Geoelectrical Prospecting for Regolith Aquifer in Kundu, Zungeru Sheet 163, Nigeria

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Abstract

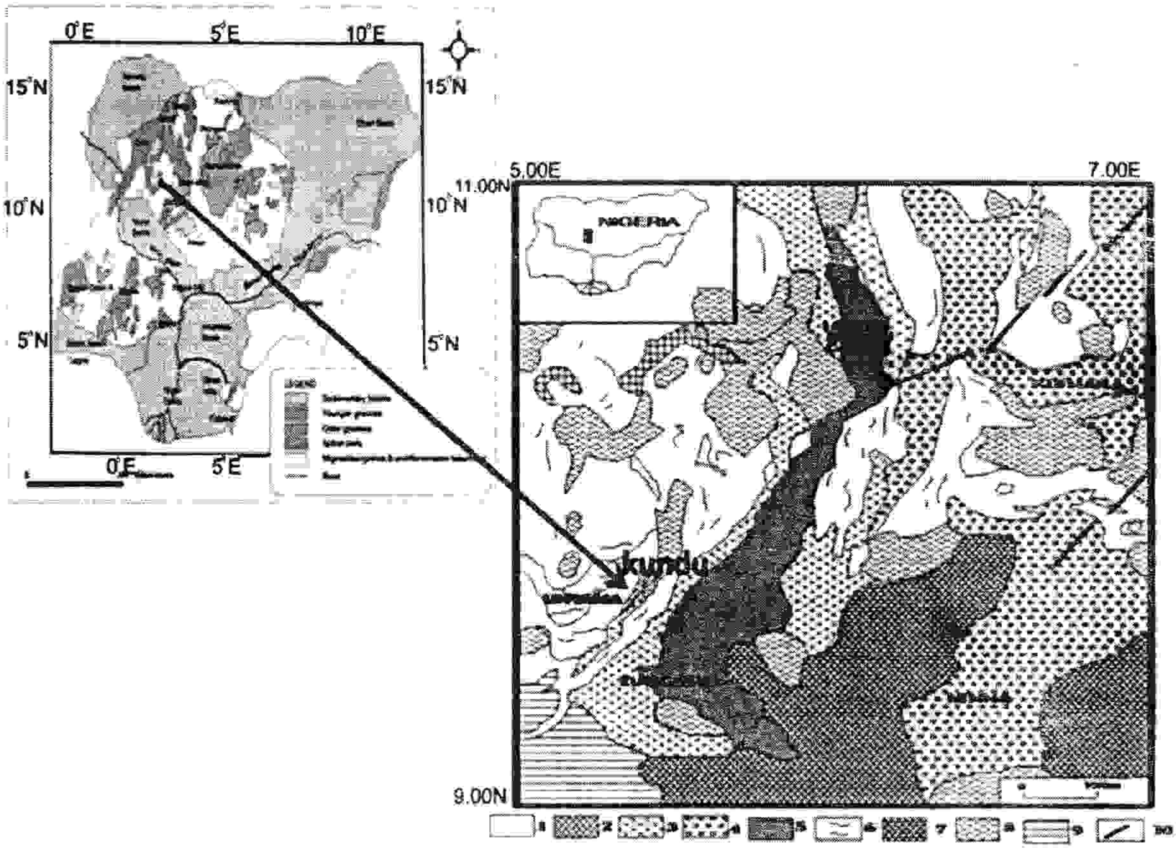
This work employed surface geological mapping, surface fracture density and permeability mapping, in combination with Vertical Electrical Sounding (VES), Spontaneous Potential (SP) and Induced Polarisation (IP) sounding to delineate places within Kundu where hand-dug wells would produce water from regolith. Such places should be potential groundwater convergence zones which combine appreciable regolith thickness with resistivity and IP values that indicate low clay content and groundwater saturation. Regolith in this work is defined as the interval from soil's top to the first fresh basement surface. The soundings were conducted at fifty one stations, using *ABEM SAS 4000* device and Schlumberger array with maximum electrode spacing of 200 m. Topographic depression within the first fresh basement surface was identified within longitudes 6°8'34.08"E - 6°9'00"E and latitudes 9°49'15"N -9°49'26.04"N. The depression constitutes a potential groundwater convergence zone within the regolith. Regolith thickness in this zone ranges from 10 to 20 m. The apparent resistivity values (150 to 450 Ωm) and IP values (lower than 10 ms) indicate groundwater occurrence and very low clay content within regolith aquifer in the zone. Significant surface fracture density (0.045-0.065 m^{-1}) and surface fracture permeability (20-80 m^2) characterise outcrops in immediate neighbourhood of regolith in the zone. Mosaic map of regolith base elevation, IP, SP and resistivity values was produced. The map reveals that regolith topographic and electrical attributes indicate high productive potential within SSE to SE (defined by longitudes 6°8'34.8"E; 6°9'0"E and latitudes 9°49'15"N; 9°49'25"N) of the study area. Hand-dug wells commonly produce water from regolith in such zones in basement terrains. Inhabitants of Kundu may dig wells manually into the delineated groundwater convergence zone within SSE to SE of the study area to obtain water from the regolith aquifer.

Keywords: Regolith, Groundwater convergence, Fresh basement surface

Introduction

Kundu is a rural community within latitudes 9°49'N to 9° 50'N and longitudes 6° 08'E to 6° 09'E, in the north-west of Zungeru Sheet 163 of Nigeria. This community is within the Ushama schist belt on the west of longitude 8°E line, which divides the Nigeria basement complex terrain into schist dominated belt (on the west) and migmatite-gneiss-granite dominated belt on the east (Figure1). In basement complex terrains, regolith is a mantle of clastic detritus derived from *in situ* weathering of the underlying fresh bedrock. The regolith may sometimes sharply overlay fresh bedrock. In the contrary situation, it includes a transitional interval of saprock (large fragments of fresh bedrock set in a weathered matrix) that overlies fractured bedrock, which in turn overlies fresh basement. In this work, the regolith is taken to be the interval from soil's top to the first fresh basement surface. The regolith is a sole aquifer unit (Rao, 1987; Olorunfemi and Fasuyi, 1993; Bala, 2008; Mbilmbe *et al.*, 2010; Ojoina, 2014; Wright, 2015). Many homes in basement complex terrains in Nigeria obtain potable water from regolith aquifer.

Only three boreholes presently produce water in Kundu. These are grossly inadequate to provide potable water for the inhabitants. Instead of exploiting the regolith aquifer via hand-dug wells, the inhabitants fetch water from nearby channel of River Kaduna, eastwards of the town, to meet their domestic water needs. Apart from the sad fact that people occasionally get drowned in the river, the brownish colour of the water in the river indicates its unfitness for drinking.



1.Migmatite gneiss (pre-pan-African) 2. Kyanite and silimanite bearing quartzite 3. Zungerumylonite 4. Kushaka Formation 5. BirninGwari Formation 6. Ushama Schist Formation 7. Foliated Tonalite 8. Late Pan-African granite 9. Cretaceous to Recent sediments 10. Major Fracture

Figure1: Study area within regional geological setting (after Ajibade *et al.*,1989).

The Addressed Problem

Outcropping rocks in Kundu include quartzite, and quartz-biotite schist that gradually changes into quartz-muscovite schist. The association of quartzite with such lateral lithofacies change suggests that the protolith for the metamorphic rocks could be sedimentary rocks.

Russ (1957) and Ajibade *et al.* (2008) already attributed sedimentary origin to the quartzite and schists in the area. It is very challenging to locate portions with productive aquifer attributes in regolith derived from such paraschists (Bala, 2008; Ismail and Yola, 2012). This is obviously because of expected high clay content in schist derived from shales. The geomorphological position of the community also contributes a problem to aquifer potential of the regolith. The community is within the floodplain on the western bank of River Kaduna's lower reaches, where the river is perennial. Perennial rivers are often effluent at their lower reaches (Karanth, 2008). The regolith aquifer in Kundu loses groundwater to River Kaduna as it recharges the river. Groundwater oozes out towards the river at the south-eastern boundary of the community, from exposed contact of the weathered interval with unconfined fractured basement. This is because the water table in the regolith-unconfined fracture system is higher than water level in the river, and so must naturally flow down gradient in conformity with Darcy's law (Todd, 1980; Deming, 2002; Raghunath, 2006; Chernioff and Whitney, 2007). The hydrogeological situation thus demands identifying areas where the water table in the regolith-unconfined fracture system is topographically lower than the water level in the river. These would be areas where thick, low-clayey weathered unit overlies saprock and unconfined fractured bedrock within localised topographic depressions in fresh basement. Such areas are yet to be delineated in Kundu.

Synopsis of Relevant Literature

Bhattacharya and Patra (1964) emphasised that prospecting for groundwater is essentially a geological problem because groundwater occurrence is controlled by geology. Parasnis (1986) stressed that the success of a geophysical survey depends upon an intelligent combination of physics and geology. Kearey and Brooks (1988) remarked that the most widely employed geophysical methods in hydrogeology are the electrical methods. Jinadasa and de Silva (2009) employed electrical resistivity and SP methods to delineate areas with high potential for groundwater accumulation within hard-rock terrains of Moneragde in Sri Lanka. Badmus and Olatinsu (2012) utilised VES data at fifteen different stations to characterise basement rocks and evaluate groundwater potential within Odeda quarry area of Ogun State in Nigeria. Sarma (2014) presented a chronological review of researches conducted on electrical techniques at the National Geophysical Research Institute in Hyderabad. He emphasised that geoelectrical techniques are used extensively to locate hidden targets that are conductive and resistive in nature. He also emphasised that SP and IP methods are currently part of electrical techniques deployed for groundwater prospecting. Kumar (2014) utilised VES data to delineate regions with exploitable groundwater resources in parts of Kalmeshwar taluk district in India. Maxwell *et al.* (2015) employed VES to ascertain bedrock depth in Abuja, the Federal Capital City of Nigeria. Yelwa *et al.* (2015) employed VES data to identify groundwater saturated zones within the regolith and fractured bedrock aquifers in Kumbosto Local Government Area of Kano State in Nigeria.

Methodology

Thickness of soil and weathered basement were determined along roadcutting and other exposed sections. Field geological mapping was conducted on a base map of scale 1:25000 generated from Sheet 123 (Zungeru) and a geological map was produced (Figure 2). During the mapping, surface fracture density (SFD) was determined at different locations using:

$$SFD = \frac{\mathrm{NF}}{\mathrm{LAF}} \quad \text{(Deming, 2002)} \qquad (1)$$

In the equation, LAF is length taken across the fractures while NF is number of fractures crossing LAF.

Surface fracture permeability (SFP) was also determined using:

$$SFP = \frac{\mathrm{SFD} * \mathrm{NFW}^3}{12} \quad \text{(Deming, 2002)} \qquad (2)$$

In the equation, W represents average width of fracture at each location. The *SFD* and *SFP* values at the different locations were contoured using *Surfer 32* contouring software.
Vertical electrical sounding (VES), spontaneous potential (SP) and induced polarisation potential (IP) soundings were conducted using *ABEM SAS 4000* device at fifty one stations, employing the Schlumberger array. The stations were distributed roughly at 50m intervals, along eighth traverses that are 100 m from each other. The traverses were oriented approximately NNW-SSE (parallel to outcrops' foliation dip direction) and the electrodes arranged NNE-SSW (outcrops' foliation strike direction). This data acquisition configuration was to minimise the influence of lateral lithologic variations that would occur if electrodes were planted in dip direction. It ensures that data was influenced largely by homogeneous lithologic units and any anomaly-generating accumulations within the individual lithologic units. The equipment measured electrical resistance, R, directly. Apparent resistivity (ρ_a) was calculated using:

$$\rho_a = GR \qquad (3)$$

$$G = \frac{\pi}{4}\left[\frac{(\mathrm{AB})^2 - (\mathrm{MN})^2}{MN}\right] \qquad (4)$$

Calculated ρ_a values, as well as cumulative ρ_a were plotted against half electrode spacing (AB/2) on log-log graph sheets. Cumulative ρ_a method of Raghunath (2006) was employed to estimate approximate number of geoelectric layers and depth to their respective top. The values obtained were adjusted using measured thickness of top soil and weathered unit at roadcutting and other exposed sections. Each geoelectric layer was assigned an approximate ρ_a. The assigned ρ_a is a distinct discontinuity value in the pattern of variation in ρ_a values within vertically adjacent geoelctric layers. The approximate number of layers and estimated depth to their respective top, as well as the approximate ρ_a for each layer, measured ρ_a and AB/2 data were inputted into *WinResist (*indirect resistivity modelling software) to generate geoelectric sections. Regolith unit was determined from the geoelectric section on the basis of resistivity variation pattern. Regolith thickness was contoured against geographic coordinates (obtained with a Global Positioning System device, GPS) at each sounding location, using *Surfer 32* contouring software. The base of the regolith was taken as top of first fresh basement layer. Depth to top of first fresh basement layer was subtracted from surface elevation (obtained with GPS) to obtain basement topographic elevation with respect to sea level. This is subsea basement elevation. The subsea basement elevation was contoured against geographic coordinates at each sounding location, using *Surfer 32*. Representative ρ_a, and IP values for the regolith at each sounding location were similarly contoured. Values of SP for the first fresh basement surface were also contoured. Areas with IP values lower than 10ms were interpreted to be portions of regolith with a very little clay content (Parasnis, 1986; Keary and Brooks, 1988; Lowrie, 1997; Musset and Khan, 2000; Reynolds, 2011). Areas that are characterised by both low ρ_a and low IP values were interpreted to be portions of the regolith with groundwater saturation attributes.

Results and Discussion

Gneiss, schist and amphibolite underlay the study area. Quarzite outcrops as lenses within the gneiss and schist (Figure 2). The rocks trend NNE-SSW and dip SSE.

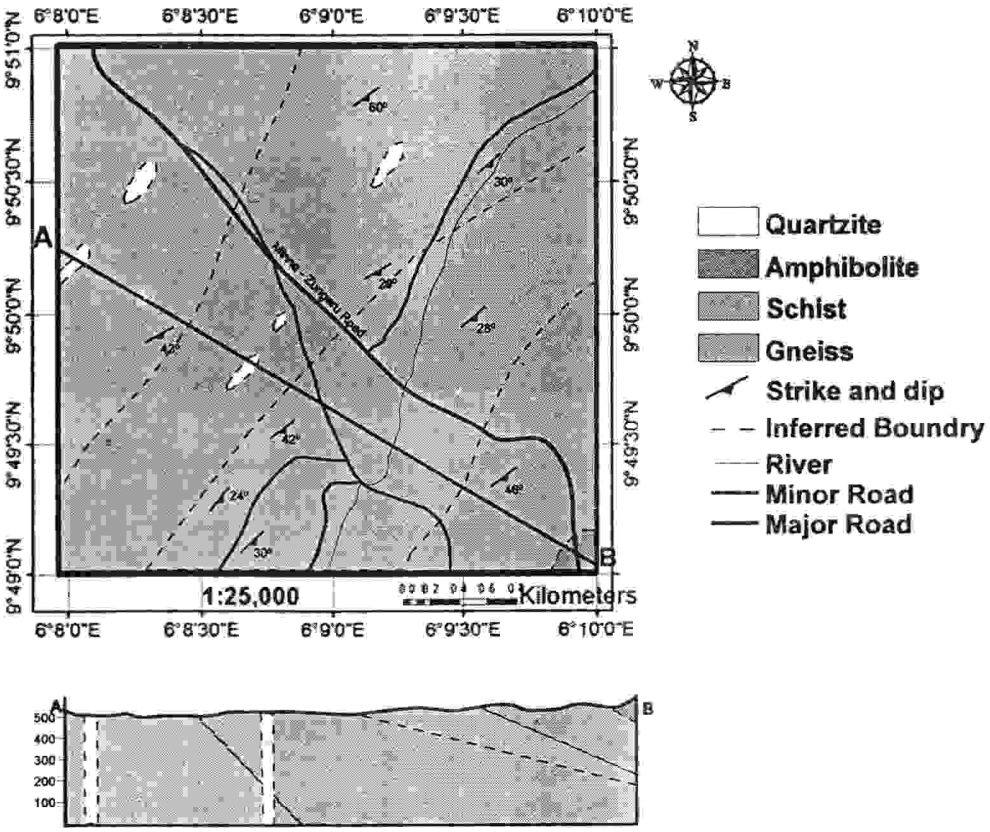


Figure 2: Geological map and cross section of the study area

The locations of the geoelectric stations are presented as Figure 3.

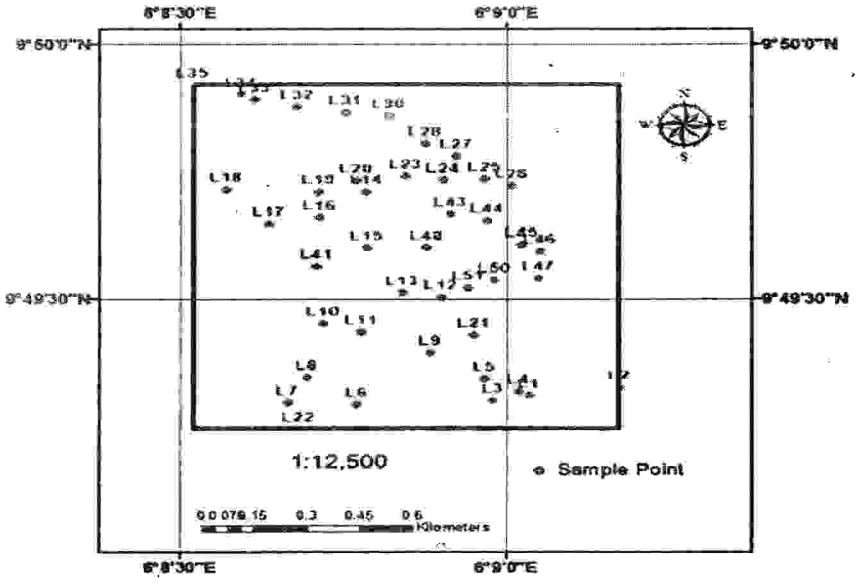


Figure 3: Location map of the geoelectric sounding stations.

Some of the field VES data (together with their modelled resistivity curve and geoelectric section) showing regolith with low resistivity values are presented as Figures 4 to 6.

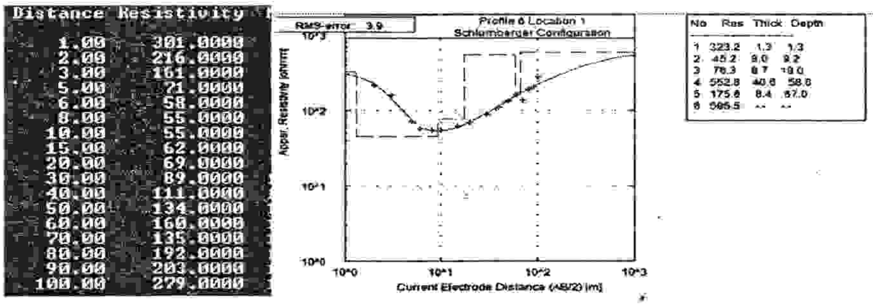


Figure 4: VES data, modelled resitivity curve and geoelectric section at VES L18 (9°49'42.96"N;6°8'42.72"E)

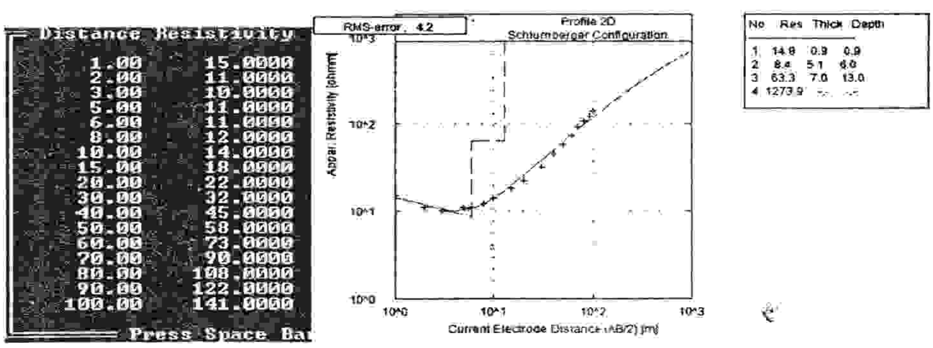


Figure 5: VES data, modelled resitivity curve and geoelectric section at VES L10 (9°49'17.76"N; 6°8'39.6"E).

Distance	Resistivity
1.00	23.0000
2.00	25.0000
3.00	22.0000
5.00	23.0000
6.00	25.0000
8.00	30.0000
10.00	36.0000
15.00	47.0000
20.00	55.0000
30.00	76.0000
40.00	138.0000
50.00	154.0000
60.00	231.0000
70.00	192.0000
80.00	126.0000
90.00	252.0000

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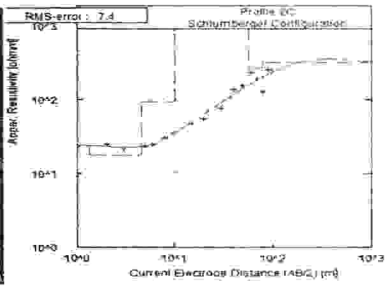

No	Res	Thick	Depth
1	24.4	1.3	1.3
2	17.2	3.3	4.6
3	92.6	5.6	10.2
4	915.8	47.8	58.0
5	264.3	19.8	17.8
6	315.5	--	--

Figure 6: VES data, modelled resitivity curve and geoelectric section at VES L5 (9°49'16.56"N; 6°8'43.4"E).

Contoured plot of the regolith thickness in the area is shown in Figure 7. The regolith thickness ranges from 2 to 40 metres. The regolith is thickest in the western and north-western portions of the study area. It generally thins toward the southern and south-eastern portions, where it is thinnest.

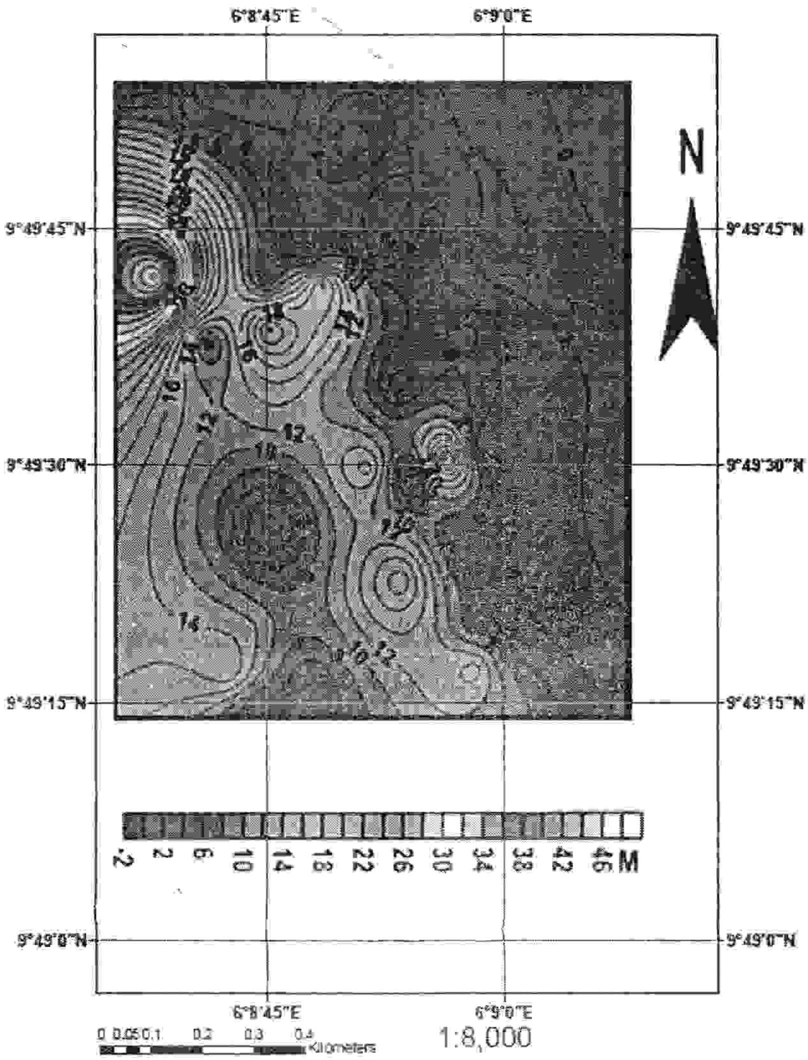

Figure 7: Regolith Thickness Map of Kundu.

Figure 8 is the topographic or elevation map (with respect to sea-level) of the regolith base (which is taken to be surface of the first or unconfined fresh basement). A pronounced topographic low (also known as localised basement depression) is indicated by black arrows on the figure in the portion defined by Long. 6°8'34.8"E; 6°9'00"E and Lat. 9°49'15.6"N; 9°49'26.4"N. Such regions are groundwater convergence zones, where wells are commonly productive (Olorunfemi and Okhue, 1992; Dan-Hassan and Olorunfemi, 1999; Olorunfemi, 2009). This is because groundwater generally flows from higher elevation areas down gradient to lower elevation regions, in response to Darcy's law (Deming, 2002; Chernicoff and Whitney, 2007; McKenzie *et al.*, 2011). The convergence zone in Figure 8 approximately coincides with zone where the regolith is locally thick (about 10 to 20 m) in southern portion of Figure 7.

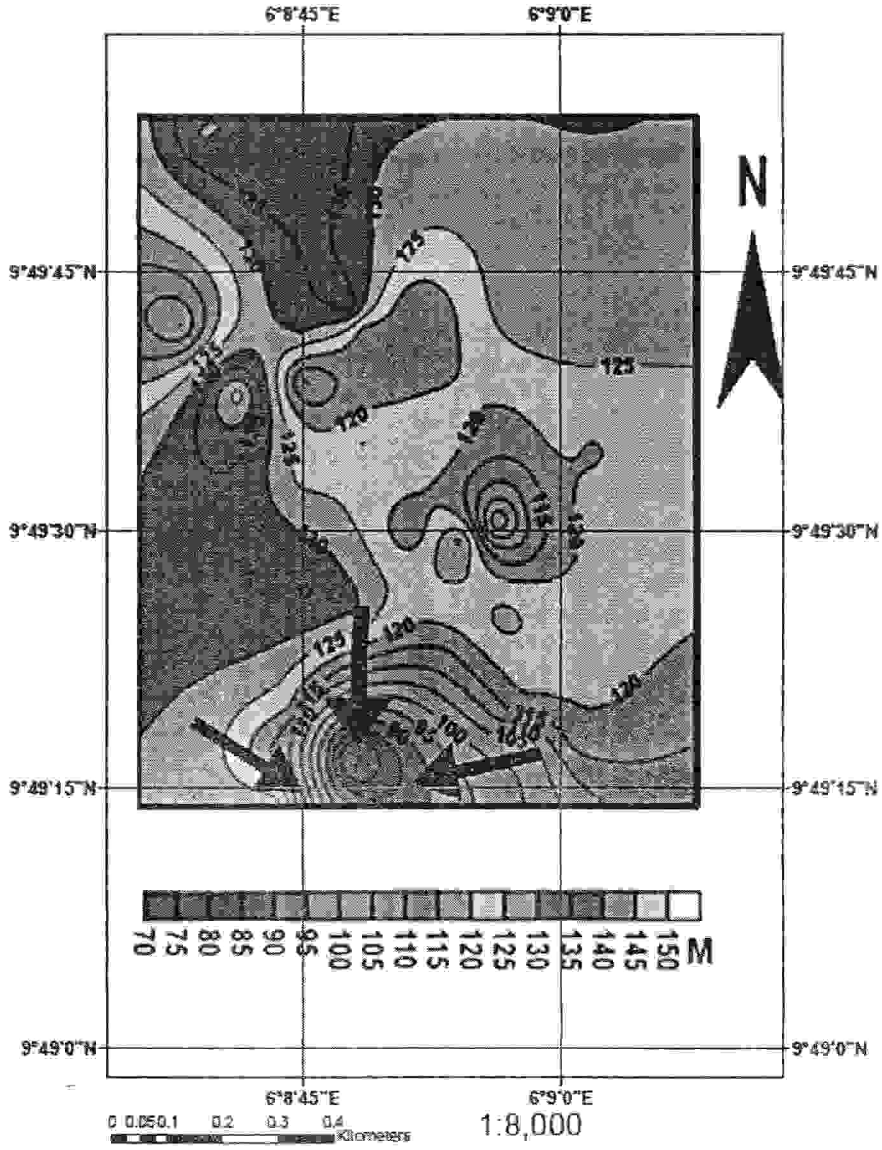

Figure 8: Regolith base (first or unconfined fresh basement surface) elevation map (with respect to sea-level).

Figure 9 is the contoured SP values map for the basement surface that under lays the regolith. Groundwater flows from zones with increasing negative SP values, through those of decreasing negative values, to zones with increasing positive SP values to create streaming potentials. Negative SP values indicate high elevations while positive SP values indicate depressions (Gay, 1967; Nayak, 1981; Telford *et al.*, 1990; Reynolds, 2011). The zone of localised high positive SP values (which reflect topographic depression) in southern portion of Figure 9 coincides approximately with localised topographic depression in southern portion of Figure 8. The arrows in Figure 9 indicate flow of groundwater from zones of negative SP values to zone of positive SP values, thereby upholding the interpretation that the topographic depression in Figure 8 (where the regolith is also locally thick in Figure 7) is a groundwater convergence zone within the regolith.

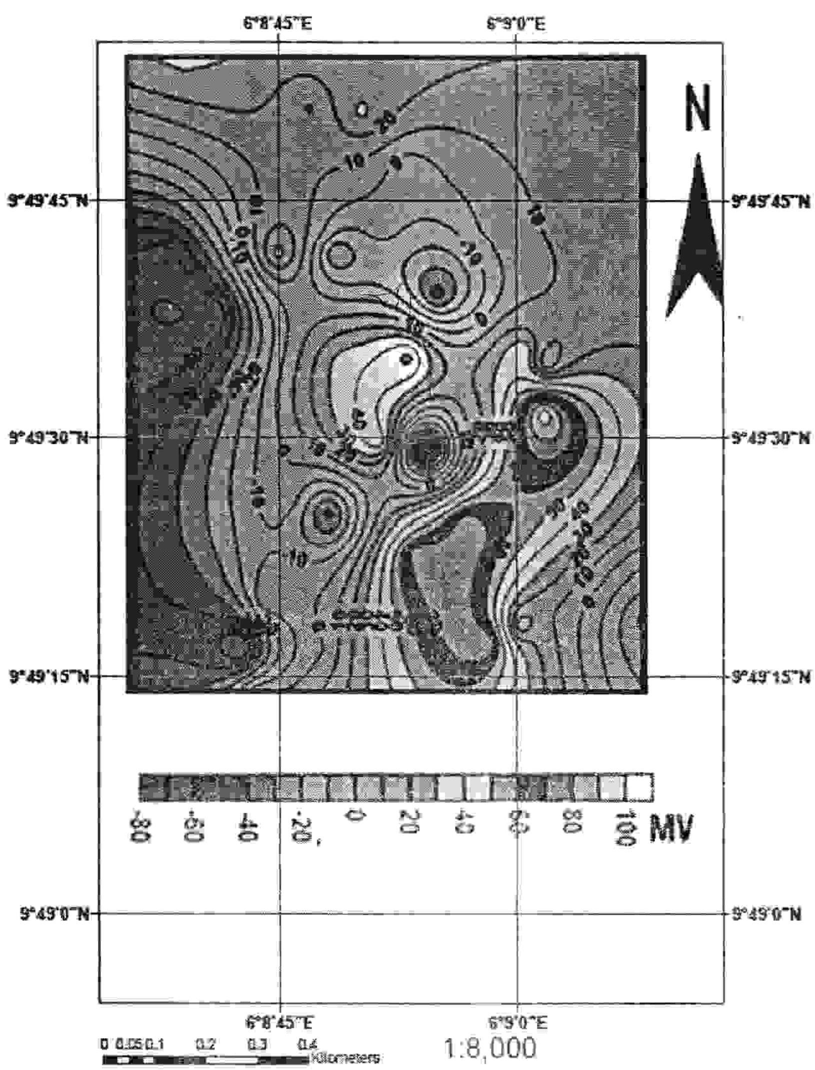

Figure 9: Map of SP values for basement surface underneath the regolith

Figure 10 is the regolith resistivity map. It indicates resistivity values of 200 to 500Ωm in the zone of topographic depression within Long.6°8'52.8"E; 6°9'00"E and Lat. 9°49'15.26"N; 9°49'26.4"N.

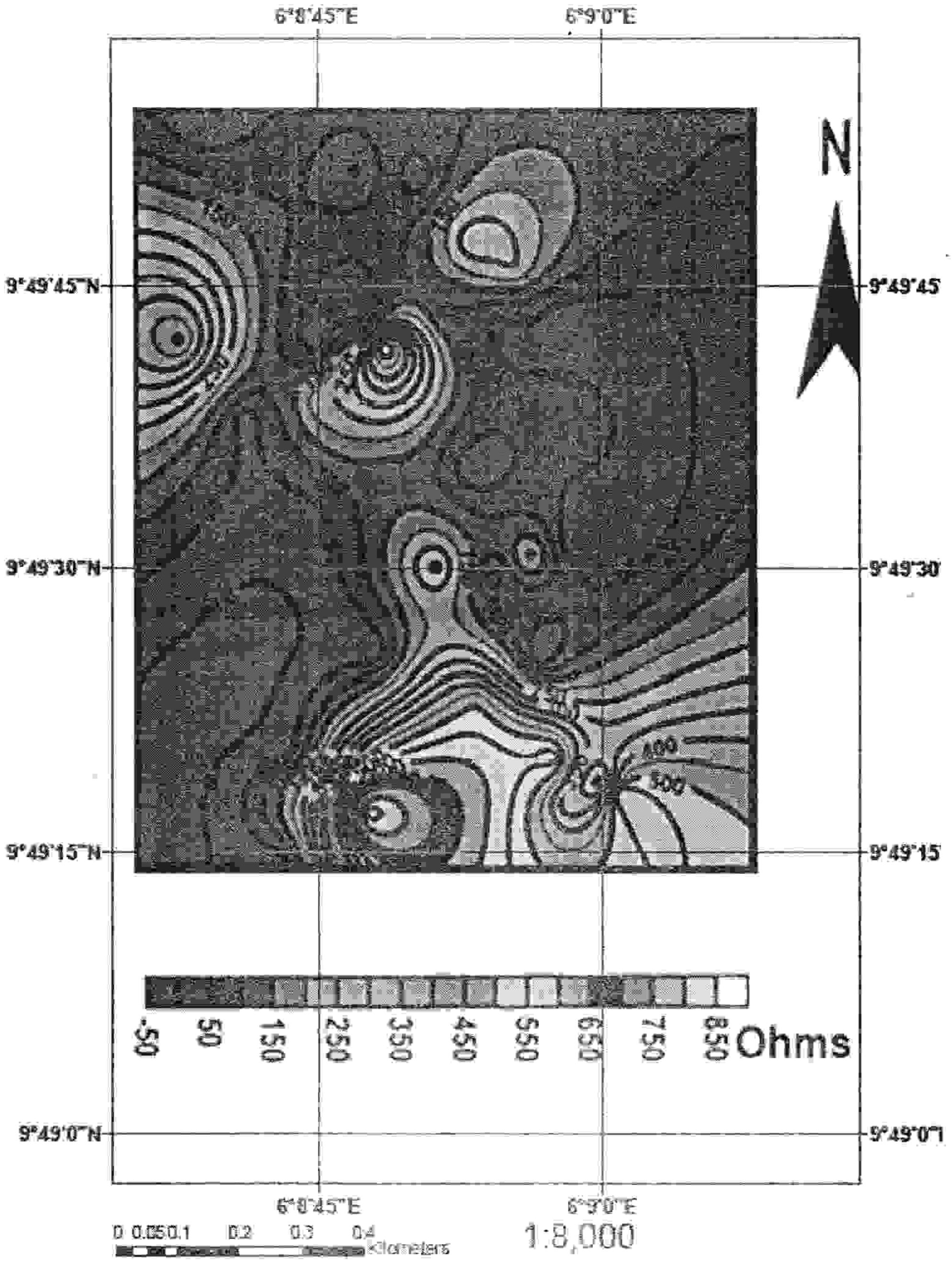

Figure10: Regolith resistivity map

Figure 11 is the IP values map for the area. The IP values are lower than 10 ms within the regolith in the topographic depression. Such IP values within regolith indicate very low clay content (or a very sandy regolith) in line with Keller and Frischknecht (1970), Kearey and Brooks (1988) and Lowrie (1997).

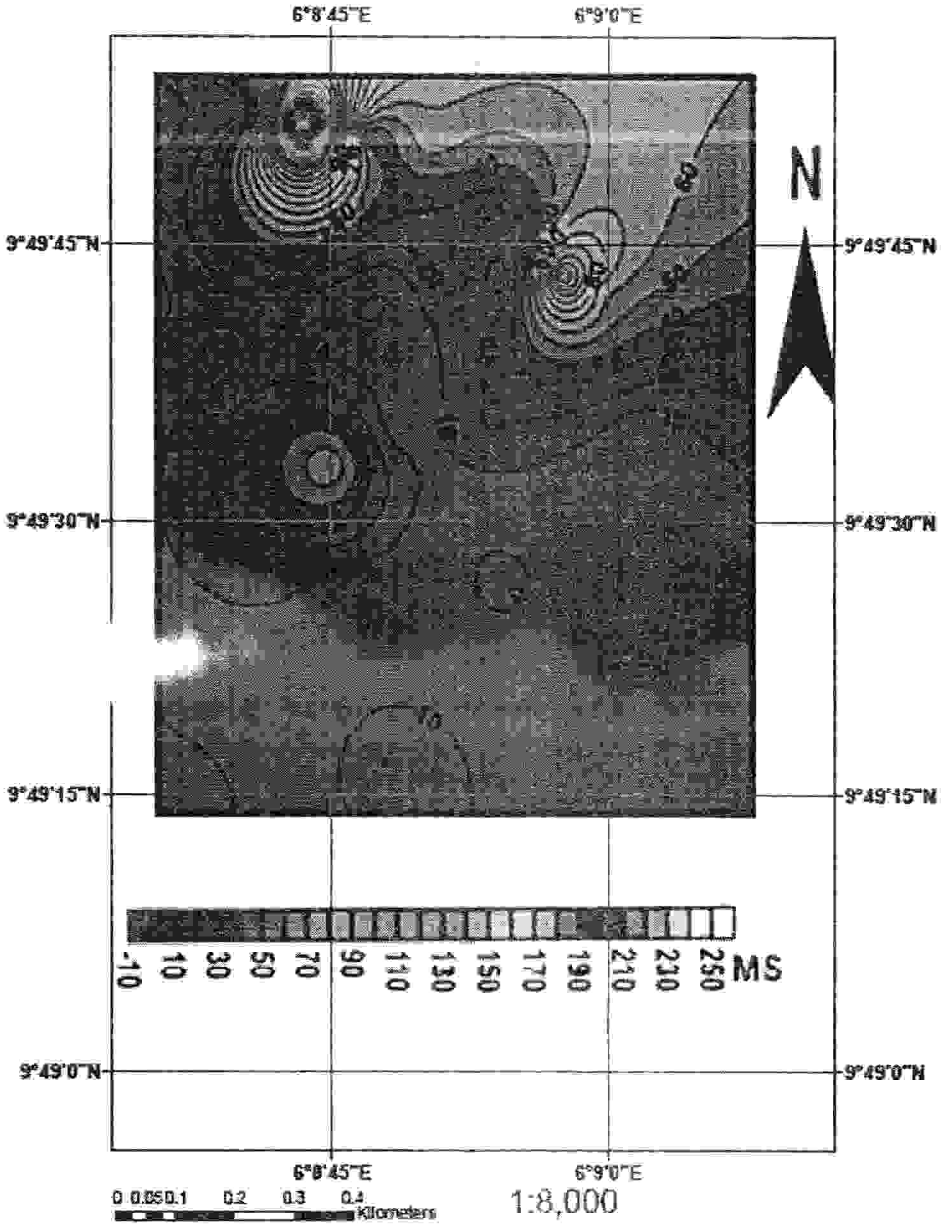

Figure 11: Regolith IP Map of Kundu.

Figures 12 and 13 are respectively the map of surface fracture density and surface fracture permeability. They reveal that the basement topographic depression is part of the highest surface fracture density and surface fracture permeability zones, defined within 6.143E (or 6°8'34.8"E); 6.148E (or 6°8'52.8"E) and 9.823N (or 9°49'22.8"N); 9.835N (or 9°50'16.8"N). The association of high surface fracture density and surface fracture permeability with thick non-clayey regolith indicates high groundwater potential. Hand-dug wells would produce water throughout the seasons of the year in such groundwater converging basement topographic depression zone that contains about 20 m of non-clayey regolith.

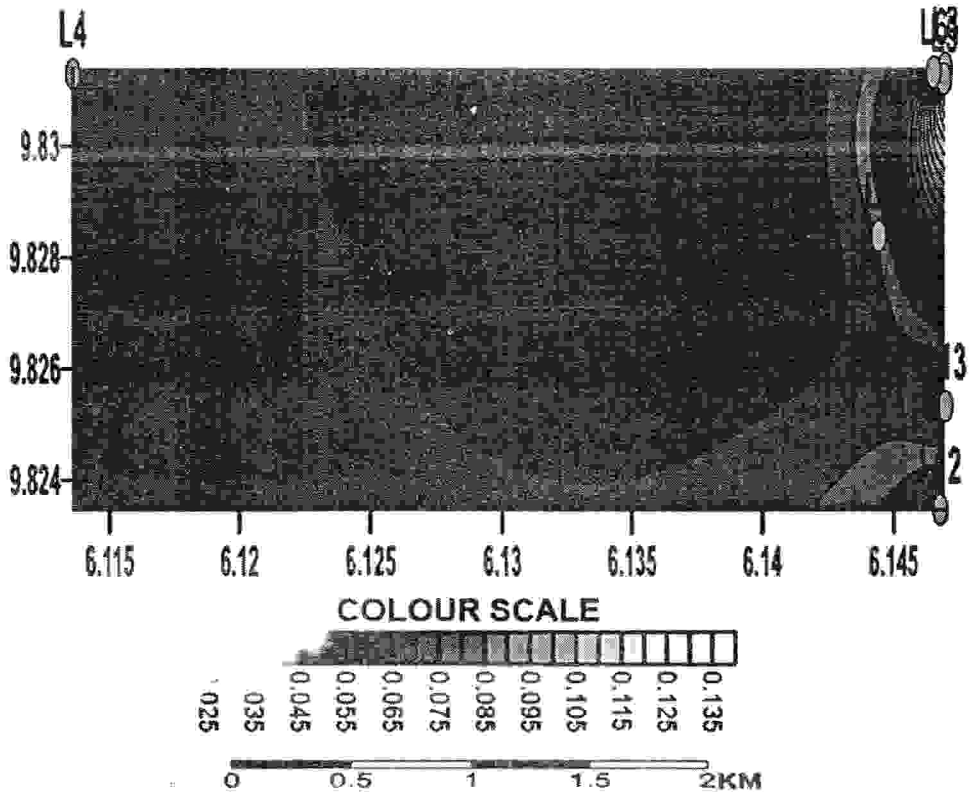

Figure 12: Surface Fracture Density map of Kundu (in m^{-1}).

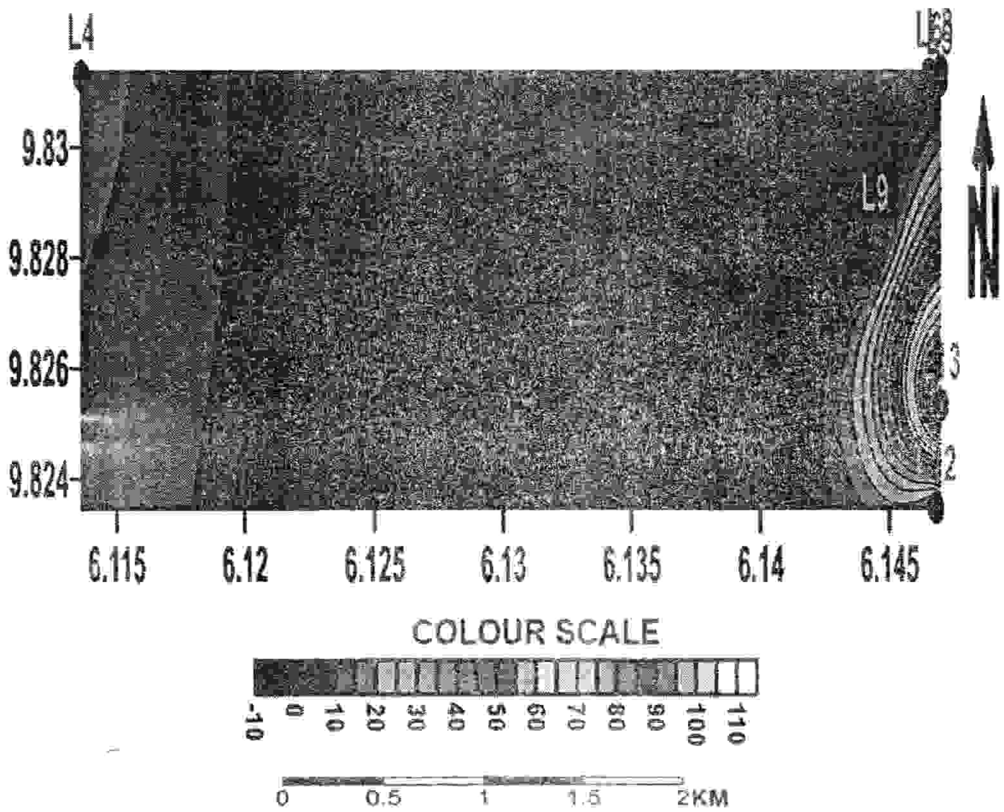

Figure13: Surface Fracture Permeability map of Kundu (in m^2).

Figure 14 is the mosaic map of regolith base elevation, IP, SP and resistivity values. The shaded portion on the mosaic map captures the zone where topographic depression on the first fresh basement surface coincides with all the groundwater indicative values of SP, IP and electrical resistivity. This zone is within SSE to SE of Kundu. The observed swamp in this portion of the study area validates its groundwater convergence setting and high potential for productivity of hand-dug wells.

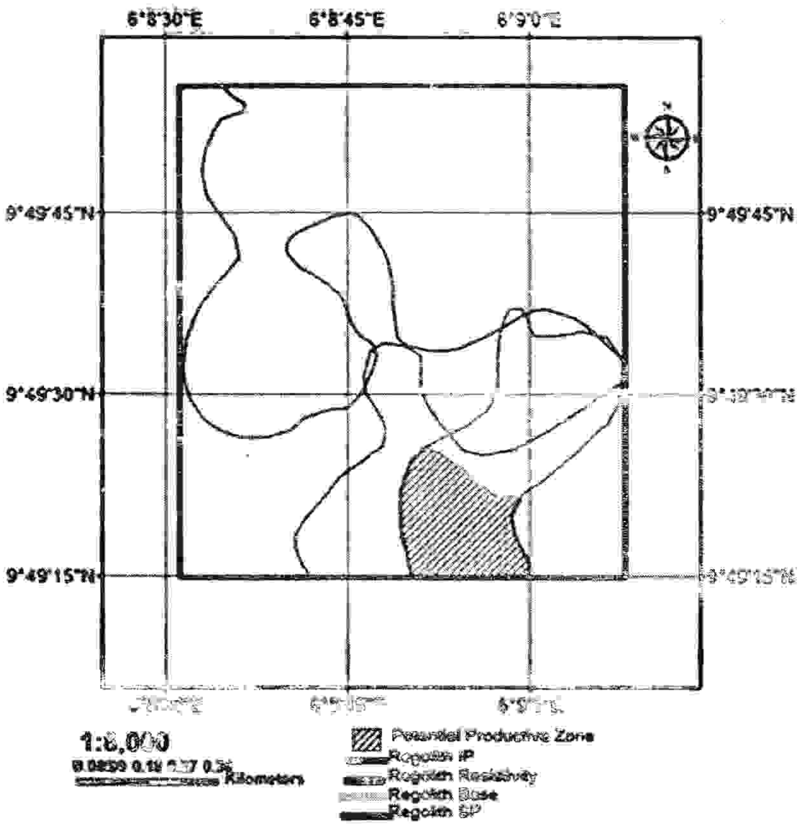

Figure 14: Mosaic map of regolith base elevation, IP, SP and resistivity values.

Conclusions and Recommendation

This study has employed electrical resistivity sounding data to identify subsurface basement depression zone with high potential to serve as groundwater convergence region within longitudes 6°8'34.8"E, 6°9'0"E and latitudes 9°49'15"N, 9°49'26.4"N. The probable inflow of groundwater into the convergence zone is validated [illegible] in magnitude of positive SP values towards the zone from its neighbourhood. Apparent resistivity values in the range of 150 to 450 Ωm and IP values lesser than 10 ms within the convergence zone have ascertained that it is likely groundwater saturated and non-clayey. The study has employed the coherence of topographic attribute for groundwater convergence with groundwater indicative resistivity values and non-clayey IP values to ascertain that hand-dug wells would be productive in part of Kundu that lies within longitudes 6°8'34.8"E, 6°9'0"E and latitudes 9°49'15"N, 9°49'25"N. Inhabitants of the study area may commence digging wells manually in [illegible] identified to possess productive regolith aquifer attributes.

References

Ajibade, A.C.,Woakes, M. and Rahaman, M.A. (1989). Proterozoic crustal development in the Pan- African regime of Nigeria. In:Kogbe, C.A. (ed.). *Geology of Nigeria*. Rock View Nig. Ltd.: 257-275.

Ajibade, A.C., Anyanwu, N.P.C., Okoro, A.U. and Nwajide, C.S. (2008). The geology of Minna area. *Geological Survey Agency*, Madol Press, Abuja.

Ajibade, A.C, Fitches, W.R., and Wright, J.B. (1979). The Zungeru mylonite, Nigeria: recognition of a major tectonic unit. *Rev.de Geol.Phys.*, 21(5), 359-363.

Ayuk, M.A., Adelusi, A.O. and Adiat, K.A.W. (2013). Evaluation of groundwater potential and aquifer protective capacity assessment at Tutugbua-Olugboyega area, off Ondo road, Akure, SW Nigeria. *International Journal of Physical Sciences*, 8(1), 37-50.

[illegible]mus, B. [illegible]ansu, O.B. (2012). Geophysical characterisation of Basement Rocks and Groundwater Potentials Using Electrical Sounding Data from Odeda quarry site, South-Western Nigeria. *Asian Journal of Earth Sciences*, 5(3), 79-87.

Bala, A.E. (2008). Optimum depth for boreholes in regolith aquifer in parts of Northern Nigeria.*Savanna*, 21(1), 81 – 90.

Bhattacharya, P.K. and Patra, H.P. (1968). Direct current geolectrical sounding. Elsevier Pub. Co., 135p.

Chernicoff, S. and Whitney, D. (2002). Geology: An Introduction to Physical Geology (fourth edition) Pearson prentice hall, New Jersey, 679p.

Dan-Hassan M.A. and Olurunfemi, M.O. (1999). Hydrogeophysical investigation of a Basement Terrain in theNorth Central part of Kaduna State Nigeria. *Journal of Mining and Geology*,35 (2),189-206.

Deming, D. (2002). Introduction to Hydrogeology. First Edition, McGraw Hill, New York, 463p.

Gay, S.P. (1967). A 1800 millivolt self-potential anomaly nerHualgayoe, Peru. *Geophysical prospecting*, 66: 236-245.

Ismail, A.Y. and Yola, A.L. (2012). Geoelectrical Investigation of Groundwater Potential of DawakinTofaLocalGovernment Area of Kano State Nigeria. *American International Journal of Contemporary Research*, 2 (9), 33-40.

Jinadasa, S.V. and de Silva, R.P. (2009). Resistivity imaging and self-potential applications in groundwater investigations in hard crystalline rocks in Sri Lanka. *Journal of Natural Science Foundation*, 37(1), p23-32.

Karanth, K.R. (2008). Groundwater assessment. Tata Mc-Graw Hill, New Delhi, 716p.

Keary, P. and Brooks, M. (1988). An introduction to geophysical prospecting, Blackwell Scientific publications, UK, 296p.

Keller, G.V. and Frischknecht, F.C. (1966). Electrical methods in geophysical prospecting, Pegamon Press, Oxford, 517p.

Kumar, D., Rai, S.N., Thiagarajar, S. and Kumari , Y.R. (2014). Evaluation of heterogeneous aquifers in hard rocks from resistivity sounding data in parts of Kalmeshwartaluk of Nagpur district, India. *Current Science*, 107(7), p 1137-1145.

Lowrie, W. (1997). Fundamentals of geophysics. *Wiley and Sons*, Cambridge.

Maxwell, O., Ejike, E.T. and Ugwuoke, D. E. (2015). Geophysical Analysis of Basement Terrain Using Vertical Electrical Sounding: A case Study of Part of Abuja, North Central Nigeria. *International Journal of Geophysics and Geochemistry*, 2(4), 29-97.

McKenzie, G.D., Strom, R.N., and Wilson, J.R. (2011). Groundwater processes, resources, and risks. In:BUSCH,R.M. (Editor). Laboratory Manual in Physical Geology. Prentice Hall, New York, p275-291.

Mbilmbe, E. Y., Samaila, N. K. and Akanni, D. K. (2010). Groundwater Exploration in a Complexterrain using electrical Resistivity Sounding (VES): a case study of Rimin Gado town and Environs, Kano State North Central Nigeria. *Continental Journal Earth Sciences, 5*(1), 56-63.

Mussett, A.E. and Khan, M.A. (2006). Looking into the earth: an introduction to geological geophysics. Cambridge University Press, New York, 470p.

Nayak, P.N. (1981). Electrochemical potential in surveys for sulphides. *Geoexploration*, **18**: 311-320.

Ojoina, O.A. (2014). Hydrogeophysical Investigation for Groundwater in Lokoja Metropolis, Kogi State, Central Nigeria. *Journal of Geography and Geology*, Vol. 6, 1(20), p81-95.

Olorunfemi, M.O. (2009). Groundwater exploration, borehole site selection and optimum drill depth in basement complex terrain. *Water Resources Special Publication Series 1*, 19p.

Olorunfemi, M.O. and Okhue, E.T. (1992). Hydrogeologic and geologic significance of a geoelectirc survey at Ile-Ife, Nigeria. *Journal of Mining and Geology*,8(2), 221-229.

Olorunfemi, M. O. and Fasuyi, S. A. (1993). Aquifer types and the geoelectric/hydrogeologic characteristic of partof the central basement terrain of Nigeria. *Journal of Africa Earth Science, 16*(3), 309-317.

Parasnis, D.S. (1986). Principles of Applied Geophysics.Fourth Edition. Chapman and Hall, New York, 383p.

Raghunath, H.M. (2006). Groundwater.Third Edition.New Age International Publications, New Delhi, 504p.

Rao, M.K. (1987). Geophysical studies for groundwater over metamorphic terrains. In : BHATTACHARVA, B.B.(Editor). Advances in Geophysics. IBA Publishing Co., New Delhi, 65-77.

Reynolds, J.M. (2011). An introduction to applied and environmental geophysics. Second Edition. *Wiley-Blackwell*, New Delhi, 778p.

Russ, W. (1957). The geology of parts of Niger, Zaria and Sokoto provinces. *Bulletin of Geological Survey of Nigeria,*15.

Sarma, V.S. (2014). Electrical (ER), Self Potential (SP), Induced Polarisation (IP), Spectral Induced Polarisation (SIP) and Electrical Resistivity Tomography(ERT) prospection in NGRI for the past 50 years: A Brief Review. *Journal IndianGeophy. Union, 18(2), 245- 272.*

Telford, W.M., Geldart, L.P., Sheriff, R.E. and Keys, D.A. (2001).Applied Geophysics. Cambridge University Press, UK, 763p.

Todd, D.K. (1980). Groundwater Hydrology.Second Edition. John Wiley and Sons, London, 535p.

Wright, E.P. (2015). The hydrogeology of crystalline basement aquifers in Africa. 27p. http://sp.lyellcollection.org/

Yelwa, N.A., Hamidu, H., Falalu, B.H., Kana, M.A. and Madabo, I. M. (2015).Groundwater prospecting and Aquifer Delineation using Vertical Electrical Sounding (VES) method in the Basement complex terrain of Kumbotso Local Government Area of Kano State Nigeria. *IOSR Journal of Applied Geology and Geophysics, 3(1),* p1-6.