USING GEO-ELECTRICAL SURVEY METHOD TO DELINEATE GROUNDWATER POTENTIAL ZONES – CASE STUDY OF MANDO/RIGASA AREA, KADUNA, NORTHWESTERN NIGERIA

JAMIU A. ALIMI
National Water Resources Institute, Kaduna
Correspondence: jamiualimi69@yahoo.com; +234(0)8039104697

ABSTRACT
Groundwater is an important source of water in both rural and urban settlements in Nigeria for various water needs. This resource is invisible and often there is very limited data available on its physical distribution and aquifer characteristics. Nigeria's geology is made up of sedimentary basins and Basement Complex roughly in equal proportions. While groundwater exploration in the sedimentary basins is not tedious, groundwater exploration in the Basement Complex is often difficult, because of low storage and spatial variability in groundwater occurrence. This study is aimed at delineating potential groundwater zones using geo-electrical survey method in Mando/Rigasa area, Kaduna, northwestern Nigeria. Well inventory was carried out in 45 open hand-dug wells. Thirty-nine Schlumberger configured Vertical Electrical Sounding (VES) stations spread across the study area were used to determine subsurface conditions. The geology of the area is predominantly granite-gneiss with quartzite. Four geoelectrical layers were delineated which are the top soil, sandy and gravelly weathered layer, the partially weathered/fractured layer and the fresh basement. Isoresistivity maps generated from the resistivity value distributions at depths of 10 m, 25 m and 50 m from the ground surface, as well as isopach maps drawn for the thicknesses of the overburden layer and aquifer zone from the interpreted field VES data indicate that the areas around the north/northwest, central and southeastern parts have relatively higher groundwater potential. Areas around southwest and northeast are interpreted to have moderate groundwater potential. The areas considered to have high and medium groundwater potential are hence recommended for further investigations before siting of boreholes.

KEYWORDS: *Groundwater, Geoelectrical Survey, Mando/Rigasa, Isoresistivity, Isopach*

INTRODUCTION

Groundwater is invisible and often there is very limited data available on its physical distribution and aquifer characteristics (African Groundwater Network, 2015). In unconsolidated formations which are made up of porous media (gravels, sands, silts and clays), groundwater is stored and travels in the pore spaces between the particles. In crystalline basement, groundwater occurs in thin, discontinuous mantle of weathered rocks or in the joint and fracture systems in the unweathered basement, which provide secondary reservoir. While sedimentary basins are known to have high groundwater potential because of the great thickness of the sediments which are almost permeable all through, basement aquifers generally have low groundwater potential because of the thin, discontinuous nature of the secondary reservoirs. Despite their poor hydrogeological characteristics, basement complex rocks are still important in groundwater development in Nigeria, because they provide a lot of water needs of the rural population in over 50% of the country (NWRI-RWSSC, 2012). Because of the spatial variation in the degree of weathering and fracturing of basement rocks across the country, groundwater potential varies from place to place and there is need to carry out hydrogeological investigations of a location before siting water wells or boreholes, especially in the basement terrain. To enable a more precise siting of boreholes, and thus optimizing the utility of the groundwater exploration tools, a ground geophysical survey is often carried out (Olayinka, 1992). Among the more commonly used geophysical techniques in hydrogeological investigations is the electrical resistivity survey. In this work, the geophysical technique of vertical electrical sounding was used to map subsurface features in Mando/Rigasa area which can aid groundwater accumulation, and thus delineate potential groundwater zones in the study area.

STUDY AREA

2.1 Location

The study area (figure 1), Mando/Rigasa, falls within the southeast part of the Kaduna sheet 123 of topographical map scale 1:100,000 of Nigeria. The base map of the study area was prepared in WGS 1984 co-ordinate system at 1:25,000 scales for visualization and analysis of information at local level. The study area is located in-between Nnamdi Azikiwe Bye-pass and Birnin Gwari/Lagos road in Igabi Local Government Area of Kaduna State just on the outskirts of Kaduna metropolis. It is bounded on the north by Nigerian Defence Academy (NDA) and the Ahmadu Bello University College of Agricultural Sciences, on the south by Badiko community, on the east by Mother Cat Nigeria Limited, Kaduna, and on the west by the larger Rigasa community and Afaka Forest. The study area is located within latitudes 10^{o} 32'N and 10^{o} 36' N and longitudes 7^{o} 22' E and 7^{o} 26' E and covers about 55 km^2.

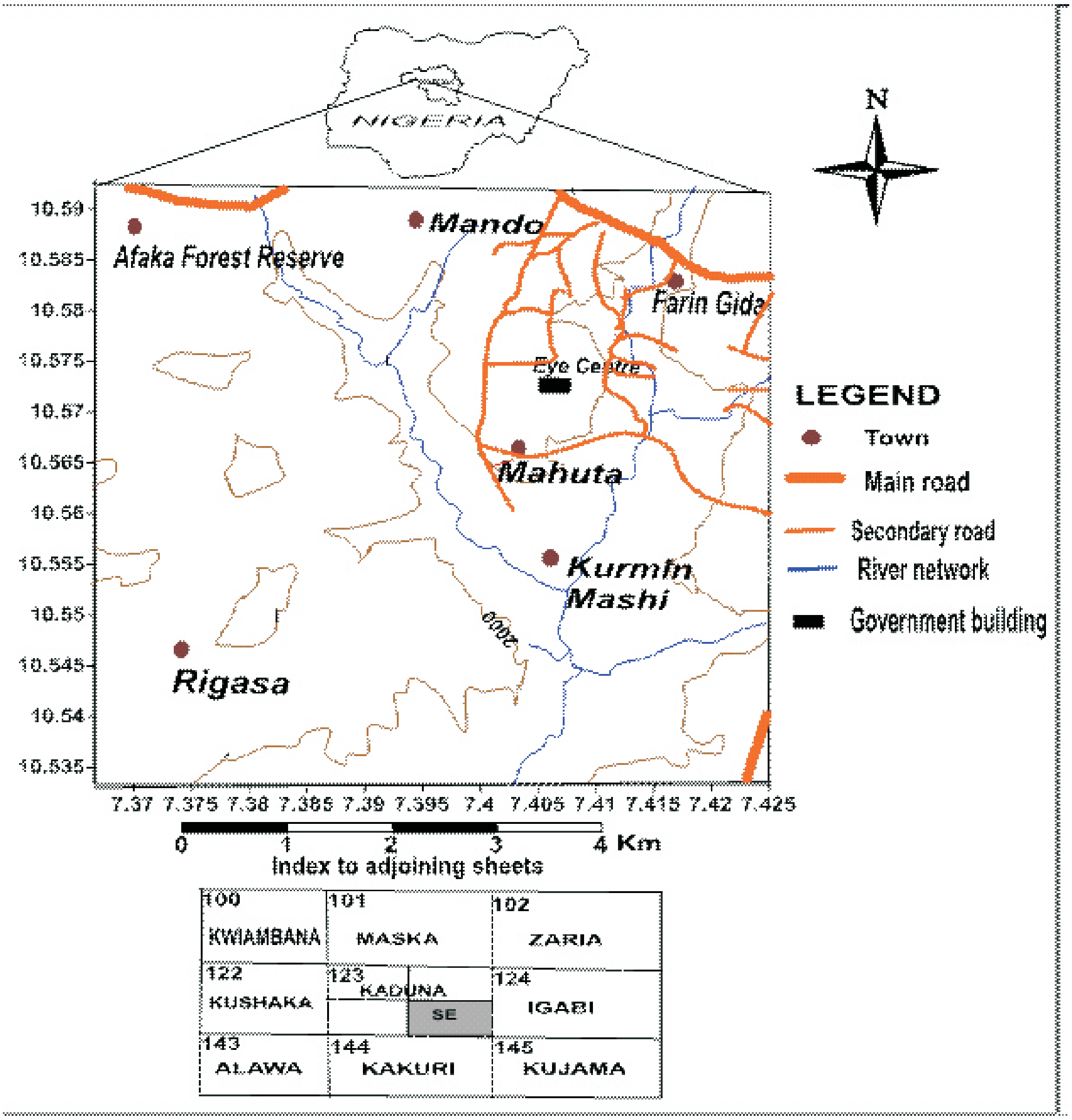


Figure 1: Location map of study area

2.2 Geology, Climate and Vegetation

The geology of the study area is predominantly migmatite-gneiss complex and metasediments consisting of schists and quartzite, trending approximately NNW-SSE where they outcrop and overlain by a mantle of the decomposed kaolinised weathered zone with a thick lateritic crust in some places. There are few outcrops of these rocks in the study area. The study area is within the tropical Savannah climate with distinct dry and wet seasons. The dry season occurs between October and April while the wet season is between May and September. The rainfall data of 35 years (1981 to 2015) obtained from the Nigerian Meteorological Agency (NIMET) shows that the annual rainfall ranges between 793.4 mm and 1655.2 mm with mean annual rainfall as 1197.1 mm. The mean monthly rainfall ranges from zero in the driest months to above 300 mm in August. The diurnal temperature ranges between 9 ^{0}C and 34 ^{0}C. The landform in and around the area is gently undulating with heights above the mean sea level not more than 600 m. The area is drained by

River Mashi and its tributaries which form a dendritic drainage pattern. This drainage network empties into the main River Kaduna on the eastern part of the study area. Vegetation is of typical guinea savannah, characterised by sparse shrubs and interrupted by large isolated trees. There is more continuous grass cover in the rainy season. The area is still undergoing urbanization, subjecting most part to construction of settlements, commercial and related infrastructure. Cultivation of cereals and vegetable is practiced in the area.

METHODOLOGY

Measurements of water table and ground elevation were carried out in 45 open wells to prepare water level elevation map. Water table values were subtracted from the ground elevation values to obtain groundwater elevation values which were placed on the map of the study area and contoured using *Surfer 10* software to produce groundwater level elevation map. Thirty-nine (39) vertical electrical soundings (VES) were conducted to cover the study area (figure 2). The latitudes and longitudes of all measurement stations were obtained with ***eTrex Garmin 30X*** Global Positioning System (GPS). The Schlumberger array was used with maximum half current-electrode separations (AB/2) of between 64 and 100 meters. The geophysical equipment used in the field surveys consisted of the Japanese made ***McOHM-EL*** resistivity meter powered by a 12 volts rechargeable battery, four copper alloy stainless electrodes, multicore electric cables wound on cable reels with crocodile clips to connect the cables to the electrodes, measuring tapes and hammers.

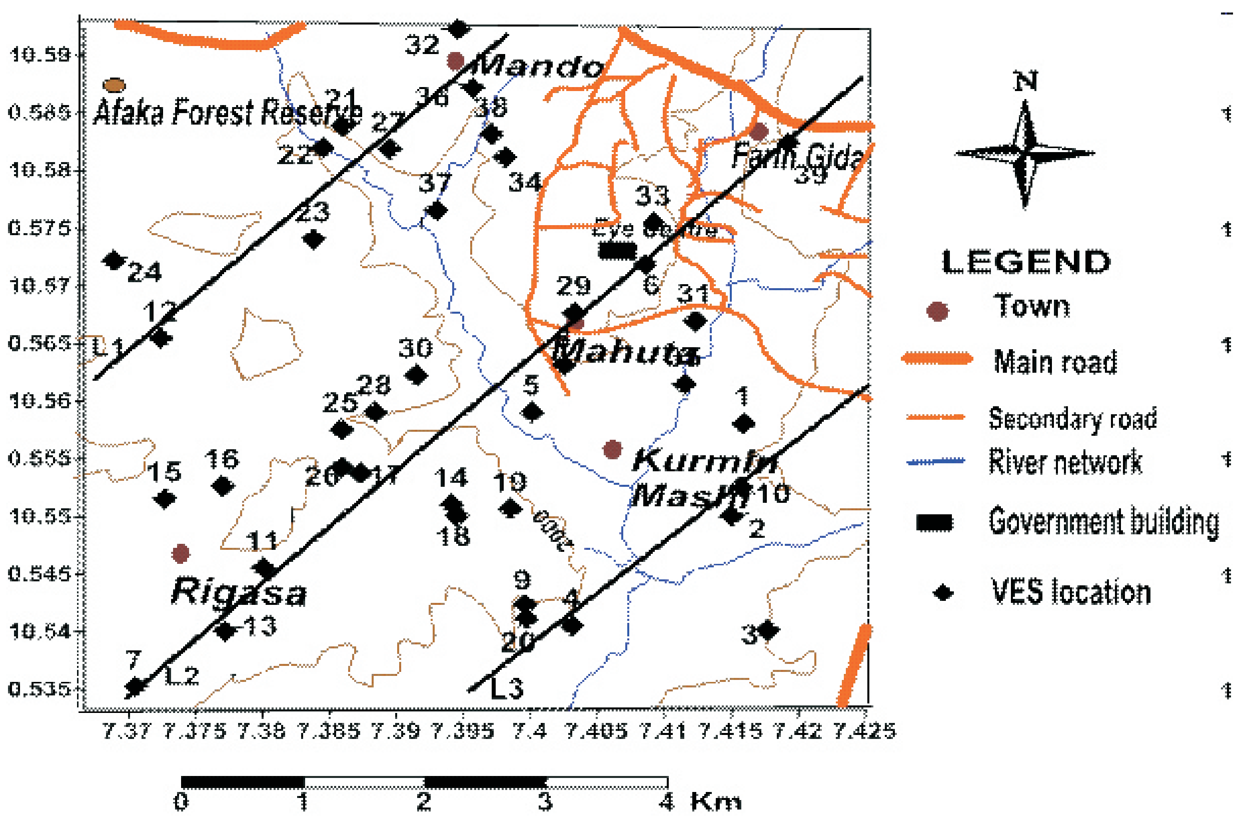


Figure 2: Map of the study area showing the locations of the VES points (L1, L2 and L3 are geoelectrical section lines)

The process involves passing electrical current into the ground through two current electrodes and measuring the voltage or potential difference across two potential electrodes. Conventionally, in the four-electrode array such the Schlumberger array used in this study, the two outer electrodes (A and B) are the current electrodes while the two inner electrodes (M and N) are the potential electrodes (figure 3).

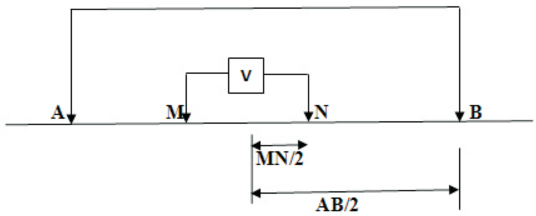


Figure 3: Schlumberger field array

An apparent resistivity value is obtained by multiplying the ratio of voltage to current by a geometric factor (which is a factor of the distance between the electrodes) to give an apparent resistivity (ρ_a) value according to the equation below (Terhemba *et al.*, 2016):

$$\rho_a = \frac{\pi(AB^2 - MN^2)}{4MN} \cdot \frac{\Delta V}{I} = \frac{K\Delta V}{I}$$

Where AB= current electrodes spacing, MN= potential electrodes spacing, V/I= resistance measured by the resistivity meter, and K is a geometric factor. The apparent resistivity values obtained from equation (1) were plotted as a function of AB/2 on bi-logarithmic scale and then inverted to resistivity models. The models obtained were used for computer iteration to obtain the true resistivity and thickness of layers. The computer-generated curves were compared with corresponding field curves using the *WINRESIST* software. Computer iterations of between 1 and 29 were carried out to reduce errors to minimum limit and to improve the goodness of fit. The apparent resistivities at depths of 10 m, 25 m and 50 m below ground level were used in generating the iso-resistivity maps of the study area using *SURFER 10* software. Isopach maps of the weathered layer and the aquiferous zone were also drawn from the thicknesses of the overburden layer and aquifer zone in the interpreted field VES data using *SURFER 10* software. The iso-resistivity maps were analyzed for resistivity trend and directional anomalies in high and low resistivity values in order to interpret the results hydrogeologically. The isopach maps help to identify where the weathered layer and the aquifer are very thick which can aid groundwater accumulation. Potential groundwater zones that can yield significant quantities of water were identified by super imposition of the iso-resistivity and isopach maps on to the base map of the study area.

RESULTS AND DISCUSSION

Water table ranges between 0.5 m and 6 m. This indicates that the aquifers in the study area are shallow aquifers. Figure 4 shows groundwater level elevation map. From the groundwater level elevation map the major groundwater flow direction is northeast, while minor groundwater flow direction is southwest. The digital elevation model of water level is shown in figure 5. The peaks in the model represent higher hydraulic heads which coincide with recharge areas from where groundwater flows to areas at lower hydraulic head which represent discharge areas.

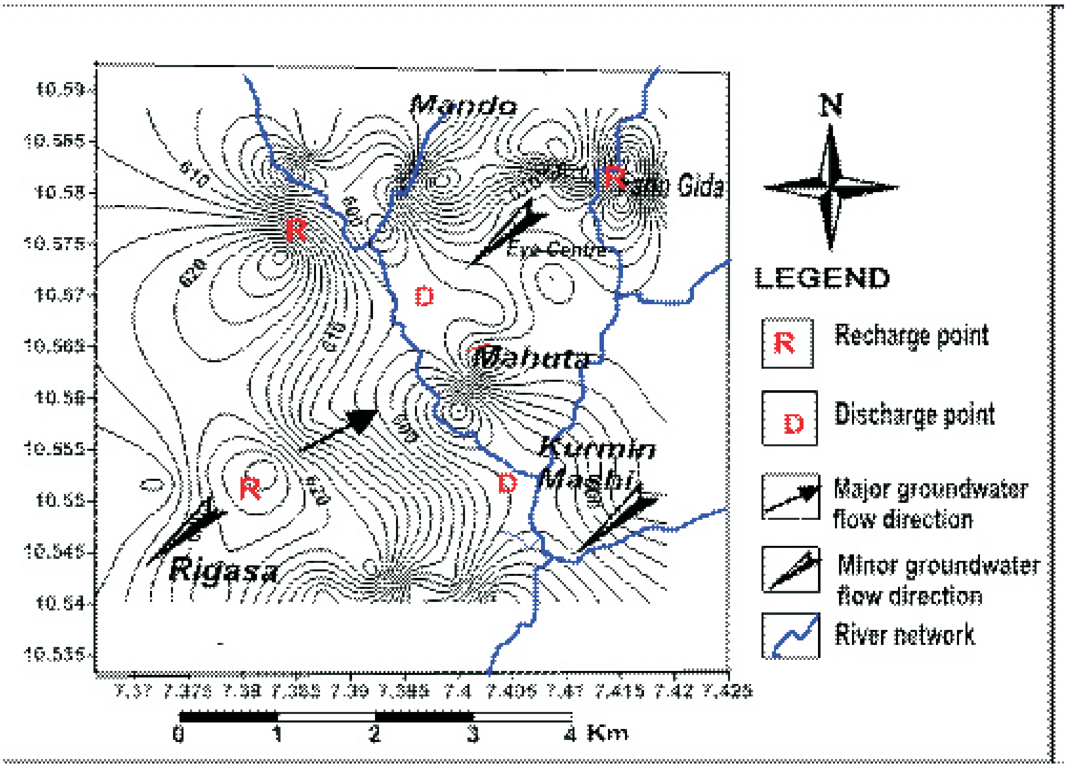


Figure 4: Water level elevation map in Mando/Rigasa area

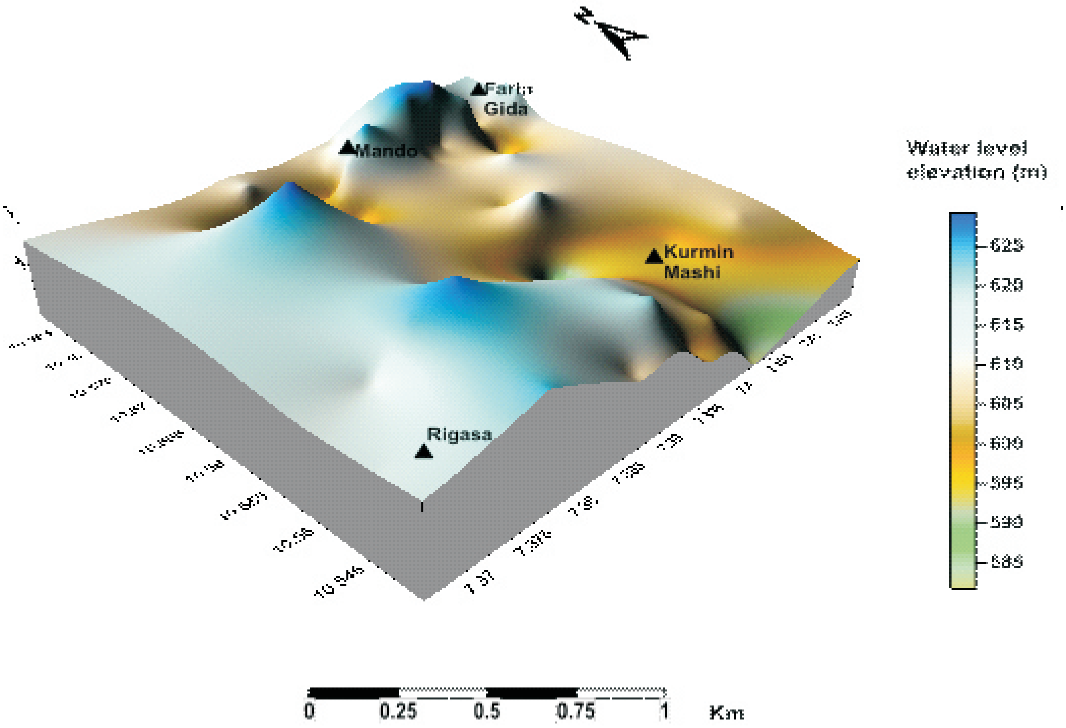


Figure 5: Digital elevation model of water level in Mando/Rigasa area

From figures 4 and 5, the groundwater in the study area is recharged around the northeast and western parts while groundwater is discharged around the central and southern parts.

The interpreted results of the vertical electrical sounding data, supported by some borehole log reports obtained from National Water Resources Institute Kaduna; indicate four geoelectrical layers which are the top soil, sandy and gravelly weathered layer, the partially weathered/fractured layer and the fresh basement. Geoelectric logs (figure 6) were drawn to show the various lithologies identified.

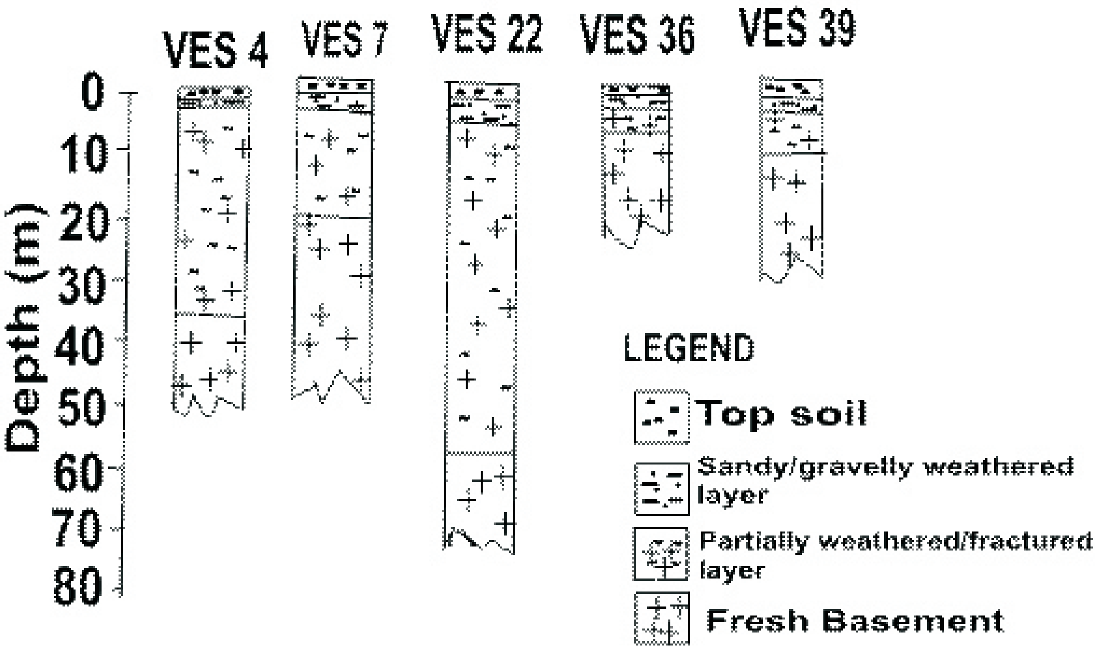


Figure 6: Geoelectric logs from VES data in Mando/Rigasa area

The top soil is relatively thin, ranging between 0.5 m and 4.9 m with apparent resistivity values ranging between 34 ohm-m and 268 ohm-m. However, at some locations such as at VES 14 and VES 16 the resistivity values were higher (above 1000 ohm-m) suggesting that those VES locations were situated barely on a basement outcrop. The sandy and gravelly layer has thickness ranging between 0.7 m and 18.6 m and apparent resistivity values ranging between 30 ohm-m and 1100 ohm-m. This layer forms the shallow aquifer in some parts of the study area where most hand-dug wells terminate. The partially weathered/fractured layer has thickness ranging between 0.8 m and 75 m and apparent resistivity values between 30 ohm-m and 1450 ohm-m. This layer forms the deep aquifer in the area where most drilled boreholes terminate. The fresh basement has apparent resistivities between 115 ohm-m and 10,212 ohm-m at the points where the sounding penetrated and its thickness unknown. However, this layer was not reached at some sounding points. The isoresistivity map at 10 m below the ground level which is taken to represent the sandy and gravelly layer is presented in figure 7

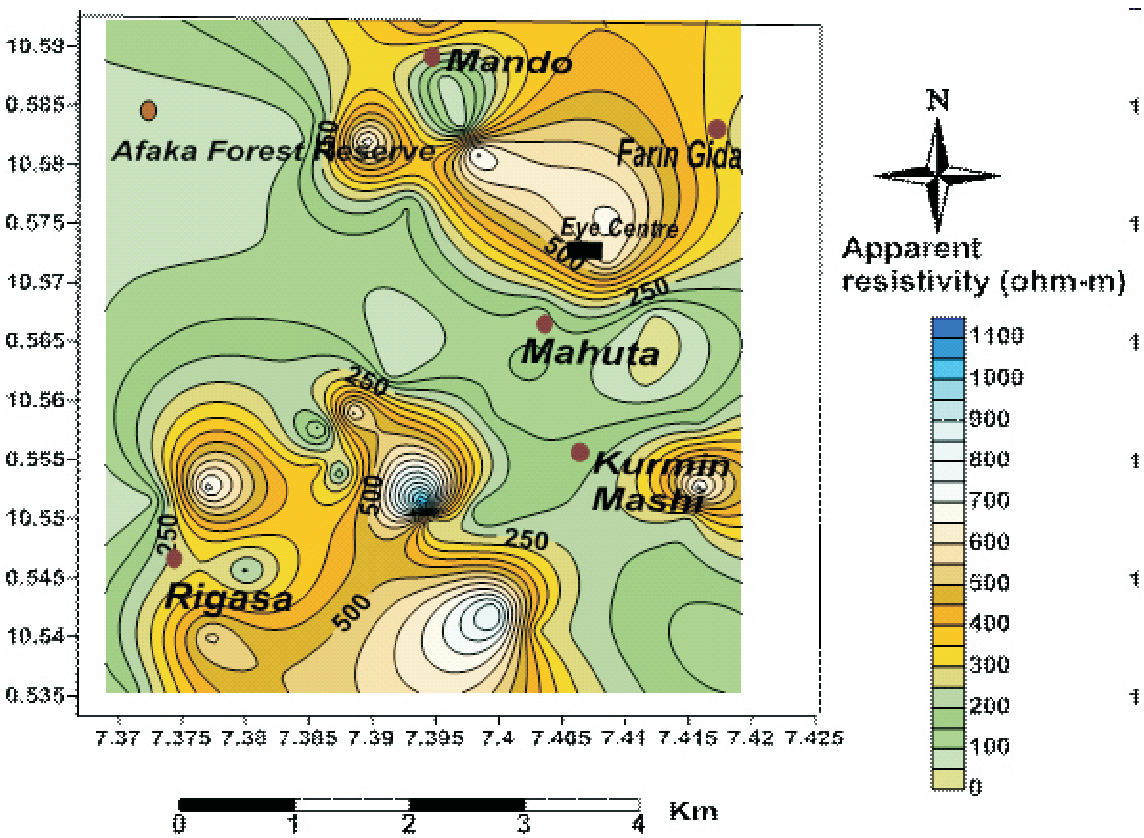


Figure 7: Isoresistivity map at 10 m depth for the study area

In the above figure the apparent resistivity contours show anomalous zones in the northeast around Farin-Gida/Mando, southwest around Rigasa and Kurmin Mashi in the southeast with high resistivity values and closely spaced contours. These zones are interpreted to represent massive crystalline rocks which show that the boundary of these crystalline rocks is discontinuous in space. These massive crystalline rocks grade into weathered zones having low resistivity values with widely spaced contours in the northwest, the central part around Mahuta and the southern part of Kurmin Mashi. The low resistivity areas indicate greater groundwater potential than the high resistivity areas. This pattern extends to 25 m and 50 m below the ground level as indicated by the isoresistivity maps of the study area at depth 25 m (which represents shallow part of the partially weathered/fractured layer) in figure 8 and at depth 50 m (which represents deeper part of the partially weathered/fractured layer) in figure 9 respectively.

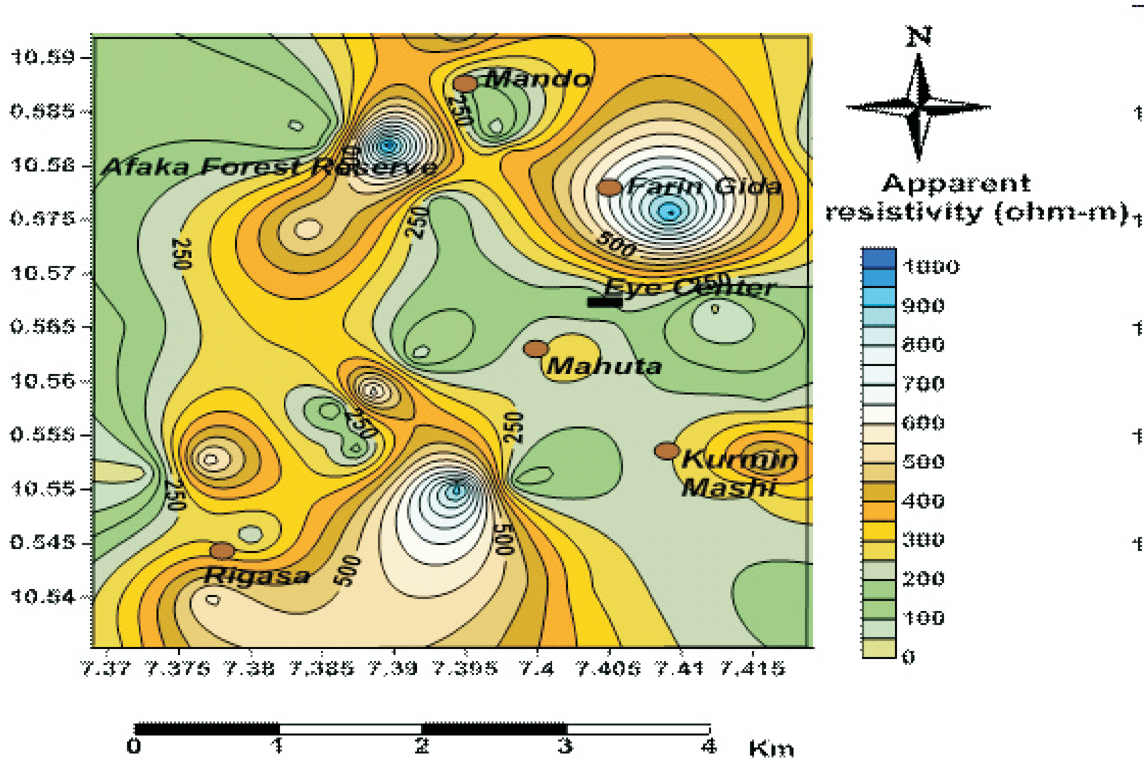


Figure 8: Isoresistivity map at 25 m depth

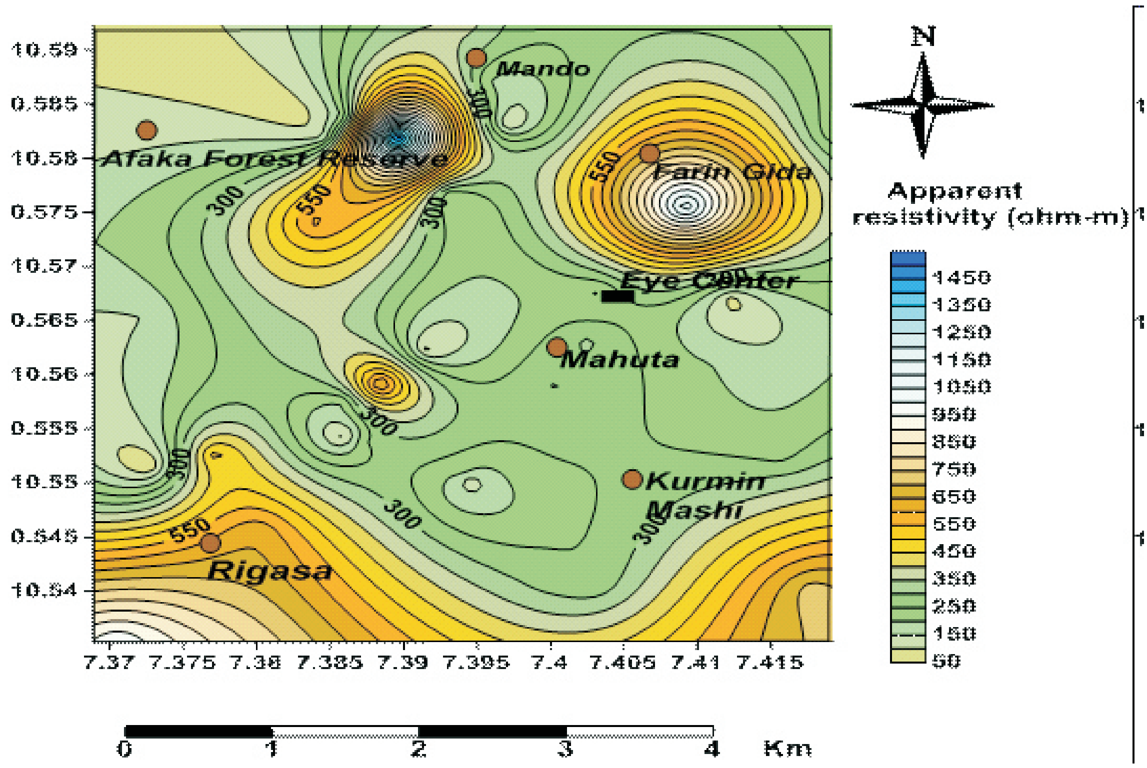


Figure 9: Isoresistivity map at 50 m depth

In the isoresistivity map at 50 m depth (fig. 9) the apparent resistivity contours are widely dispersed around the central part of the study area and around Mando in the northern part representing a low resistivity anomaly that could be a potential ground water zone due to increased aquifer thickness. Figures 10 and 11 show the isopach maps of the overburden layer and the aquifer zone respectively.

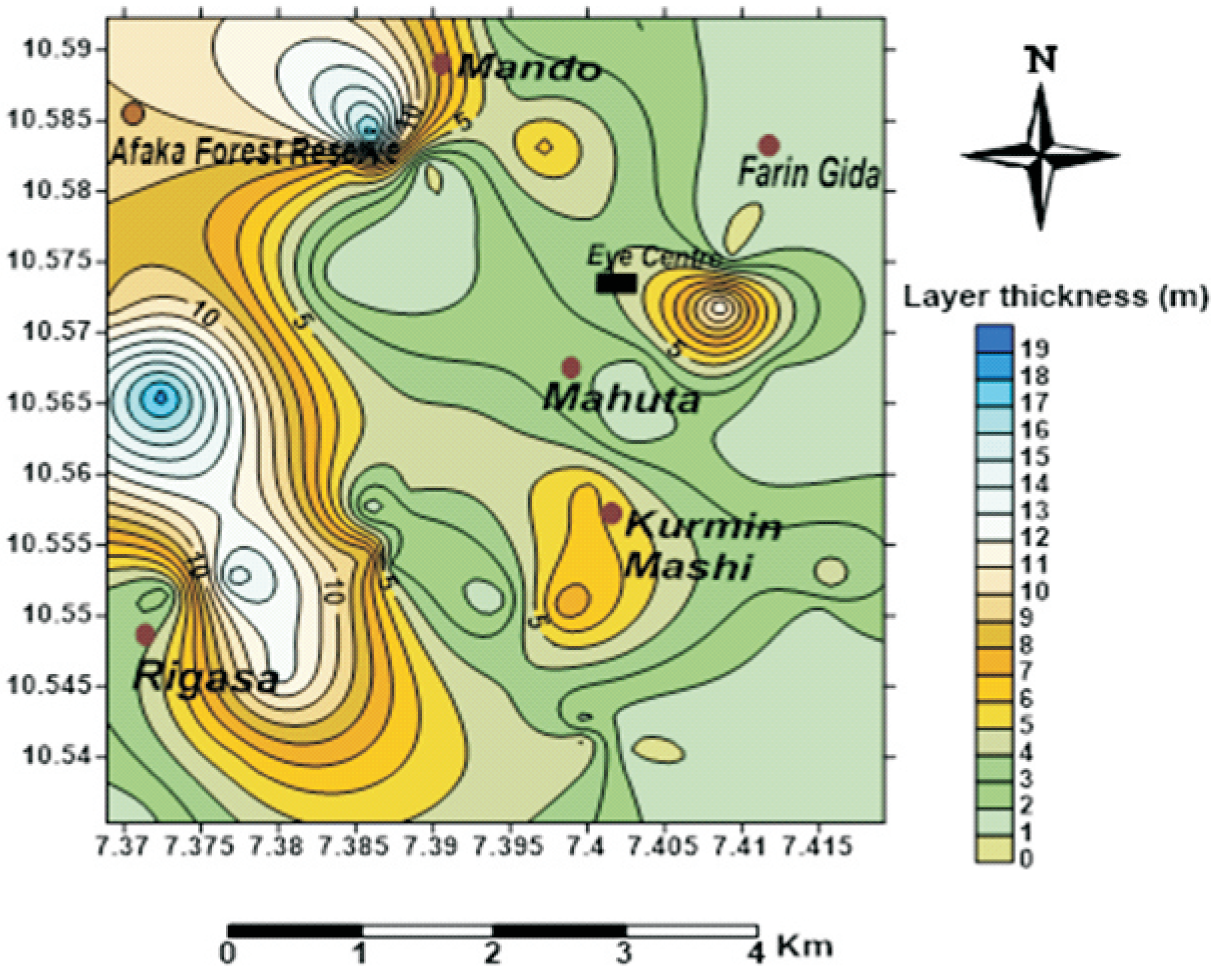


Figure 10: Isopach map of the overburden layer

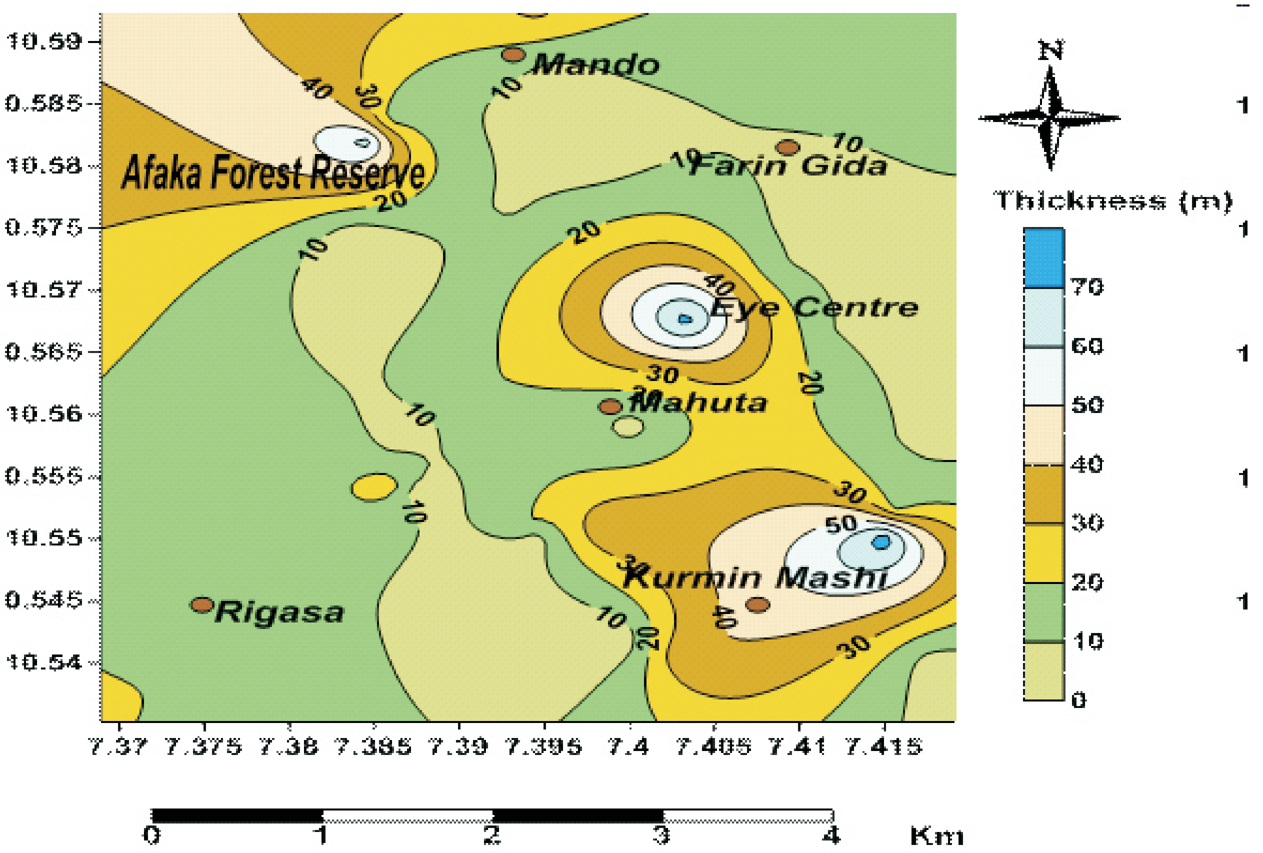
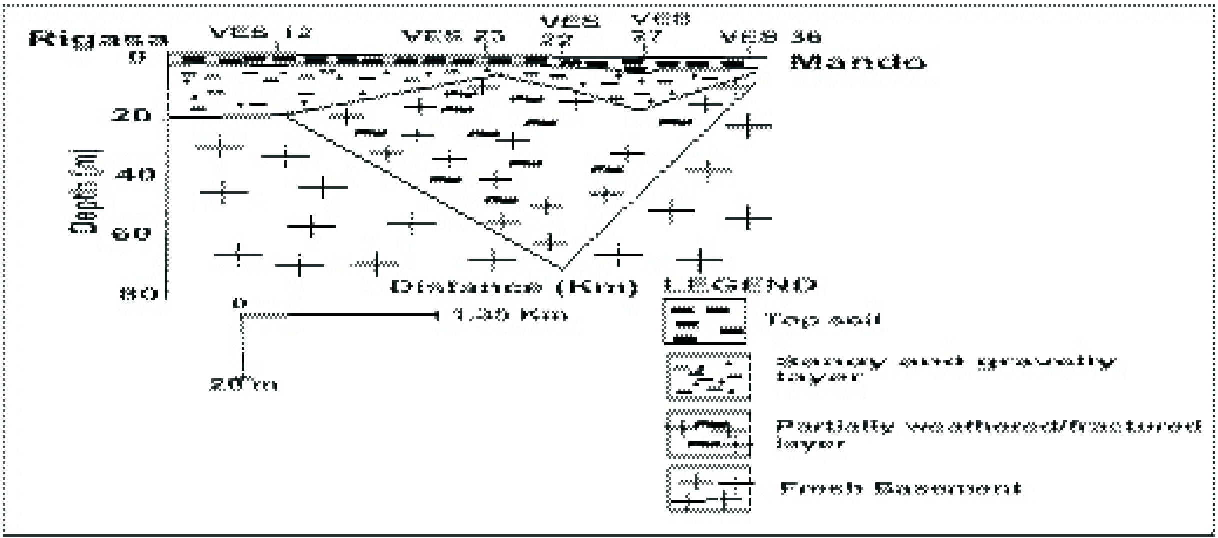
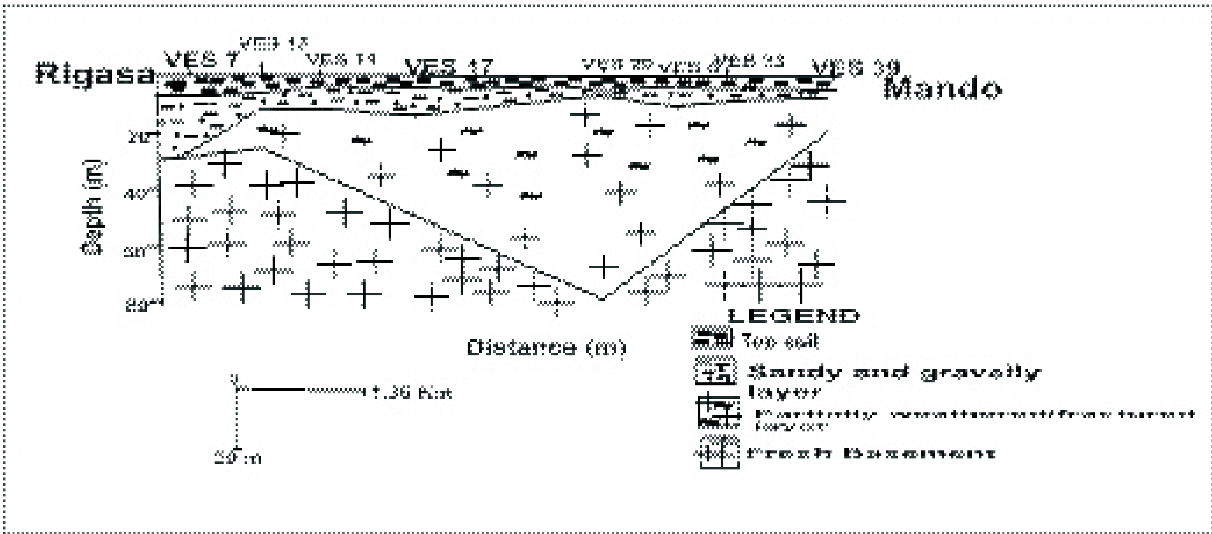


Figure 11: Isopach map of the aquifer zone

The isopach map of the overburden layer indicates that the layer has greater thickness (between 10 m and 20 m) around the western part of the study area comprising western Mando and Rigasa area, Kurmin Mashi in the southern part and around Eye Centre in eastern part. In most parts of the eastern, central, northeastern and southern parts of the study area the overburden layer is thin, being less than about 10 m thick. The greater the thickness of the overburden zone, the higher the groundwater potential. This variability in the thickness of the overburden layer in the study area indicates the absence of a strong and continuous weathered formation. Figure 11 indicates that the aquifer zone is greater than 40 m in thickness around the Afaka Forest Reserve in the northwest (as indicated by VES 23, VES 22 and VES 27 in figure 12a below), Eye Centre in the central part (as indicated by VES 17 and VES 29 in figure 12b below) and Kurmin Mashi in the southeastern part (as indicated by VES 4 and VES 2 in figure 12c below). Aquifer thickness is between 20 m and 40 m around Mahuta in central part, parts of Kurmin Mashi in the southeast and Afaka Forest Reserve in the northwest. Around Mando in the north and Rigasa in the southwest the aquifer is about 20 m thick (VES 12 and VES 36, VES 7 and VES 39, and VES 20 in figure 12). Again this variability in aquifer thickness in the study area shows that generally basement complex aquifers are not continuous in space. Three geoelectric sections drawn for sections between Rigasa and Mando are presented in figure 12



(a)



(b)

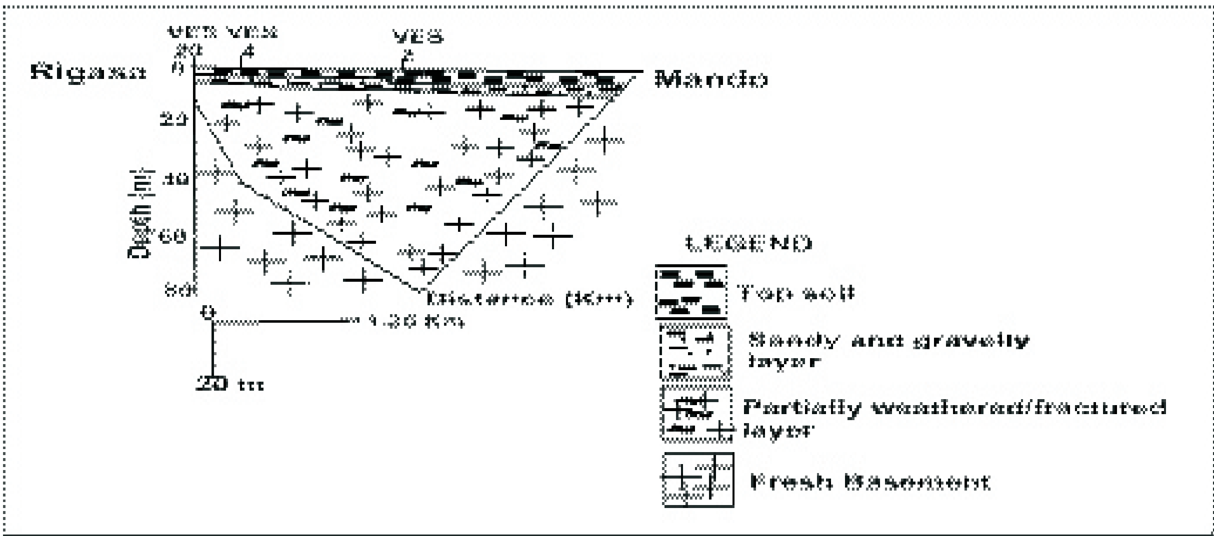


Figure 12: Geoelectrical sections: (a) along L1 profile, (b) along L2 profile and (c) along L3 profile (refer to figure 2).

Table 1 below shows the summary of the results of the vertical electrical sounding interpretation in the study area.

CONCLUSION

This study aims at understanding the groundwater potential of the study area using hydrogeological investigation and Schlumberger configuration of vertical electrical sounding (VES) method**.** The wells are generally shallow with water table in most of them being between 0.5m and 6 m. The central portion of the study area serves as the groundwater discharge area while the western and eastern flanks serve as recharge areas. The interpretation of the isoresistivity and isopach contours placed on the base map of the study area helped in delineating potential groundwater zones in the area. Isoresistivity maps were generated from the apparent resistivity value distributions at depths of 10 m, 25 m and 50 m from the ground surface. Isopach maps were drawn for the thicknesses of the overburden layer and aquifer zone from the interpreted field VES data. The interpreted results show that the overburden layer and the aquifer zone are discontinuous in space in the study area. The interpreted results indicate that the areas around the Afaka Forest Reserve in the northwest, Mahuta/Eye Centre in the central part, Kurmin Mashi in the southeast and Mando in the northern part have relatively higher groundwater potential because of the relatively great thickness of the overburden and the aquifer zones and relatively low apparent resistivity values indicating permeable zones. Areas around Rigasa in the southwest and Farin-Gida in the northeast are interpreted to have moderate groundwater potential because of the relatively moderate thickness of the aquifer and relatively high apparent resistivity values which indicate poorly weathered/fractured crystalline rocks. The areas considered to have high and medium groundwater potential are hence recommended for further investigations.

VES NO	Lat (N)	Long (E)	Layer resistivity (ohm-m)					Layer thickness (m)			
			ρ1	ρ2	ρ3	ρ4	ρ5	h1	h2	h3	h4
VES 1	10.5581	7.4159	117.7	222.2	195.8	292.4	-	0.7	2.4	9.6	-
VES 2	10.5501	7.415	220.1	465.95	249.9	2436.7	-	0.9	1.5	75.8	130.4
VES 3	10.5402	7.4177	87.4	125.3	58.3	353.5	10212.	1.2	1.5	4.6	5.7
VES 4	10.5406	7.4031	181.2	489.8	272	770.5	-	0.5	0.8	38.9	-
VES 5	10.5591	7.4001	55.3	130.4	459.1	-	-	0.6	6.3		-
VES 6	10.5719	7.4086	98.2	667.18	1226.	-	-	0.4	12.3	-	
VES 7	10.5353	7.3705	129.1	35.4	218.4	522.9	1221.7	2.5	1.3	0.8	20.1
VES 8	10.5632	7.4025	133.7	81.4	136.3	404.9	636.7	1.2	1.2	2.4	28.7
VES 9	10.5424	7.3996	254.1	2088.4	1033.	546.7	290.5	0.5	1.7	1.6	4.9
VES 10	10.5526	7.4157	474.7	1386.6	334.8	27.8	115.5	2	4.6	10.5	16.9
VES 11	10.5456	7.3801	54.1	236.7	4447.	-	-	0.7	12.5	-	-
VES 12	10.5655	7.3724	66.2	127.4	311	-	-	0.8	18.6	-	-
VES 13	10.5401	7.3772	77.4	618.4	371.3	640.5	1035.1	0.5	5.9	2.7	19.7
VES 14	10.5511	7.3941	1046.4	396.3	1801.	355.5	206.2	0.9	1.3	6.2	19.8
VES 15	10.5516	7.3727	67.6	209.9	40.4	180.5	-	1.1	2.4	14.8	-
VES 16	10.5527	7.377	1686.4	736.2	251.5	12061.	-	1.7	14.6	15.1	-
VES 17	10.5538	7.3873	49	304.7	34.3	273.9	7239	0.9	2.8	5.2	6.2
VES 18	10.5501	7.3945	982.4	344.1	123.2	953.4	384.5	2.2	2.4	14.6	6
VES 19	10.5507	7.3985	49.1	165.5	86.3	336.3	343.7	0.9	7.9	10.6	38.9
VES 20	10.5412	7.3997	150.8	1325.85	171.7	312.5	-	0.5	5.2	6.3	-
VES 21	10.5839	7.386	117.7	224.9	1354.	338.3	577.3	0.6	18.2	9.4	15.7
VES 22	10.582	7.3845	135.6	74	219.4	5102.1	-	3.9	6.6	64.3	-
VES 23	10.5741	7.3838	87.9	188	48.7	384.9	540.4	0.7	1.1	2.5	1.1
VES 24	10.5722	7.3689	33.8	142.8	290.8	212.9	-	1.8	9	27.1	-
VES 25	10.5576	7.3859	82.7	409.4	73.5	425	1823.8	0.5	1.2	8.4	7.9
VES 26	10.5543	7.3859	113.2	539.5	37.7	709	193.4	0.6	8.9	19.8	5.9
VES 27	10.5819	7.3895	50.4	570	4273.	399.2	4835.9	0.4	0.7	2.4	14.6

VES 28	10.5591	7.3884	263.9	740	546.8	844.5	-	0.7	4.2	9.7	-
VES 29	10.5677	7.4033	76.2	496.5	135.5	459.7	-	3.8	1.7	74.4	-
VES 30	10.5623	7.3915	44.7	194.3	67.3	183.7	-	4.2	4.8	19.2	-
VES 31	10.567	7.4123	46.9	101.1	26.6	471.4	-	0.7	1.4	9	-
VES 32	10.5923	7.3946	424	596.3	1064.	330.7	1184.7	2.2	2.7	5	31.8
VES 33	10.5755	7.4092	105.2	1155	665.5	1682.2	-	0.4	0.7	7.7	-
VES 34	10.5812	7.3981	508.9	791.2	474.7	260.5	-	1	5.1	3.9	-
VES 35	10.5615	7.4115	146.5	242	30.4	581.7	274.6	0.8	1.2	4.1	18.4
VES 36	10.5872	7.3957	55.5	113.5	56.4	561.9	-	0.7	3.6	4.3	-
VES 37	10.5766	7.393	41.1	300	88.8	427.7	-	0.8	2.1	9.1	-
VES 38	10.5832	7.3971	62.9	56.3	34.1	360.8	-	1.2	6.4	8.7	-
VES 39	10.5824	7.4192	250	690.1	170	204	-	4.9	1.3	13.6	-

Note: The values in bold type are aquifer parameter

ACKNOWLEDGEMENTS

The author is grateful to the management of National Water Resources Institute, Kaduna, Nigeria for providing field equipment for this study. The contribution of HND 2 students 2018/2019 of the NWRI in acquisition of field data is hereby acknowledged.

REFERENCES

African Groundwater Network (2015). Integration of Groundwater Management into Transboundary Basin Organizations in Africa- *A Training Manual by AGW-Net, BGR, IWMI, CapNet, ANBO, & IGRAC*

NWRI-RWSSC (2012). National Water Resources Institute- Rural Water Supply and Sanitation Centre. Course 3: Drilling Technology. NWRI-RWSSC, Kaduna.

Olayinka, A.I. (1992). Geophysical Siting of Boreholes in Crystalline Basement areas of Africa. *Journal of African Earth Sciences,* Vol. 14, No. 2, pp. 197-207.

Terhemba, B.S., Obiora, D.N., Josiah, C.U., Paul, E.O., Jika Hilary, J., & Ibuot, J.C. (2016). Aquifer Vulnerability Mapping in Katsina-Ala Area, Central Nigeria Using Integrated Electrical Conductivity (IEC). *Journal of Environment and Earth Science,* 6(6), 15-22.