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Estimation and characterization of aquifer production using Dar-Zarrouk parameter in crystalline basement terrain, southwest, Nigeria

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General Note
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ABSTRACT
The estimation and characterization of aquifer productivity of thirty six vertical electrical soundings were applied to hydrogeological and geophysical data. The data was acquired, digitized and analysed; which was aimed at characterizing the productivity of the aquifer system using Dar-Zarrouk parameter. From the borehole logs 13 wells has poor aquifer while 23 wells are good aquifer. The results show hydraulic conductivity, transmissivities, total transverse resistance and longitudinal unit conductance range from

0.31m/s to 11.4m/s; 0.78 to 243.5m/s; 159.1 to 50,425.7Ωm^2 and 0.01 to 0.22 siemens respectively. It is evident that aquiferous zones have poor to good permeability which revealed why wells in the study area usually have low to high yield due to clay and weathered/fractured layers respectively.

Keywords: Estimation, characterization, aquifer production, permeability and borehole logs.

1. INTRODUCTION

The need for potable water for human consumption, industrial and agricultural purpose has increase over the years (Buchanan, 1983). This challenge prompted the urgency to estimate and characterize geophysical and hydrogeophysical data in respect to their geometry, depth of aquifer and groundwater productivity. On the contrary, groundwater is shielded from surface pollutants as composed of various subsurface layers which acts as natural filters to infiltrated water. Groundwater rarely needs to be treated before consumption, hence cheaper to develop. It is interesting to note that the volume of groundwater is considerable. Buchanan (1983) puts its volume at 2000 times that of the volume of water in global rivers at any given time. Its development thus, constitutes a viable supplement to the costly concrete dam system of surface water supply, wherever the groundwater potential is good.

The occurrence of groundwater resources in crystalline basement terrain depends immensely on the development of secondary permeability arising from weathering and fracturing of parent rocks and also to great extent on the fracture patterns (Carruthers, 1985). Groundwater in crystalline basement terrain occur under three principal conditions (Bannerman and Ayibotele, 1984): firstly, the fractured poorly decomposed or fresh rock overlain by a relatively deep zone of well decomposed rock; secondly, the fractured rocks and finally, the fractured veins existing in otherwise non water-bearing regolith (Wright, 1992, Olayinka and Olorunfemi, 1992; Olorunfemi and Fasuyi, 1993). The basement aquifers are often limited in extent vertically and laterally (Satpathy and Kanugo, 1976). The discontinuous nature of the basement aquifer system necessitates detailed knowledge of subsurface geology, its weathering and structural disposition through hydrogeological and geophysical investigation. Therefore groundwater development in crystalline basement terrain is preceded by detailed hydrogeophysical mapping.

Preferentially, groundwater might reside in regions where weathered layer attains considerable thickness as well as places where the jointing and fracturing are intense. However, gneisses lineaments are characterized with thin overburden thickness and fault, fractures, joints/shear zones in basement rocks. Moreover, it is mostly observed that when water occurs I fractures and joints, it is of very good quality and high well yield (Olorunfemi and Fasuyi, 1993)

Olorunfemi and Fasuyi (1993) deduced that the boreholes which penetrate weathered basement aquifer have lower yield than those which penetrate both weathered and fractured basement aquifers. In contrast, Olorunfemi et al, 1999 inferred that the nature of overlying weathered layer determines, to a significant extent, the production of borehole, irrespective of the thickness of the subsurface fracture basement column. When the overlying layer is clayey (<100 Ωm), the yield of the borehole is low. Barker et al (1992) observed that the highest producing boreholes in the basement terrain of Zimbabwe are linked with the weathered layers with resistivity values between 100 Ωm and 600 Ωm.

Geology and Hydrogeology

Figure 1 show the geological map of the study area underlain by rocks of Precambrian basement complex of Nigeria and area made up of biotite gneiss, unmineralized pegmatite, granite gneiss, undifferentiated schist and phyllites (Rahaman and Ocan, 1978; Rahaman, 1988).

The study area falls within the Precambrian basement complex area of Ikire, in the southwest of Nigeria lies within latitude $7^0 12^1$ - $7^0 30^1$E and longitude $4^0 07^1$ - $4^0 25^1$N. Physiographicaly, the area shows a dendritic drainage pattern with general flow toward the River courses in the southeast part of the study area.

Hydrogeology

Weathering process creates superficial deposit with varying degrees of porosity and permeability in Ikire. Regolith and fractured bedrock generally occur in basement terrain (Odusanya and Amadi, 1999); while unconsolidated overburden could constitute reliable aquifer, if significantly thick (Olorunfemi and Olorunniwo, 1985; Dan-hassan and Olorunfemi, 1999; Omosuyi et al, 2003). Edet et al, 1994 postulated that high lineament are obtained in areas where basement rocks outcrops or are close to the surface and areas with thin overburden whereas low lineament frequencies are features of areas with deeply buried basement rocks.

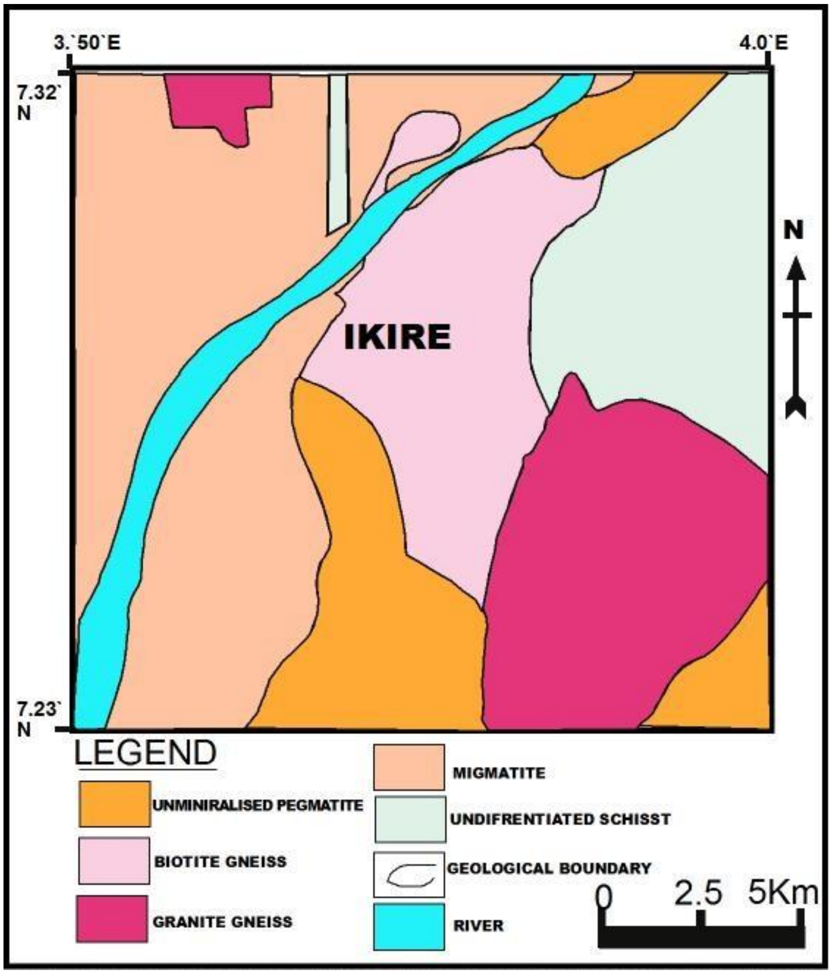

Figure 1 Showing the Geological map of the study area (Modified after NGSA, 2006)

2. MATERIALS AND METHODS

The geographic coordinates of 32 wells was determined with the aid of GARMIN-12 global positioning system (GPS). We measured the static water levels from the data, we prepared the static water level, groundwater relief map.

The Schlumberger array was used to obtain a total of thirty six (36) vertical electrical sounding (VES) through surface measurement of electrical resistance of the subsurface to the induced current using the ABEM SAS 300.

The measured earth resistance values were presented in terms of the subsurface apparent resistivity distribution beneath the sounding location. Electrode current spread length (AB) for separation varied from 1 to 100m, while the spacing between the potential electrodes (MN) were intermittently varied between 0.5 and 10m in order to achieve suitable current penetration and depth of investigation that will enable proper delineation of basement relief and allow good estimate of aquifer parameters.

WINRESIST2 inversion program was used for the automated 1-D inversion of sounding curves obtained from the field data. We used SURFER 9 software to plot the spatial qualitative and quantitative interpretation of geophysical data in relative to well locations and aquifer parameters.

Inverted electrical sounding curves were interpreted in form of borehole logs displaying subsurface structure and stratigraphy on the basis of the distribution of depth, thickness and effective resistivity values. The SURFER 9 worksheet was populated with the calculated and geoelectrical parameters were analysed using SURFER 9 analysis applications to generate 3D composite map. The map is derived on statistical estimate and prediction of values at single location using interpolation method (Z-value calculation); prediction of measured value at a location using a geostatistical tool and spatial sensitivity analysis.

Hydraulic conductivity relation $K\ (10^{-5}) = 95.5^{-1} \times \rho^{1.195}$ (m/s) was used to estimate the whole of 36 VES stations while Niwas and Singhai (1981) relation $Tc = KR\ \rho^{1-} = KS\ \rho$ was used to calculate the total transverse resistance.

3. RESULTS AND DISCUSSION

Figures 2-5 show contour map of the groundwater elevation level, groundwater hydraulic head, and groundwater depth to well level as well as groundwater total depth of well respectively. The static water level is relatively deep within the northern central, western, south-eastern and southern part of the study area while virtually the north-eastern through the eastern part of the study area are shallow. The groundwater hydraulic head (relief) map shows that groundwater flows into the main collecting centre. Groundwater flow direction emanate from south-western to southeast as well as southernmost part of the study area. Since the flow diagram displays that the flow system is directed towards the river system, we infer that the river is significantly recharged through the groundwater base flow. Groundwater depth to well level is relatively high in the northern and southern part and low at the eastern and western part of the study area. More so, the groundwater total to depth of well level display high elevation at the northern and western region and low at eastern and southern part of the study area. Based on the groundwater flow pattern, the study area is collecting and radiating centres; that is low and high groundwater potential zone.

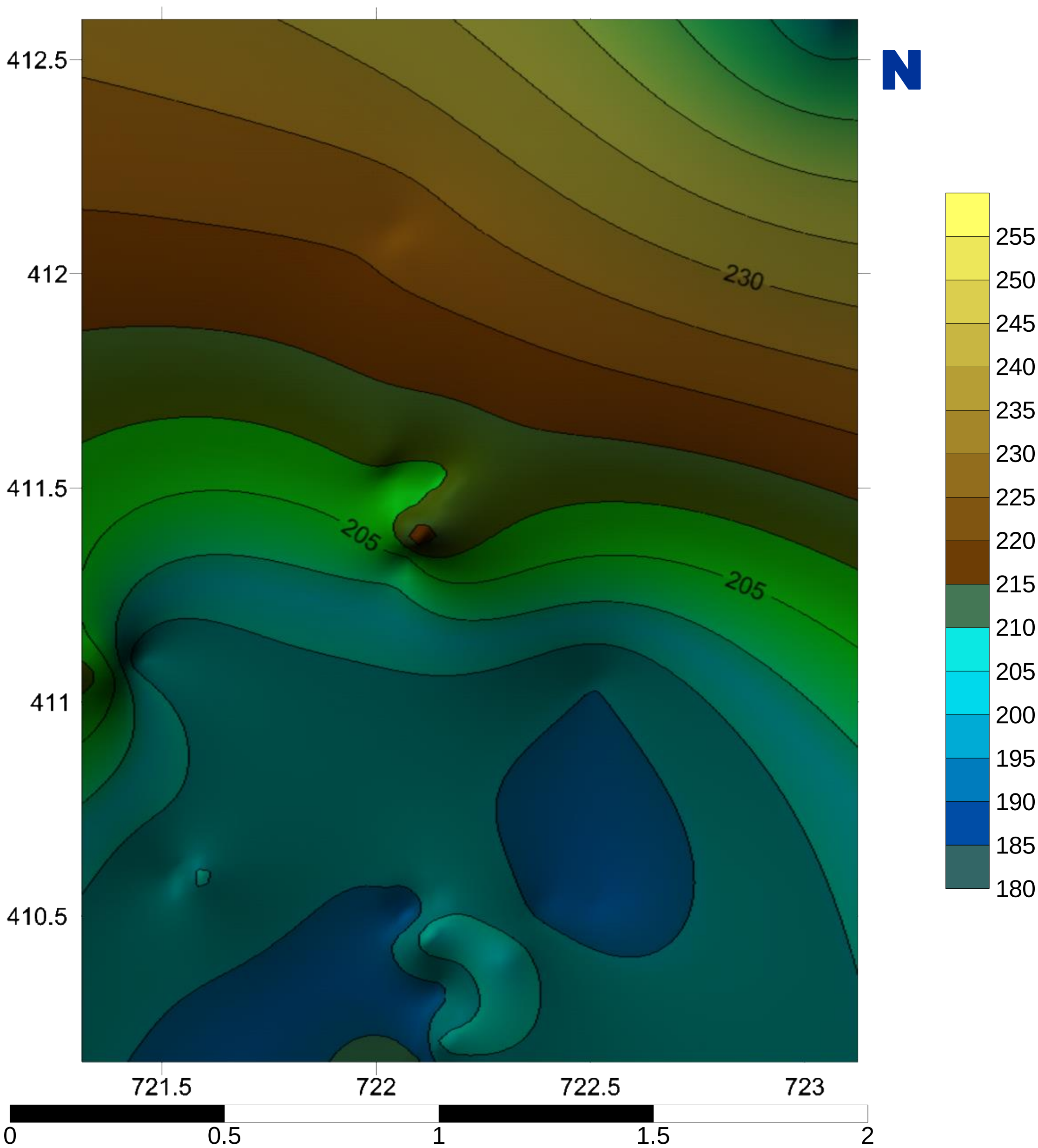

Figure 2 Contour Map of the study area showing the Groundwater Elevation Level

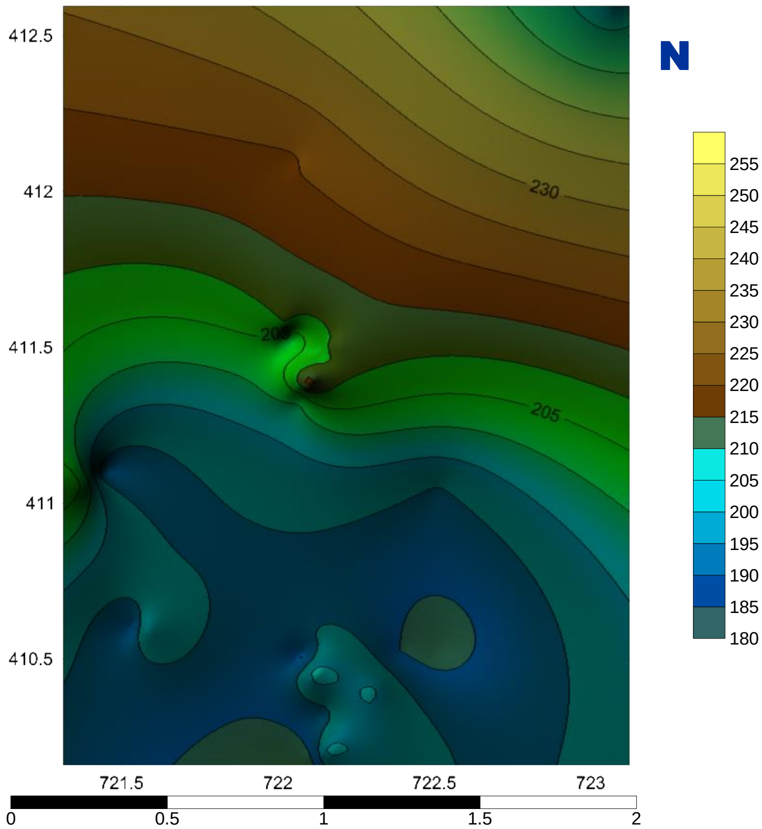

Figure 3 Contour Map of the study area showing Groundwater Hydraulic Head

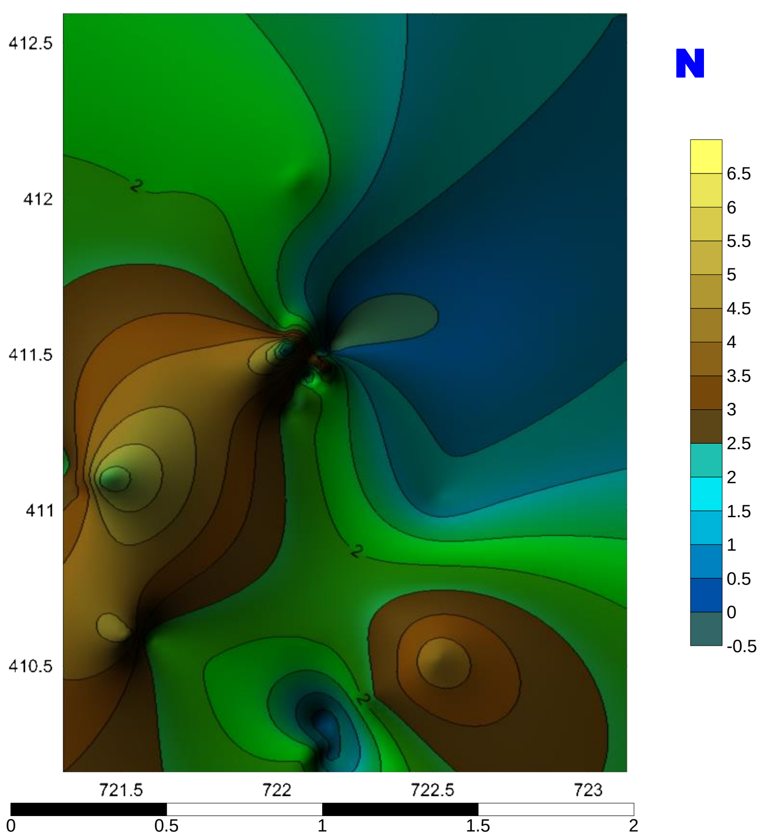

Figure 4 Contour Map of the study area showing Depth to water Level

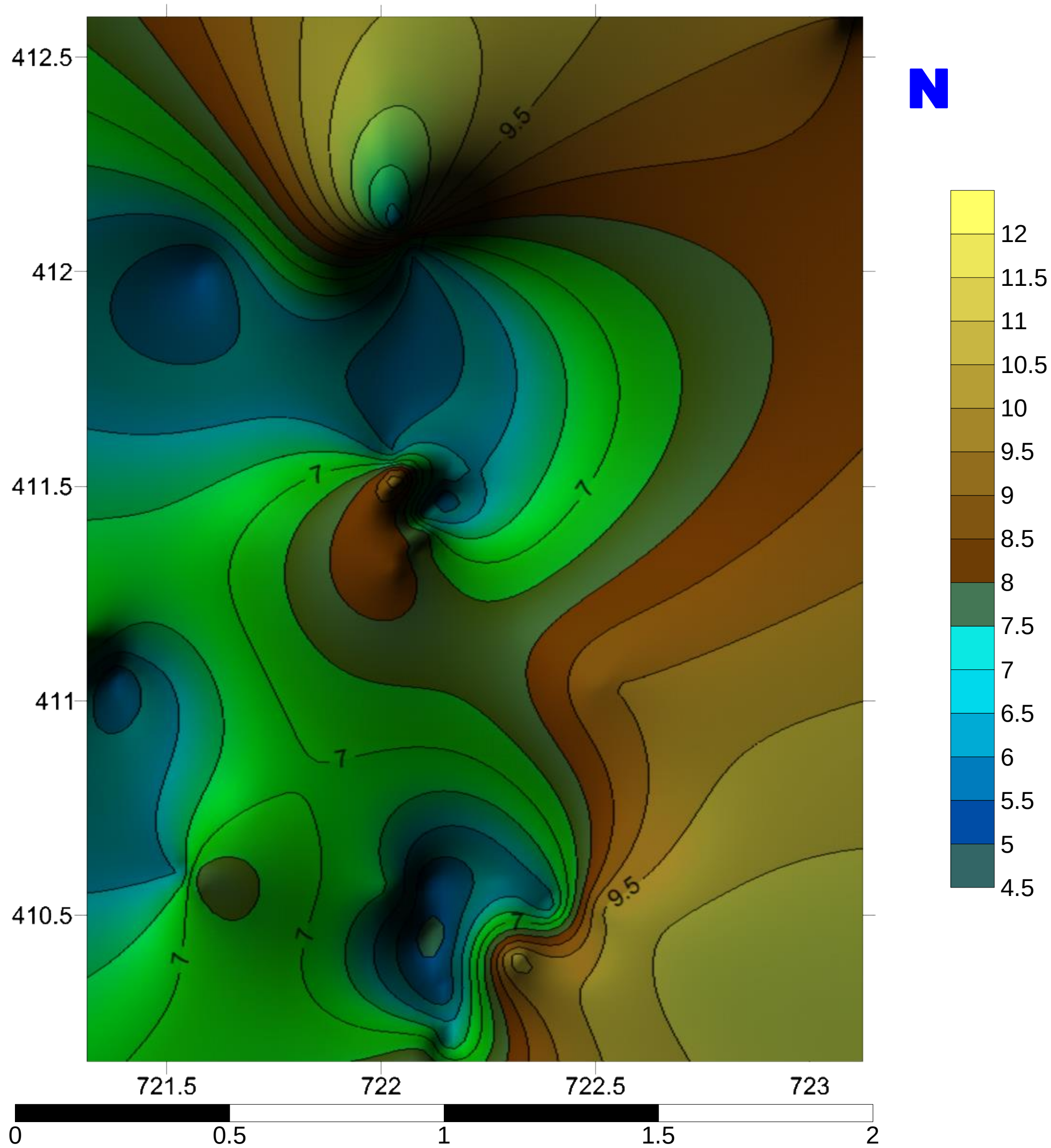

Figure 5 Contour Map of the study area showing Total depth of Water

Figures 6-7 captured that Twenty two (22) of the borehole logs (9,10,11,12,13,14,15,16,17,18,19,20,21,22,24,26,28,31,33,34,35,36) were classified as confined (good) aquifer. High development of secondary porosity arising from fractured bedrock and favourable for high groundwater yield while fourteen (14) of the borehole logs (1,2,3,4,5,6,7,8,23,25,27,29,30,32) were classified as unconfined (poor) aquifer. The lithological logs are characterized by a series of brown to grey fine grained/clayey texture as the topsoil, saturated clay/sandy clay/clay, weathered/fractured basement and the basement unit. The sustained appreciable groundwater yield (3.0-5.0 litres/seconds or more) of the numerous shallow (not deeper than 7.0m) tube-wells located within the weathered/fractured basement aquifer in the study area over the years indicates that the weathered/fractured basement have potentials for moderate to high groundwater yield. Thus, efforts are concentrated on the thickness of the weathered/fractured basement and its immediate underlying strata in characterizing the groundwater potential of the site. The yield of boreholes in the present study area probably depends to some extent on the saturated thickness of the alluvium aquifer, its storage and discharge capabilities, weathered/fractured basement is generally known for its great storage potential.

The poor aquifer symbolizes high resistance and low permeability in the subsurface geology. High percentage of these demonstrate that is significantly low rate of development of secondary porosity, between low groundwater yield due to low permeability and porosity of underlying fresh bedrock.

The hydrogeologic significance of development of secondary porosity within the Precambrian basement rocks is attributable to the presence of fractures, faults, and joints within the subsurface geology, which to significant extent; improve the aquifer productivity and enhancing the transverse vertical resistance, hydraulic conductivity and transmissivity.

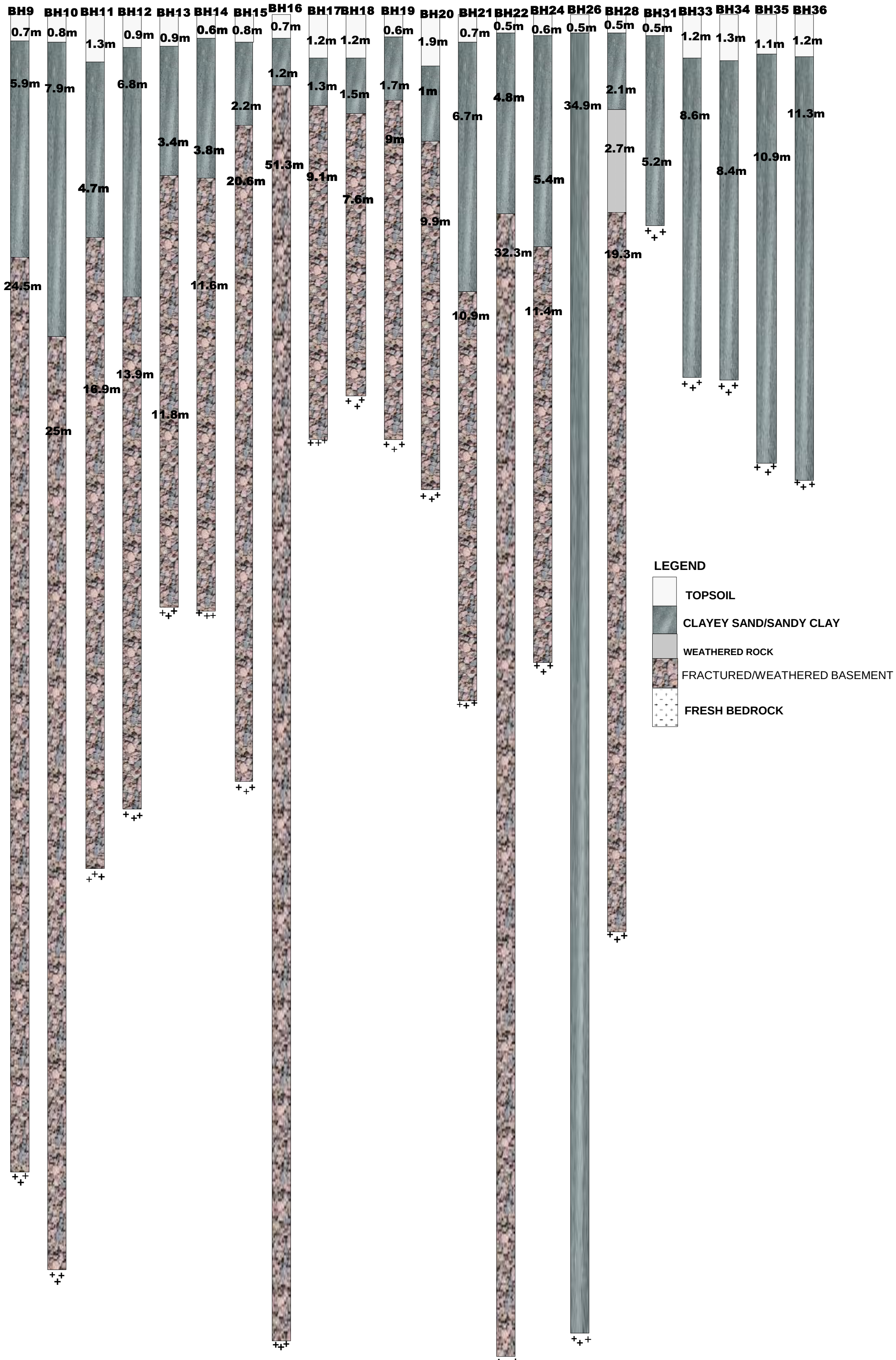

Figure 6 Borehole Logs showing Confined (good) Aquifer System

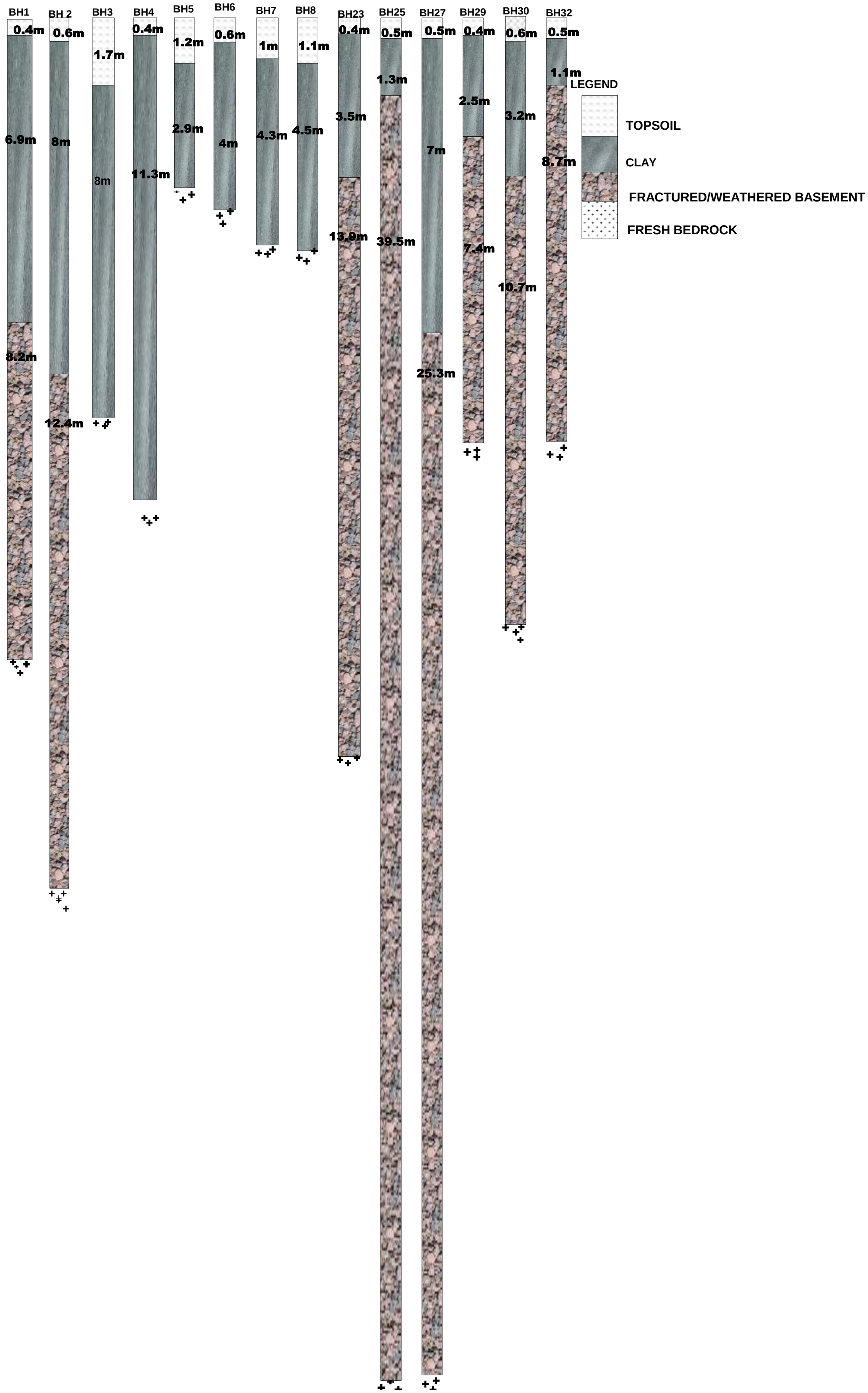

Figure 7 Borehole Logs showing Unconfined (poor) Aquifer System

Figure 8 shows contour map of the overburden thicknesses from the study area. The overburden thickness comprises of all materials above the presumably fresh bedrock. The isopach map display a range between 4.1m to 53.2 m in thickness. It is relatively thick around the south-western and western (25 to 53.2m) while the thin overburden is within the north, north-eastern and south-eastern (4.1 to 25m) part of the study area. Therefore, groundwater yield is highly productive in places with thick overburden thickness and also serve as a recharge zone for the weathered/fractured aquifer.

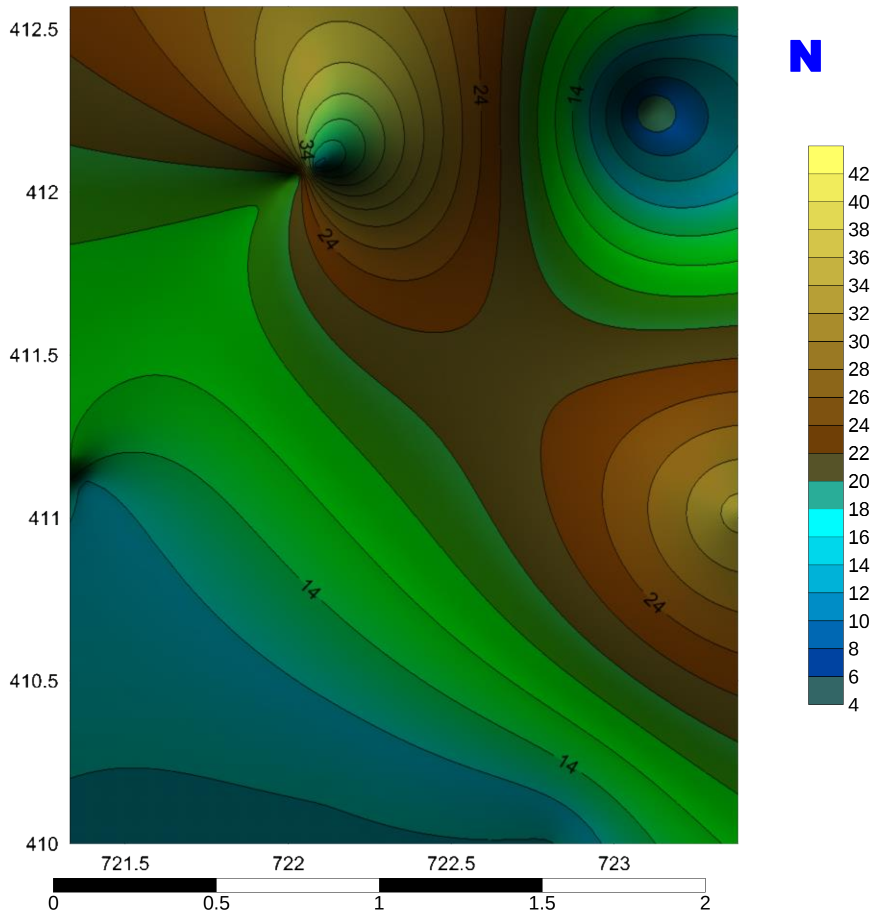

Figure 8 Contour Map of the study area Showing Overburden Thickness

A map of longitudinal unit conductance (S) values was modelled by using the resistivity data and the calculated longitudinal unit conductance. The map put a demarcation between high and low longitudinal unit conductance which varied from 0.01 to 0.11siemens and 0.11 to 0.17siemens respectively. Figure 9 shows that the contour pattern and boundaries is clear and displays overlapping features and is related to clay content of the aquifer system. The map shows an increase in porosity and decrease in permeability towards the north while towards the west there is decrease in the high absorption and retention capacity and increase in high retention and absorption capacity of groundwater. Hence, the regolith has high retention and absorption capacity.

Figure 10 shows contour map of the bedrock relief of the fresh bedrock elevation in all the VES stations. These elevations were obtained by subtracting the overburden thickness from the surface elevations at the VES stations. The relevance of the bedrock relief is its reflection of the bedrock topography and structural disposition. The hydrogeologic relevance has been recognised by Olorunfemi and Okhue, 1992; Dan-hassan and Olorunfemi, 1999 and Omosuyi et al. 2003. Topographic depression and ridges area identifiable in the bedrock relief map. The basement is high towards the west and decreases towards the east. The west is a divergence zone while the southeast is a convergence for siting boreholes. Depressions are characterized by thick overburden while ridges noted for thin overburden cover which implies that basement depressions forms groundwater collecting trough from bedrock crests.

In figure 11, we observe that the map of the Hydraulic conductivities of aquifer in the study area varied from 0.31 to 9.89 m/s. The low values is attributable to the clay content in the aquifer system and the fact that the degrees of the hydraulic conductivity between the clay and weathering layers are low while the high values is pointing to the weathering and fracture bedrock layers.

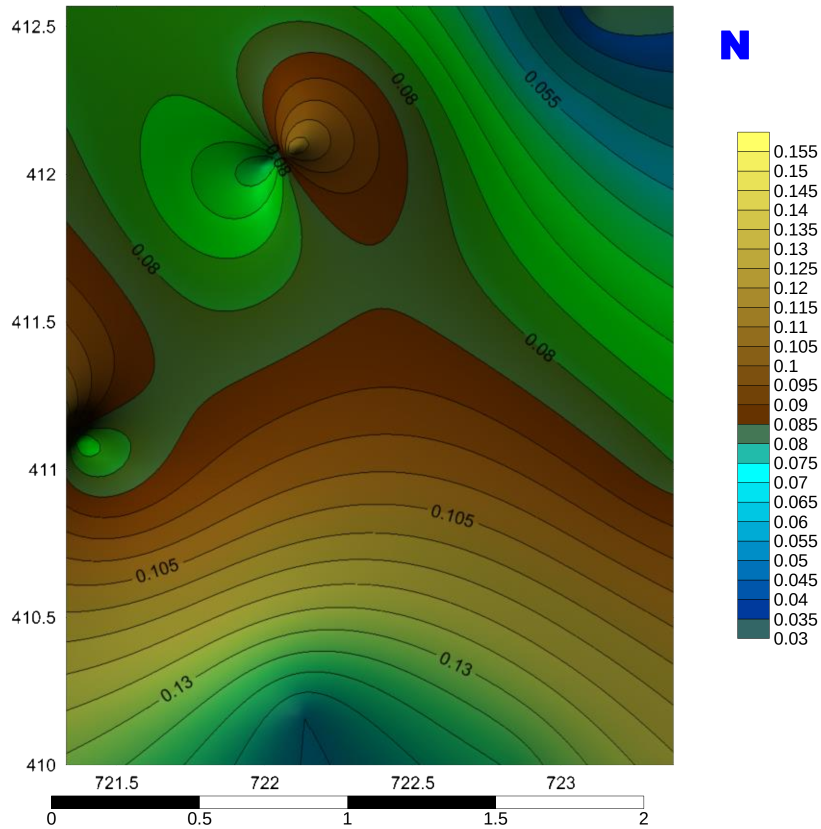

Figure 9 Contour Map of the study area Showing Longitudinal Unit Conductance

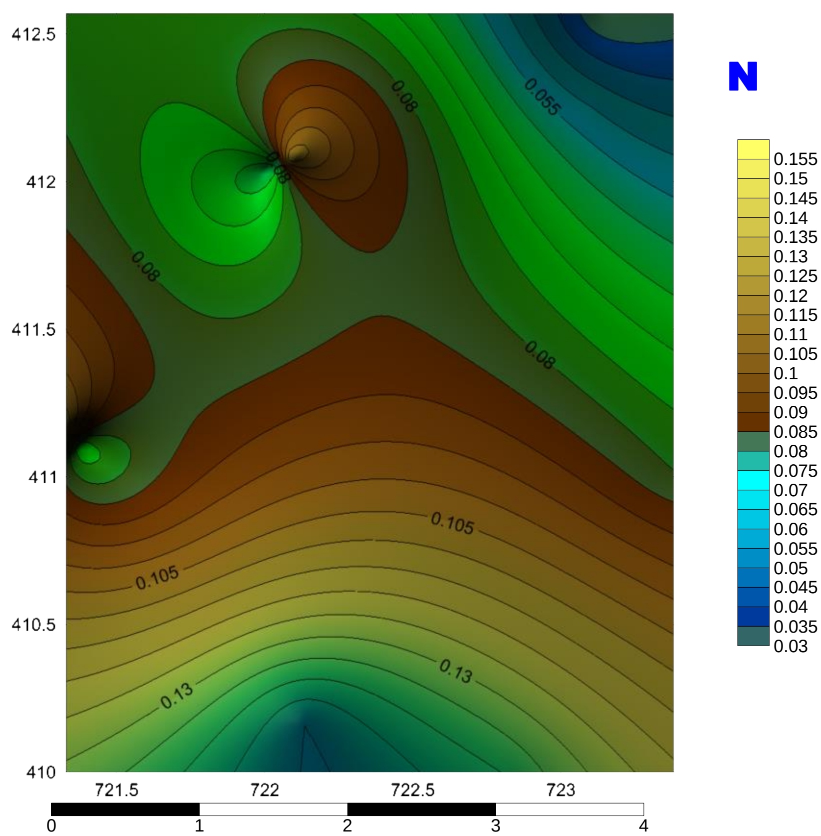

Figure 10 Contour Map of the study area Showing Basement Relief

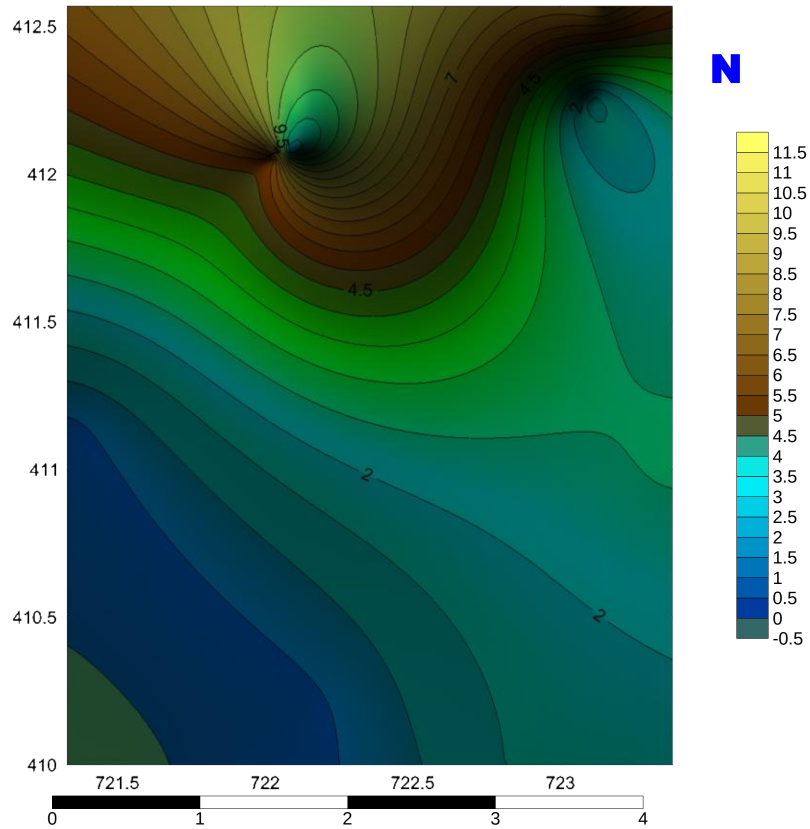

Figure 12 Contour Map of the study area Showing Hydraulic Conductivity

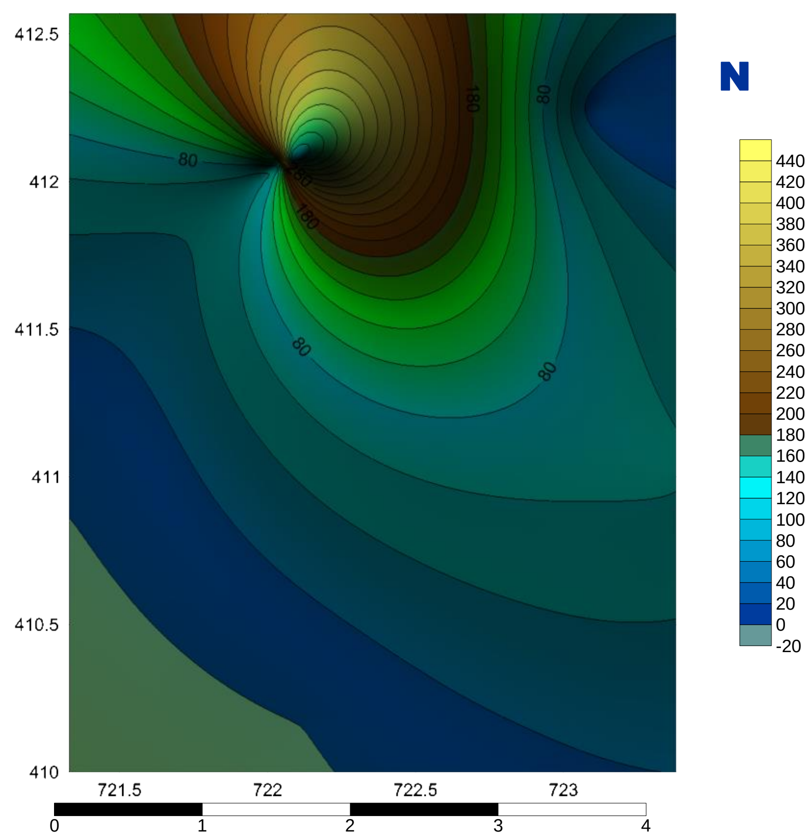

Figure 13 Contour Map of the study area Showing Transmissivity

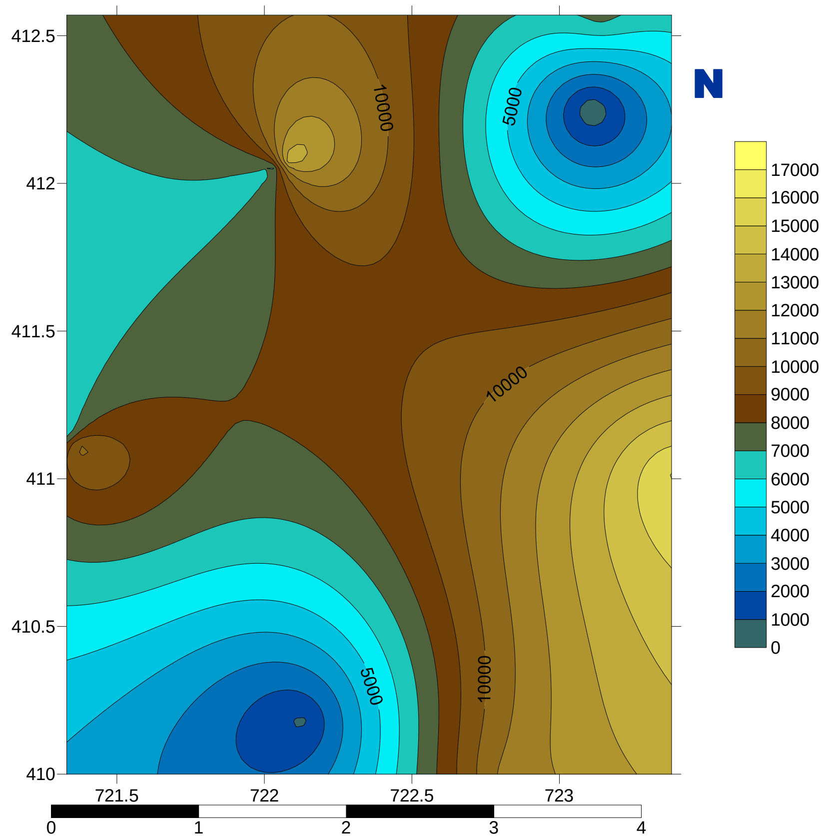

Figure 14 Contour Map of the study area Showing Total Transverse Resistance

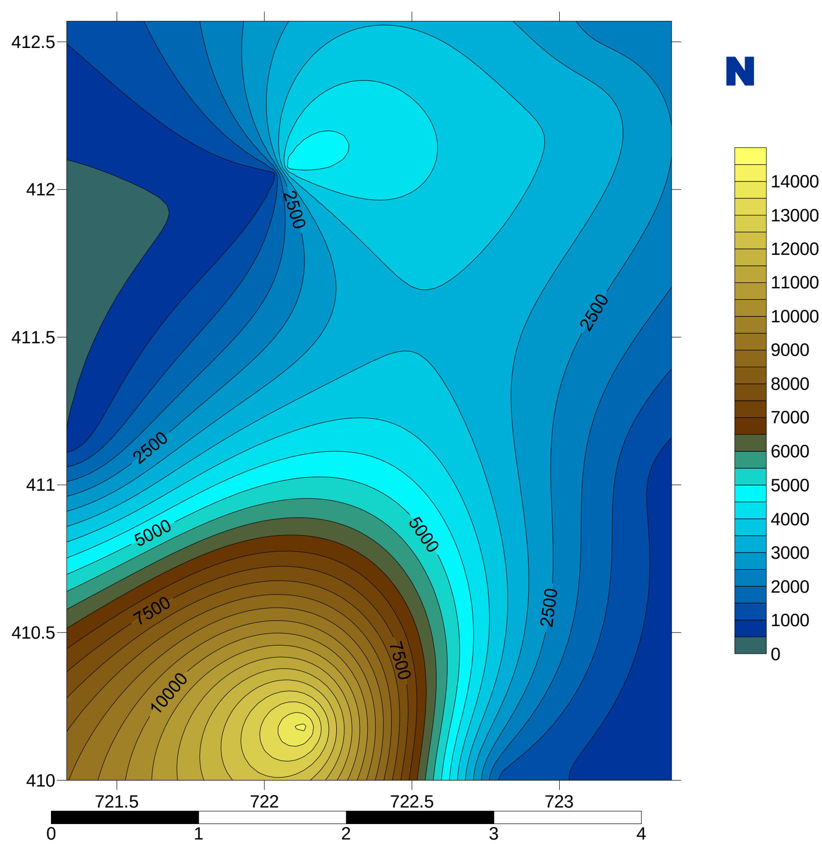

Figure 15 Contour Map of the study area Showing Bedrock Resistivity.

Figure 12 shows a typical map calculated from the whole saturated thickness of the aquifer. The map indicate that the weathered/fracture nature of the basement rocks that direct implications for the relatively high transmissivity values. The estimates of the transmissivities obtained from this approach in the study area shows that the transmissivity (T) ranges from 0.78 to 450.3 m/s/.

The 3D contour map in figure 13 shows that the southern and south-western part of the study area have crest-like structure with high resistive values ranging from 7000-50425.7Ωm^2 while the south-eastern and the north-western part of the study area -shows a depressions having low resistive values from 263.2-7000 Ωm^2. The total transverse resistance defines the weathered/fractured patterns thickness of the rocks in the study area; hence, the aquiferous potential units.

The bedrock resistivity 3D map is shown in figure 14 where the resistivity values of bedrock varied from 220.03 Ωm to 15234.3 Ωm. The highly resistive fresh bedrock (5000 to 15234 Ωm.) lies within the south-eastern part of the area and the overburden thickness is high displaying good potion for borehole siting. The low resistive bedrock structure (220.3 to 5000Ωm) is displayed towards the north, north-eastern and south-western part of the study area. Hence, the shallow buried rocks give high resistive stripe-shaped contours while deep buried rock give low resistive stripe-shaped contours.

4. CONCLUSIONS

The estimation and characterization of aquifer productivity using Dar-zarrouk has been successfully used in the study area. The areas with thin overburden thickness relate with high resistive values and bedrock trough while areas with low bedrock resistivities were areas of interest for groundwater exploitation. Occurrences of confined aquifer are attributable to the development of secondary porosity associated with joints, fractures, bedrock at greater depth. The borehole logs show that fourteen to twenty two aquifers across the study area are poor to good aquifer respectively. Therefore, characterization of low to high aquifer productivity is directly related to low to high hydraulic conductivity and transmissivity values respectively. More so geoelectrical parameter like (bedrock relief, longitudinal unit conductance, bedrock resistivity, total transverse resistance) displayed significant role in low to high aquifer yield in the study area.

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