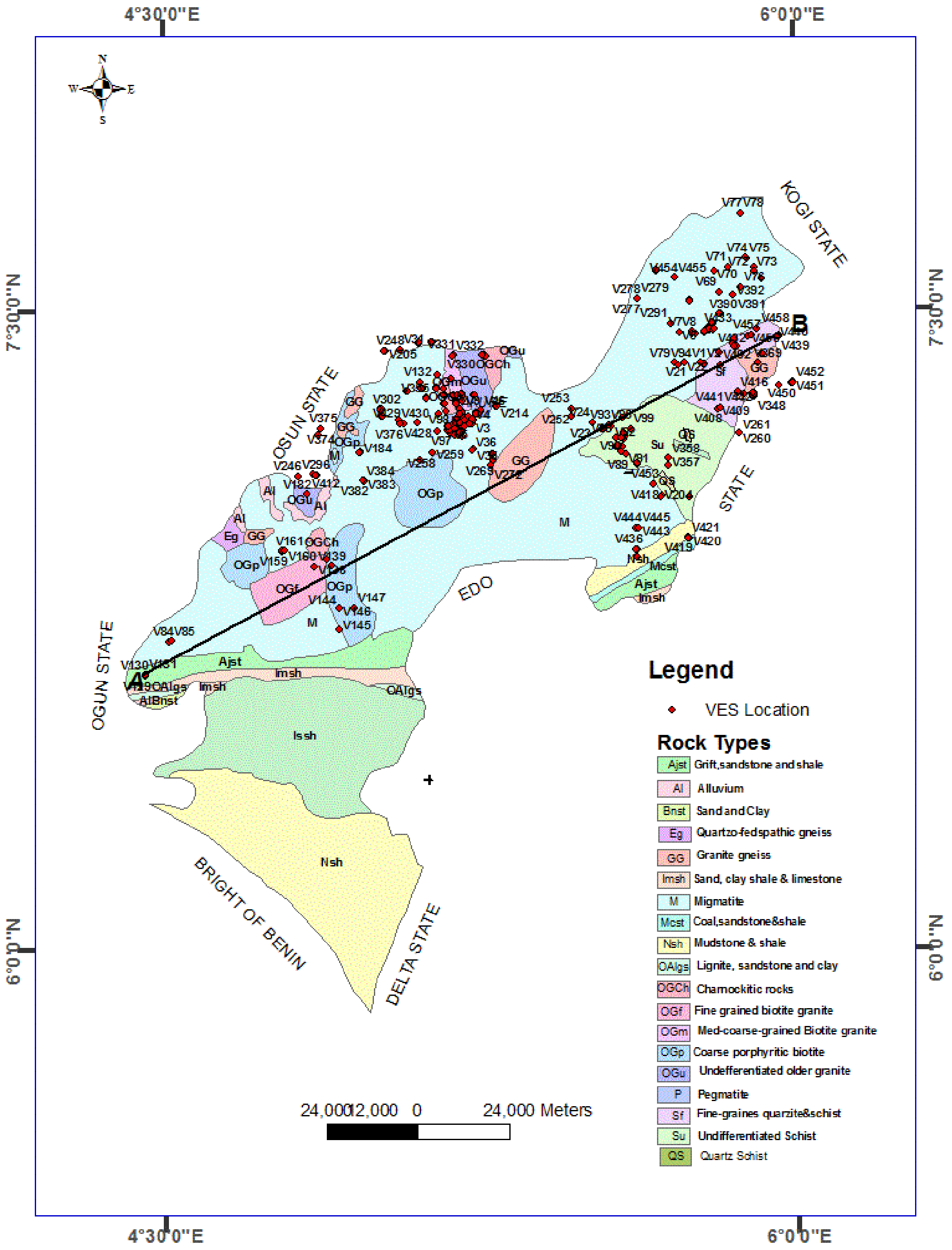

Figure 2. Geologic map of Ondo State (Adapted from NGSA, 2006).

of development of secondary porosity within the basement rocks has been attributed to the existence of fractures and/ or faults within the subsurface geology, which to significant extents, improve the groundwater yield and contribute to enhancing the hydro geological characteristics such as the hydraulic conductivity and vertical movement of groundwater within the permeable formations.

RESULTS AND DISCUSSION

The geoelectric parameters obtained were used in the generation of the earth models that were presented as subsurface structure and stratigraphy on the basis of the

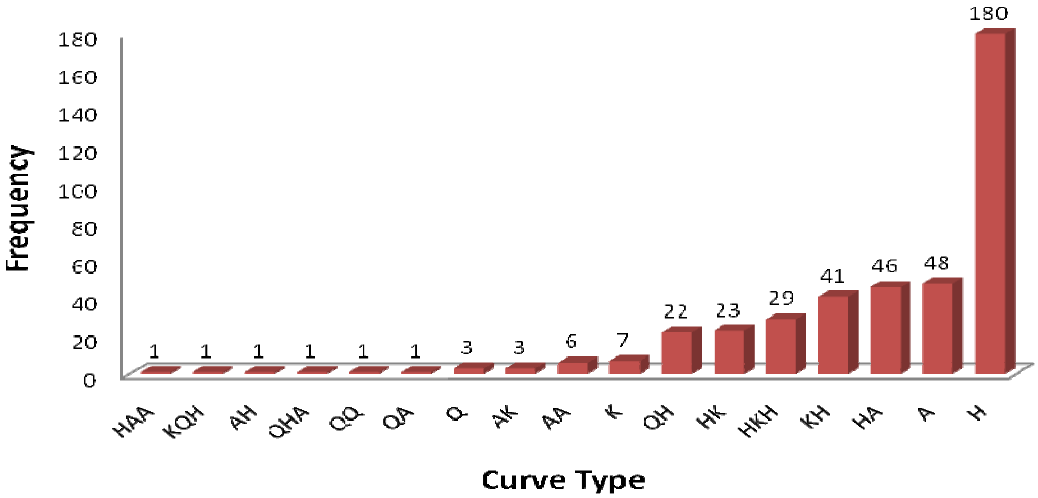

Figure 3. Curve type frequency distribution.

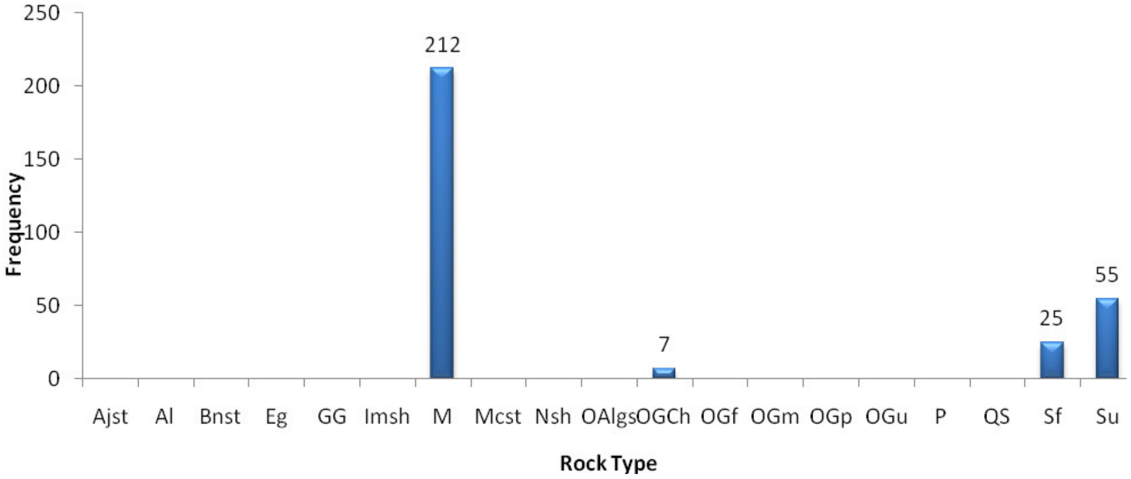

Figure 4. Distribution of unconfined aquifer on rock types.

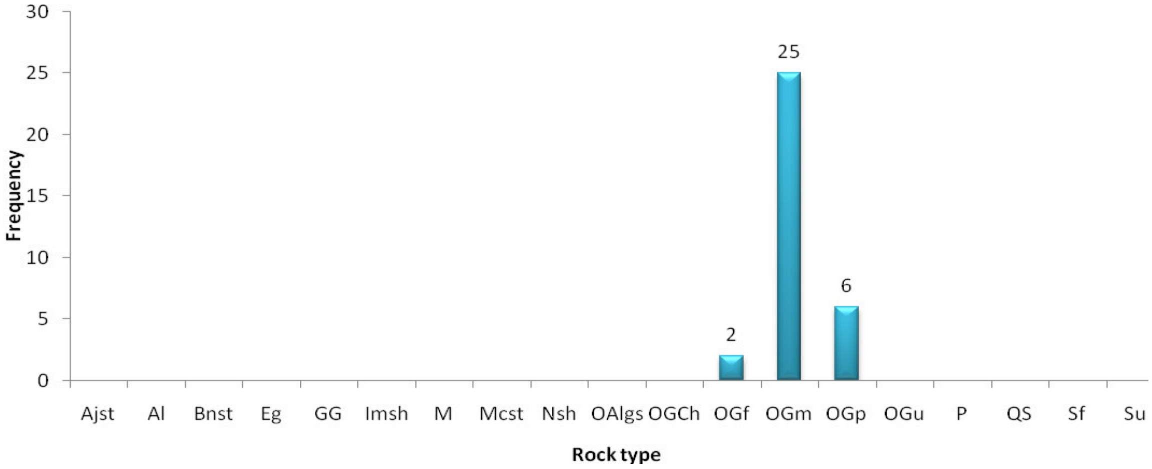

Figure 5. Distribution of leaky aquifer on rock types.

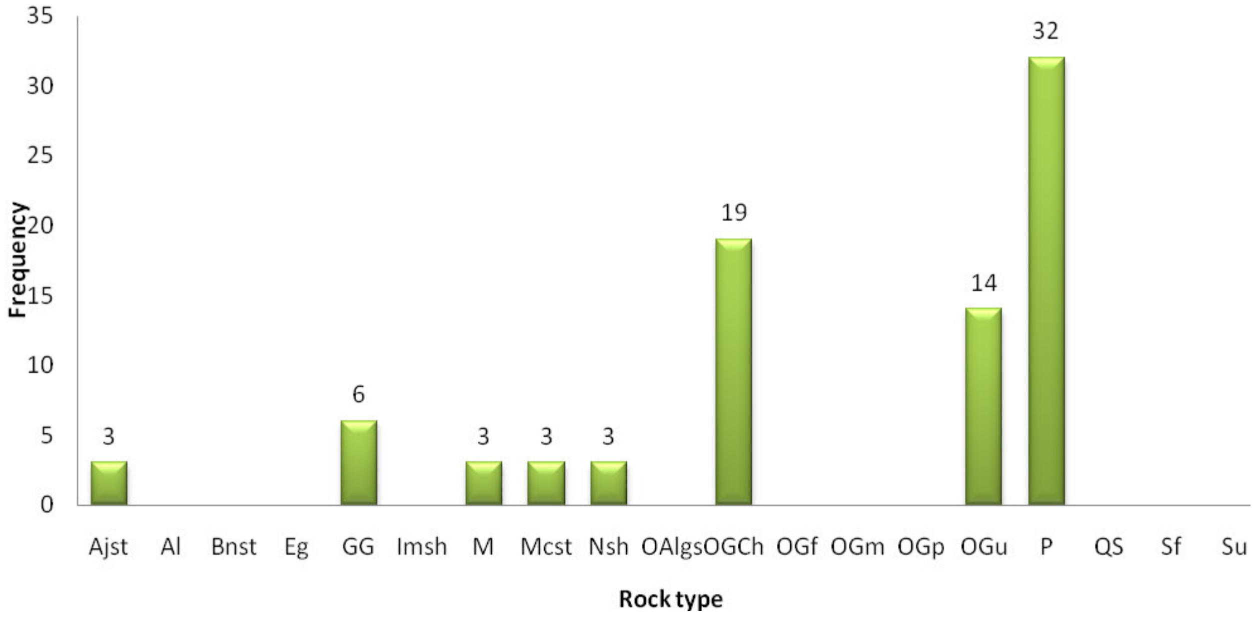

Figure 6. Distribution of confined aquifer on rock types.

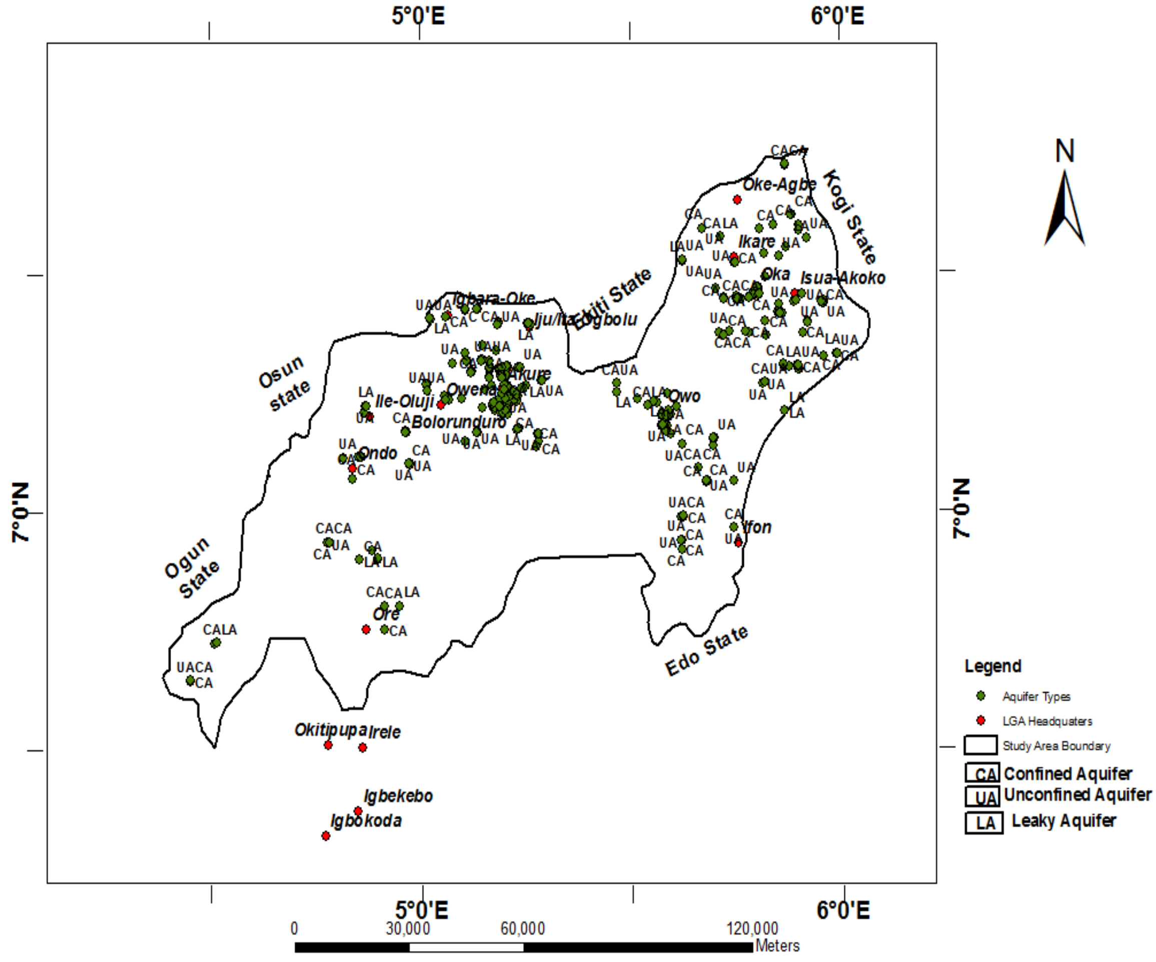

Figure 7. Aquifer classification map of the study area.

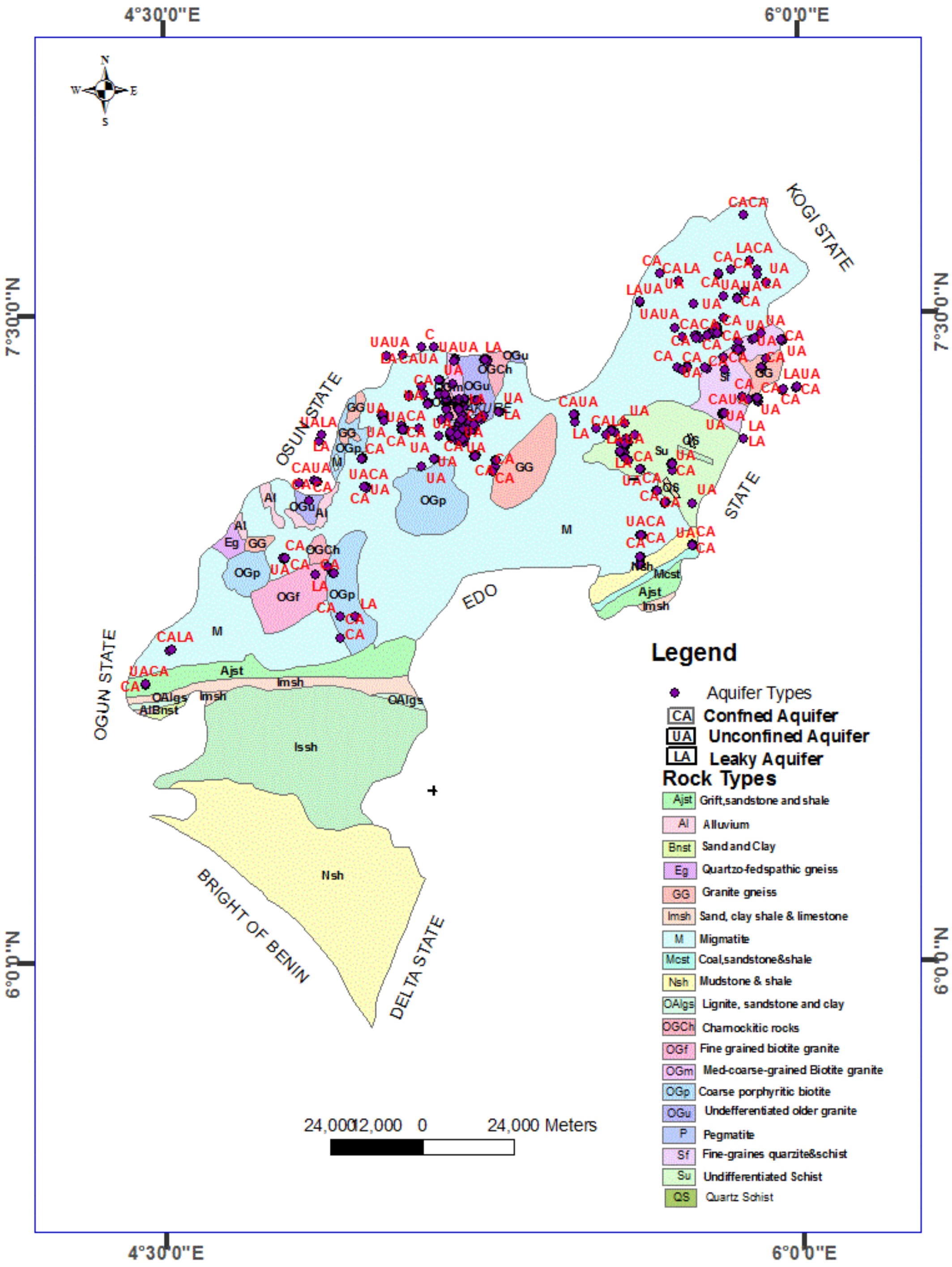

Figure 8. Aquifer type distribution map.

effective resistivity of the underlying geologic units from which aquifer units can be identified on the basis of their electrical properties (Idowu and Ajayi, 1998; Lashkaripour et al., 2005; Alile et al., 2008). From the sounding curves, maximum of four geologic units were delineated. These include top soil, lateritic/weathered layer, weathered layer and fractured/fresh basement.

The topsoil has thickness varying from 0.3 to 6.3 m and layer resistivity values ranging between 10 and 35,500 Ωm. Average thickness and resistivity values are 0.9 m and 950 Ωm respectively. The lateritic/weathered layer has thickness between 0.8 and 48.1 m with resistivity ranging from 26 to 10,650 Ωm with average values of 5.9 m and 365 Ωm respectively. The weathered layer has

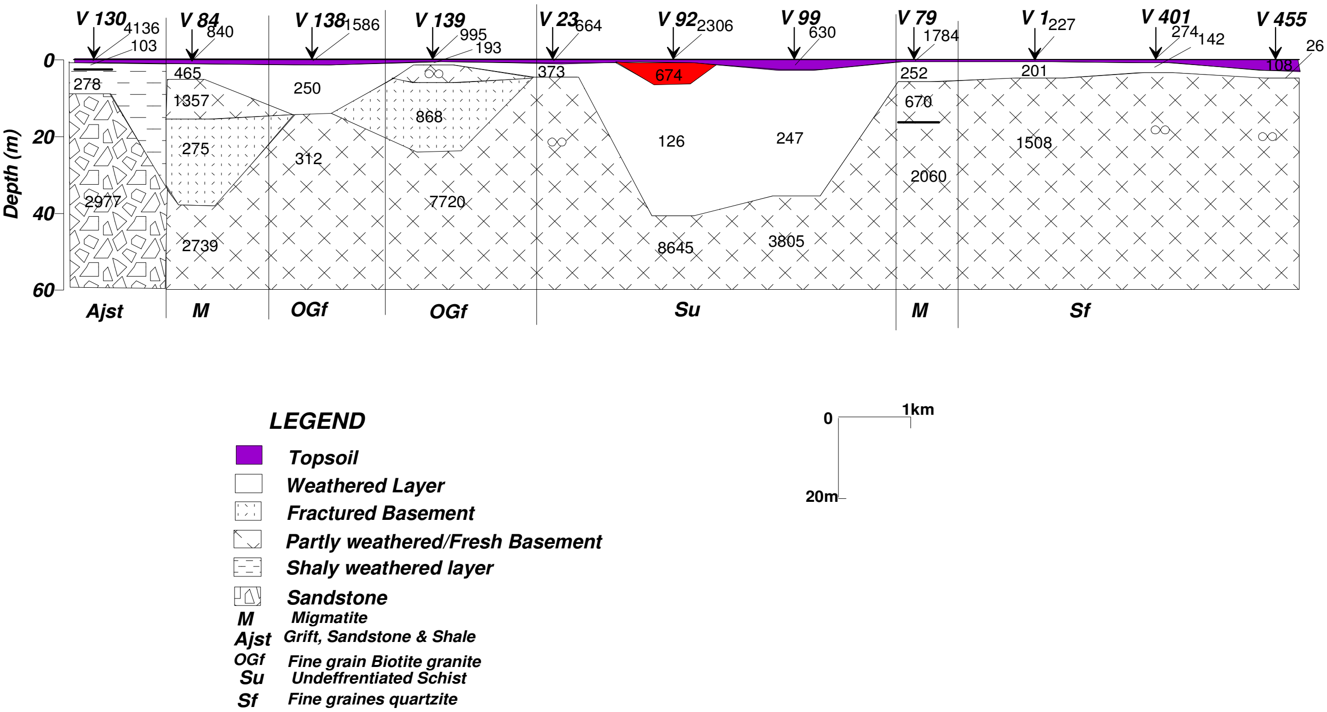

Figure 9. Typical geo-electric section across various rock types in the study area.

thickness between 0.8 and 53.1 m with resistivity value ranging from 21 to 15,000 Ωm. Average thickness and resistivity values are 13.8 m and 25, 000 Ωm respectively. The fractured/fresh bedrock has resistivity values ranging between 21 Ωm and infinity, while depth to basement bedrock lies between 1.1 and 61.2 m. Basement fracture/fault were delineated beneath some of the VES locations in the study area.

While the low resistivity within the topsoil and underlying layer can be attributed to silts and surface contamination from effluents from the industrial waste or mechanic workshops, high resistivity values can sometimes be attributed to out cropping bedrock in the basement terrain.

Figure 9 shows a typical geo-electric section across the rock units in the area. It was discovered that overburden is mostly thick over undifferentiated Schists, grifts and sandstone formations, ranging from 15 to about 61.2 m, while generally in the study area the overburden is relatively thin as reflected in the average depth to basement of 13 m. Basement fracture exists mostly in areas underlain by migmatite, porphyritic biotite and medium-coarse-grained biotite gneiss.

Resistivity distribution within the earth depends on many factors among which are the composition of the subsurface materials, degree of weathering or fracturing, saturation of the vadoze zone and ionic concentration within the saturated zone (Al-Tarazi et al., 2006; Corriols and Dahlin, 2008).

From Figures 4 to 6, the aquifer types are classified into three:

(1) Unconfined: *in-situ* weathered or weathered/fractured aquifer.
(2) Confined: weathered/fractured bedrock aquifer or fractured bedrock aquifer overlying by impermeable lithology.
(3) Leaky aquifer: semi-confined aquifer underlying or overlying by fractured/porous medium.

In Figure 4, predominant aquifer type is the unconfined aquifer (type I) occurring majorly on four rock units: migmatite (212), undifferentiated schists (55), fine grained quartzite and schists (25) and charnokitic rocks (7). This is followed by type-II (confined aquifer) which occur most on pegmatite (32), followed by charnokite (19), undifferentiated older granite (14), granitic gneiss (6), grifts and sandstone (3), migmatite (3), shalley formations (3), as shown in Figure 5. In Figure 6, type-III (leaky aquifer) occur least across the area on the medium-coarse-grained biotite gneiss (25), porphyritic biotite (6) and fine grained biotite (2).

Since groundwater occurs under water-table conditions in the clayey sand/sand aquifer as well as under semi-confined to confined conditions in the weathered/fractured zone (Adepelumi et al., 2006), there is a need to investigate interrelationships between geology, aquifer characteristics and geoelectric parameters

(Olorunfemi and Fasuyi, 1993).

Geophysically, this relationship can be investigated by computing hydraulic conductivity and transmissivity in terms of the electrical resistivity rather than conventional approach of employing effective porosity or other hydrogeologic parameters of the aquiferous zone (Röttger et al., 2005; Singh, 2005). These parameters are made use in deriving the relationship between the aquifer characteristics, geology and geo-electric parameters over the study area. According to Singh (2005), the non-linear relationship between hydraulic conductivity (K) and aquifer resistivity (ρ) is:

$$K = 0.0538e^{0.0072\rho} . \qquad (1)$$

Where ρ equals the resistivity of the aquifer unit.

The transmissivity; $T = K \times h$ (2)

Where h is the thickness of the aquifer unit.

For the unconfined aquifer, on the basis of aquifer resistivity and thickness values, the estimated hydraulic conductivity (K) varies from 0.0057 to 418.1052 m/day, and transmissivity values ranges between 0.0065 and 926.995 m^2/day for the clayey/clayey sand aquifer. For the semi-confined aquifer, the hydraulic conductivity ranges from 0.0063 to 26.147 m/day, while the transmissivity values ranges between 0.005 and 371.2869 m^2/day. For the weathered/fractured aquifer, the estimated hydraulic conductivity values varies between 0.0063 and 256.2448 m/day, while the transmissivity values ranges from 0.0112 to 3356.806 m^2/day.

The estimated average hydraulic conductivity for the aquifer units are 4.43, 0.96 and 4.58 m/day, while their mean transmissivity values are 13.00, 8.71 and 60.18 m^2/day. Estimated parameters show that the aquifer units indicate very poor to moderately permeability.

Conclusion

The integration of geoelectric assessment and GIS analysis had been successfully used for evaluating the impact of rock types on aquifer characterization in the hard-rock area of Southwestern Nigeria. The VES interpretation revealed a maximum of four geologic units, which include top soil, lateritic/weathered layer, weathered layer and fractured/Fresh basement beneath the VES stations. The aquifer types recognized in the area are the confined, unconfined and leaky aquifers. In most cases overburden is generally thin across the basement terrain with the exception of areas underlain by undifferentiated schists, grifts and sandstone formations.

The results of geospatial analyses and correlation between the geoelectric soundings and rock types revealed that there is significant impact of rock types on the aquifer types in the area. It was discovered that distribution of unconfined aquifers appears to spread across most of the rock types due to their occurrence at shallow level, but confined and leaky aquifers are restricted in distribution to certain rock types. Occurrences of leaky and confined aquifers are attributed to development of secondary porosity associated with joints, fissures and fractured bedrock at greater depth. It is also evident that aquifer units across the study area have very poor to moderate permeability, which is the reason why most wells in the area usually have low groundwater yield. However, areas characterised with aquifer types having high hydraulic conductivity and high transmissivity values are good zone for groundwater development in the area. In addition, most groundwater systems in the study area require water treatment due to high clay content within the aquifer units as well as possible contamination that could arise from infiltration into the shallow aquifers in areas underlain by crystalline rocks.

REFERENCES

Adepelumi A, Yi-j MJ, Kim JH, Ako BD, Son JS (2006). Integration of surface geophysical methods for fracture detection in crystalline bedrocks of southwestern Nigeria. Hydrogeol. J., 14: 1284-1306.

Alile MO, Jegede SI, Ehigiator OM (2008). Underground water exploration using electrical resistivity method in Edo State, Nigeria. Asian J. Earth Sci., 1: 38-42.

Al-Tarazi E, El-Naqa A, El-Waheidi M, Abu RJ (2006). Electrical geophysical and hydrogeological investigations of groundwater aquifers in Ruseifa municipal landfill, Jordan. Environ. Geol., 50: 1095-1103.

Asfahani J (2006). Geoelectrical investigation for characterizing the hydrogeological conditions in semi-arid region in Khanasser valley, Syria. J. Arid Environ., 68: 31-52.

Bala AN, Ike EC (2001). The aquifer of the crystalline basement rocks in Gusau area, North-western Nigeria. J. Min. Geol., 37(2):177-184.

Barker R, Rao TV, Thangarajan M (2001). Delineation of contaminant zone through electrical imaging technique; Curr. Sci., 81(3): 277–283.

Bello AA, Makinde V (2007). Delineation of the aquifer in the South-Western part of the Nupe Basin, Kwara State, Nigeria. J. Am. Sci., 3: 36-44.

Corriols M, Dahlin T (2008). Geophysical characterization of the Leon-Chinandega aquifer, Nicaragua. Hydrogeol. J., 16: 349-362.

Dan-Hassan MA, Olorunfemi MO (1999). Hydro-geophysical investigation of a basement terrain in the north central part of Kaduna State, Nigeria. J. Min. Geol., 35 (2): 189-206.

Hazell JRT, Cratchley CR, Preston AM (1988). The location of aquifers in crystalline rocks and alluvium in northern Nigeria using combined electromagnetic and resistivity techniques. Q. J. Eng. Geol., 26: 59-175.

Idowu OA, Ajayi O (1998). Groundwater occurrence in Southwestern Nigeria. A comparism of two environments. J. NAH, 9: 33-40.

Ismailmohamaden MI (2005). Electric resistivity investigation at Nuweiba Harbour Gulf of Aqaba, South Sinal, Egypt. Egypt. J. Aquat. Res., 31: 57-68.

Jone HA, Hockey RD (1964). The geology of part of south-western Nigeria. Geol. Surv. Nig. Bull., 31: 87.

Khitam JM, Yolla YA, Sana TB, Waseem JH (2003). Applications of Aerial Photo-Interpretation GIS Data Model in Dams and Water Wells sites selection, Princess Tasneem Bint Ghazi for Technology Research Station (Unpublished). Al-Balqa Applied University, Al-Salt, Jordan.

Kovar K, Nachtnebel HB (1993). Application of Geographic Information Systemin hydrology and water resources management, IAHS Publication No. 211. International Association of Hydrological Sciences Press, Wallingford.

Lashkaripour GR, Sadeghi H, Qushaeei M (2005). Vertical electrical soundings for groundwater assessment in Southeastern Iran: A case study. J. Appl. Sci., 5: 973-977.

Leroux V, Dahlin T, Svensson M (2007). Dense resistivity and induced polarization profiling for a landfill restoration project at Harlov, Southern Sweden. Waste Manage. Res., 25: 49-60.

Odusanya BO, Amadi UNP (1990). An empirical resistivity model for predicting shallow groundwater in the Basement Complex Water Resources – J. Nig. Assoc. Hydrogeol., 2: 77- 87.

Olayinka AI, Mbachi CNC (1992). A technique for the interpretation of electrical sounding from crystalline basement areas of Nigeria. J. Min. Geol., 27: 63-69.

Olorunfemi MO, Fasuyi SA (1993). Aquifer types and the geoelectric/hydrogeologic characteristics of part of central basement terrain of Nigeria (Niger State) J. Afr. Earth Sci., 16(3): 309-317.

Olorunfemi MO, Ojo JS, Olayinka AI, Mohammed MZ (2001). Geophysical investigation of suspected springs in Ajegunle-Igoba, near Akure, southwestern Nigeria. Global J. Pure Appl. Sci., 7(2): 311-320.

Rahaman MA (1988). Recent advances in the study of the Basement complex of Nigeria Precambrian Geology of Nigeria. Geol. Surv. Nig., pp. 11-41.

Rahaman MA, Ocan O (1978). On the relationships in the Precambrian Magmatic Gneissis of Nigeria. J. Min. Geol., 15: 23-32.

Röttger B, Kirsch R, Scheer W, Thomsen S, Friborg R, Voss W (2005). Multifrequency Airborne EM surveys – A Tool for Aquifer Vulnerability Mapping. – In: D.K. Butler (ed.): Near surface geophysics, investigations in Geophysics No. 13, Soc. Eng. Geophys., pp. 643–651.

Satpathy BN, Kanungo BN (1976). Groundwater exploration in Hard rock terrain- A case study. Geophys. Prospect., 24(4): 725-763.

Seidel K, Lange G (2008). Direct Current Resistivity Methods. In: Environmental Geology Handbook of Field Methods and Case Studies, Knodel KG, Lange and H. Voigt (Eds.). Springer, USA., pp. 205-237.

Singh KP (2005). Non-linear estimation of aquifer parameters from surface resistivity measurements. Hydrol. Earth Syst. Sci. Discuss., 2: 917-938.