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# Analysis of groundwater potential of Dong and Lawaru areas in Demsa northeast Nigeria, using the vertical electrical sounding method

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***Abstract:***
*Dong and Lawaru are two farming communities in Demsa Northeast Nigeria with record of frequent conflicts between farmers and herders which centered on the single water source (River Shinu) for both cropping and grazing. The aim of the present study was to explore groundwater potential of the area using the vertical electrical sounding (VES) technic while employing Quantum Geographic Information System (Q-GIS) analysis, for possible groundwater exploration as additional source to the River Shinu with a view to distinguished between water for grazing and water for cropping (irrigation).Fifteen (15) vertical electric soundings were measured at different parts of the area using the Schlumberger electrode spread arrangement with maximum half-electrode spacing of 100 m. Qualitative interpretation of the curves suggested seven (7) different curve types suggesting that the area is underlain by four and five layers lithology thus the top soil that is predominantly lateritic in composition and occasionally wet, the fresh laterite, shale, and limestone layer, the shale, limestone, and clayey sand, sandstone layer, coarse sand, shale, limestone, and sandstone layer, limestone layer and the fine sandstone. The present study suggested that the aquifer in and around the study area is of moderate groundwater potential with relatively good protective capacity.*
***Keyword:*** *Vertical electrical sounding; Aquifer protective capacity; Groundwater potential; Demsa; Northeast Nigeria*

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## I. Introduction

Water is an essential component of life, both for humans and animals. It is for drinking and irrigation as well. The two important sources of water are surface (Rivers and Lakes) and groundwater that fills pore spaces within sediments, cracks and crevices in all types of rocks. In communities where both the human and animals relied on same source of water, say a river, for drinking and irrigation purposes, it is often a challenge resulting into conflicts between herders and farmers.Herder/farmer conflict in Nigeria isa tactical crime which occurred almost seasonally in recent times. In Dong and Lawaru (farming communities) in Demsa Area of Adamawa State northeast Nigeria, the frequencies and intensities of the conflict could be attributedto environmental and demographic forces narrowing down to River Shinu which provides the needed water resources for both cropping and grazing. Water resources is the geographic question at the center of the conflict hence alternative sources of water that could separate water for cropping from water for grazing would tactically separate the conflicting parties, thus putting an end to the conflict.Groundwater is such an alternative, thus the way forward, is to first and foremost, geophysically explore the groundwater potential of the area, for possible groundwater exploration as the alternative.

The aim of the present study was to estimate various aquifer parameters to infer aquiferous zones around the study area using the vertical electrical sounding (VES) while employingQuantum Geographic Information System (Q-GIS) analysis,to develop isoresistivity map of aquiferous zones (zones of low apparent resistivity) in the study area. Q-GIS is an open source GIS licensed software that can support tactical crime mapping such as the herder/farmer conflict, and a range of other strategic analysis.Herder/farmer conflict is basically a land-use suitability issue that requires proper generation, processing, and analysis of complex geographic questions such as mapping rivers and forests to adequately mitigate the frequencies and intensities of the crime. Q-GIS analysis is viable technique for processing complex geographic questions just as VES analysis does for delineation of groundwater potential.[1]submitted the viability of GIS in processing geographic questions to derive optimal recommendation for confronting complex geographic questions. In their submission, [2], [3], and [4] hinted that GIS constitutes fundamental geo-computational approach and tool for mapping and analysis of territory, landscape, and environment. Quantum-GIS is a user friendly open source software licensed under the GNU General Public License which can run on Windows and can support numerous vector, raster, and database formats and functionalities [5]. In their separate contributions [6], [7], [8], and [9] provided comprehensive overview on the subject matter of GIS which included definitions, concepts, and important characteristics of the software.[10], [11], and [12] reviewed 'Participatory' GIS (PGIS) in the context of 'democratization of GIS' to explore aspects of representations of local and indigenous knowledge, scale and scaling up, and some potential future technical and academic directions.[13]submitted that analysis of fundamental representation of space which can accurately represent wide range of relationships holds prominent place in GIS. In their separate submission, [14] and [15] opined that GIS provides powerful set of tools for decision-makers to analyze spatial information. Since 1970s, the field of GIS has evolved into mature research and application area involving Land Use Planning and Environmental Science, which will continue to play significant role even in future location model development and application [16].[17] and [18] provided overview on relevant methods for GIS-based land-use suitability mapping with focus on socio-political perspective.[19]submitted a contribution to the advancement of qualitative methodologies at the intersection of qualitative GIS, narrative analysis, 3D GIS-based time-geographic methods, and computer-aided qualitative data analysis. In general, GIS is an operational and affordable information system for strategic planning [20], which could be employed at different levels to support operational policing, tactical crime mapping, detection, and wider ranging strategic analysis [21].

Many studies established the essentiality of vertical electrical sounding (VES) measurement in evaluating and characterization of groundwater potentials. VES technique is a sound measuring tool for analysis of subsurface resistivity anomaly to identify groundwater zones.[22] and [23] submitted that VES measurement has the capacity to presents geophysical analysis to interpret groundwater configuration and evolution. In their separate submissions,[24],[25], [26], and [27] explained the usefulness of VES technique in identifying groundwater zones. Vertical electrical sounding method is sound geophysical measuring tool for evaluating groundwater potentials [28][29][30][31].[32] and [33] suggested that VES could be used to determine the precise location of resistivity anomaly for groundwater-bearing layers. Corroboratively speaking, the method of vertical electrical sounding can provide successions of subsurface geo-materials in terms of their individual thickness and corresponding resistivity values[34][35][36][37][38].

***Study area:***

Dong and Lawaru are two farming communities with high frequency of herder/farmer clashes along River Benue in Demsa L.G.A of Adamawa State, northeast Nigeria. The study area falls within the routes where nomadic herders access eastern and southern parts of Nigeria for grazing, after crossing the River Benue in Numan from northern part, through Benue State, to the southern part of the country. The area lies between latitude $9^0$.38'00''N and $9^0$.42'00''N, and longitude $11^0$.90'00''E and $11^0$.95'00''E. Farming activities around the area is mostly during rainy season with pockets of irrigation activities in dry season. Fig. 1 shows the reference map of the study indicating locations for VES points and Hand-dug Wells around the two farming communities of Dong and Lawaru. The figure also shows the pathway of the River Shinu along the area.

***Geological consideration:***

The study area lies on the Yola Arm of Upper Benue Trough, the Bima Sandstone [39]. The Bima Sandstone at the study area represents the base of sedimentary successions in the Upper Benue Trough which is subdivided into Lower, Middle, and Late Upper Albian Bima Sandstone [40]. The geological composition of the study consists, primarily, of alternating layers of poorly to moderately consolidated fine-to-coarse grained sandstones, mudstones and clay-shale.

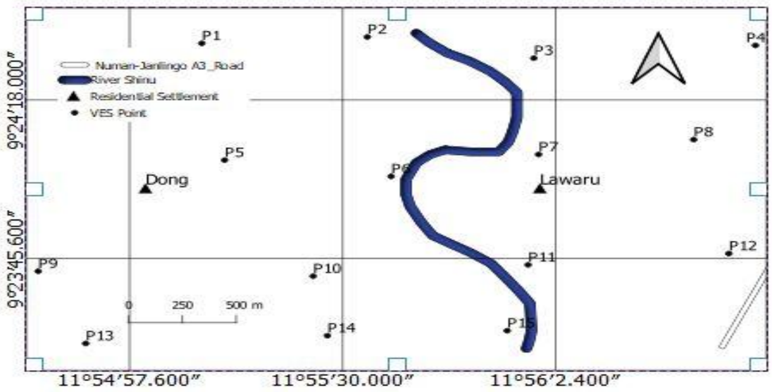



**Figure 1:** Geo-referenced Map of the Study area showing locations and positions of VES points and Hand-dug Wells

## II. Materials and Methods

***Data acquisition:***

The materials used in the present study included; ABEM SAS1000 (Resistivity meter), core cables, steel electrodes, GPS devise, laptop, and a number of computer software for analysis.

A total fifteen (15) vertical electrical sounding (VES) measurements were conducted using Schlumberger electrode configuration with a maximum current electrode spacing (AB/2) of about 100 m, and maximum potential electrode spacing (MN) of about 32 m. Currents were injected into subsurface vide the AB electrode and corresponding potential difference, and subsequently the apparent resistivity were recorded from the MN electrode, vide the Resistivity Meter. The AB/2 spacing varies between 2 and 200 m, thus 2, 4, 6, 8, 10, 12, 16, 20, 25, 30, 35, 40, 45, 50, 55, 60, 65, 70, 75, 80, 90, 100, 160, and 200 m. The MN spacing ranged between 0.5 and 32 m, thus 0.5, 0.5, 0.5, 2, 2, 2, 5, 5, 5, 8, 8, 8, 12, 12, 12, 16, 16, 16, 30, 30, 30, 32, 32, and 32 m. Electrode spacing in Schlumberger configuration increased with increasing depth (ground penetration). There was an overlap in each transition stage along the MN spacing, such 0.5 – 2, 2 -5 … 30 -32, for a near accurate record taking. The geophysical (field) data generated were processed using 1D inversion software, the IX1D, by Interpex Limited, Golden Colorado USA, where from, geoelectric layers; layers' resistivity and thickness of the study area were interpreted. Surfer 13by Golden Software, LLC and the QGIS software were used to developthe isoresistivity and contour map to highlight the aquiferous zones in the area.

***Hydraulic conductivity and transmissivity:***

The hydraulic conductivity (K) and transmissivity (T) values were estimated using equations (1) and (2), thus;[41].

$$K = 386.4\rho^{-0.93282} \qquad (1)$$

$$T = Kh \qquad (2)$$

Where; ρ is the apparent resistivity of the water-bearing layer, and h is the aquifer thickness.

At each VES point, the geophysical data generated from the field was processed using the IX1D Interpex software and information about the geoelectric layers present were established. The curves obtained as in Fig. 2, showed the number and type of curves generated. That was point where the apparent resistivity of the water-bearing layers was estimated from. These apparent resistivities were used estimate the hydraulic conductivity, and subsequently the transmissivity of the water-bearing layer.

***Aquifer protective capacity:***

The longitudinal conductance (S) of an aquifer defines the protective capacity of that aquifer against infiltration of impurities and contaminants.Thus, the higher the value of longitudinal conductance of an aquifer, the more protected the aquifer becomes, hence the purity and safety of the groundwater for drinking and irrigation. The longitudinal conductance in the present study was evaluated using equation (3).

$$S = \sum_{1}^{n} \frac{h_i}{\rho_i} \qquad (3)$$

Where;

$h_i$ = thickness of the ith layer, and

$\rho_i$ = apparent resistivity of the ith layer.

## III. Results and Discussions

Geophysical data processed in the present study revealed two curves type, namely four-layer and five-layer, geoelectric formation around the area of study. The four-layer curves consist of QH at VES points P1, P3, and P12. KH at P2 and P5, KQ appeared in P6, P8, and P10, while HA occurred in P9 and P11. The five-layer curves consists AKQ in P4 and P7, while KQQ appeared in P13 and P15 (Table 1). On average, the lithology deduced from the geophysical investigation in the present study consisted of top soil, porous limestone interchanging with hard shale, soft shale interchanging with dense limestone, and Sandstone. The aquifer layer consisted of mainly Sandstone with little occurrence of porous limestone. The resistivity variations in the water-bearing layer ranged between 46.2 Ωm at P7, and about 291.6 Ωm at P10, with thickness variation ranging from 11.7 m at P9 to about 32.4 m at P2 (Table 2).

**Table 1:**Summary of geoelectric parameters obtained at VES stations.

| VES | Easting | Northing | Resistivity (Ωm) | | | | | Thickness (m) | | | | Curve |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | ρ1 | ρ2 | ρ3 | ρ4 | ρ5 | h1 | h2 | h3 | h4 | type |
| P1 | 11.91905 | 9.408214 | 883.2 | 130 | 156.3 | 28.3 | - | 10.4 | 33.6 | 19 | - | QH |
| P2 | 11.92604 | 9.408576 | 233 | 18.99 | 77.1 | 122.3 | - | 8.1 | 40 | 32.4 | - | KH |
| P3 | 11.93308 | 9.40737 | 168.7 | 78.6 | 90 | 132 | - | 3.2 | 31 | 21 | - | QH |
| P4 | 11.94245 | 9.408094 | 77.8 | 110 | 111.3 | 83.3 | 1102 | 1.6 | 41.2 | 19.7 | 29.8 | AKQ |
| P5 | 11.92001 | 9.401581 | 338 | 13.3 | 159.6 | 81.2 | - | 1.2 | 28.5 | 28.9 | - | KH |
| P6 | 11.92705 | 9.400657 | 411.2 | 4.13 | 80.8 | 61.2 | - | 8.3 | 27.8 | 20 | - | KQ |
| P7 | 11.93328 | 9.401903 | 260 | 0.86 | 46.2 | 98.7 | 486 | 4.3 | 30 | 28.3 | 31 | AKQ |
| P8 | 11.93983 | 9.402747 | 313 | 100.7 | 138 | 143 | - | 5.1 | 33.8 | 30 | - | KQ |
| P9 | 11.91214 | 9.39527 | 300 | 88.9 | 129.6 | 101.4 | - | 5 | 42.3 | 11.7 | - | HA |
| P10 | 11.92375 | 9.394989 | 320 | 1145.8 | 291.4 | 172.6 | - | 3.2 | 38.6 | 30.9 | - | KQ |
| P11 | 11.93284 | 9.395632 | 421 | 50.3 | 180.3 | 313.4 | - | 6.3 | 41.3 | 20.3 | - | HA |
| P12 | 11.94132 | 9.396275 | 198.3 | 61.4 | 122.4 | 45.77 | - | 7.1 | 37.7 | 28.3 | - | QH |
| P13 | 11.91415 | 9.39117 | 201.6 | 97 | 71.82 | 141.2 | 218 | 2 | 61 | 18 | 11 | KQQ |
| P14 | 11.92436 | 9.391612 | 1355.8 | 83.2 | 66.4 | 280 | - | 3.8 | 32.3 | 20 | - | QQ |
| P15 | 11.93195 | 9.391893 | 618.3 | 55.8 | 148.7 | 255.6 | 333.6 | 2.9 | 55.2 | 25.8 | 31 | KQQ |

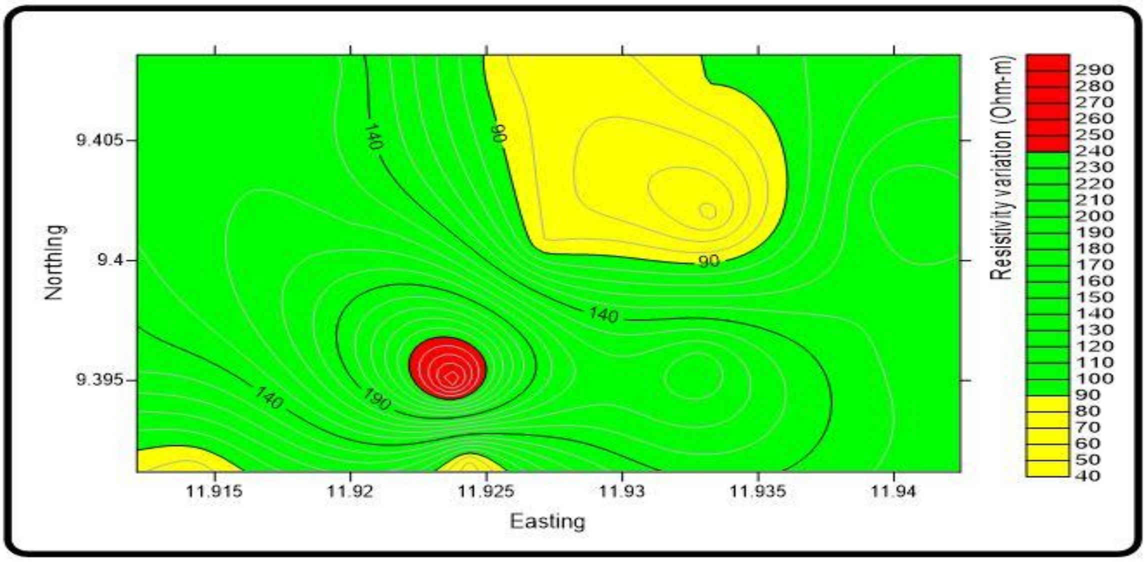



**Figure 2:** Aquifer apparent resistivity map of the study area

**Table 2** Summary of apparent resistivity and thickness of the aquifers in the study area.

| VES Point | Easting | Northing | Aquifer Resistivity (Ωm) | Aquifer Thickness (m) |
|---|---|---|---|---|
| P1 | 11.91905 | 9.408214 | 156.3 | 19 |
| P2 | 11.92604 | 9.408576 | 77.1 | 32.4 |
| P3 | 11.93308 | 9.40737 | 90 | 21 |
| P4 | 11.94245 | 9.408094 | 111.3 | 19.7 |
| P5 | 11.92001 | 9.401581 | 159.6 | 28.9 |
| P6 | 11.92705 | 9.400657 | 80.8 | 20 |
| P7 | 11.93328 | 9.401903 | 46.2 | 28.3 |
| P8 | 11.93983 | 9.402747 | 138 | 30 |
| P9 | 11.91214 | 9.39527 | 129.6 | 11.7 |
| P10 | 11.92375 | 9.394989 | 291.4 | 30.9 |
| P11 | 11.93284 | 9.395632 | 180.3 | 20.3 |
| P12 | 11.94132 | 9.396275 | 122.4 | 28.3 |
| P13 | 11.91415 | 9.39117 | 71.82 | 18 |
| P14 | 11.92436 | 9.391612 | 66.4 | 20 |
| P15 | 11.93195 | 9.391893 | 148.7 | 25.8 |

The hydraulic conductivity in the study area was estimated to have ranged from 1.94 m/day at P10, to about 10.82 m/day at P7, while the transmissivity values estimated to have ranged between 48.32 $m^2$/day at P9, to about 306.21 $m^2$/day at P7 (Table 3). Of the aquifer protective capacity of the water-bearing layer in the area, the longitudinal conductance ranged from 0.09 mS at P9 to about 0.61 mS at P7 (Table 4).

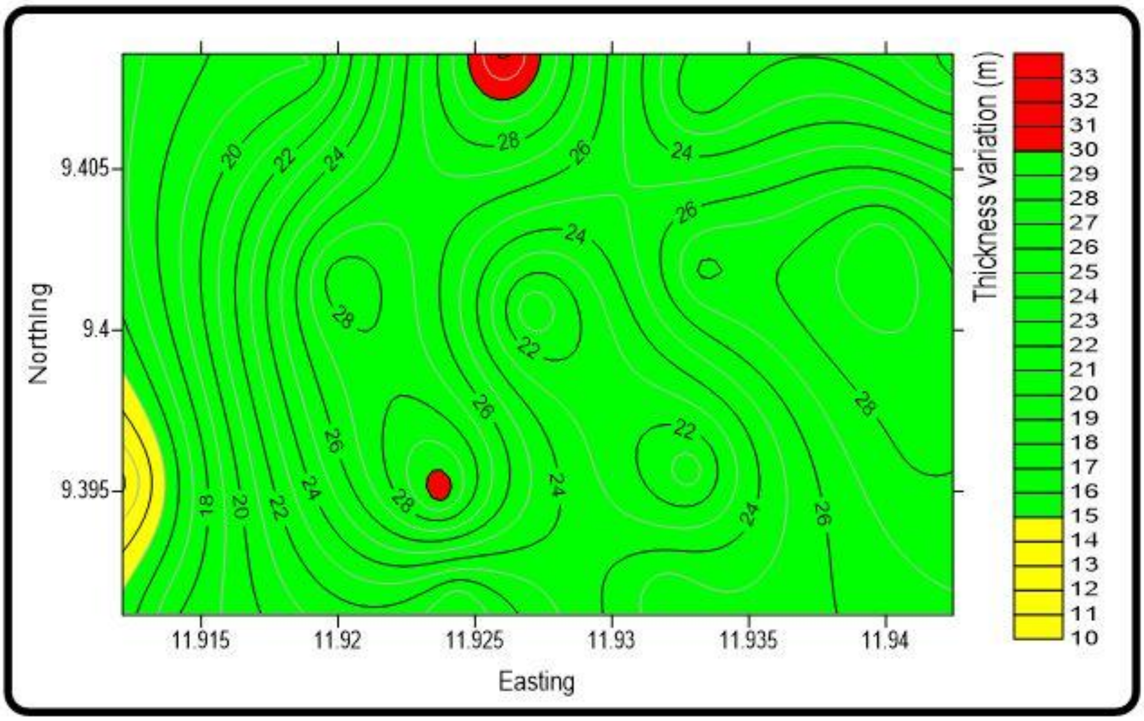



**Figure 3:**Aquifer thickness map of the study area

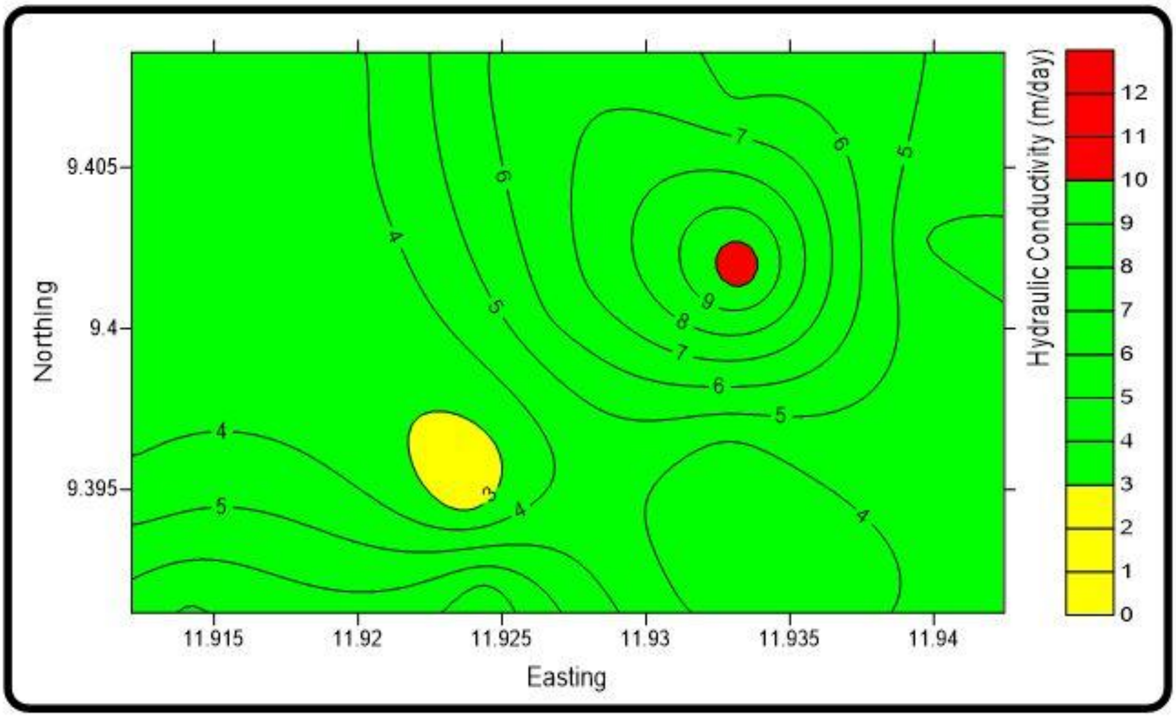



**Figure 4:** Aquifer hydraulic conductance map of the study area

**Table 3.**Summary of aquifer hydraulic conductance and transmissivity values

| VES Point | Hydraulic Conductivity (m/day) | Transmissivity ($m^2$/day) | Groundwater Potential |
|---|---|---|---|
| P1 | 3.47 | 65.93 | Moderate |
| P2 | 6.71 | 217.4 | Moderate |
| P3 | 5.81 | 122.01 | Moderate |
| P4 | 4.76 | 93.77 | Moderate |
| P5 | 3.4 | 98.26 | Moderate |

| | | | |
|---|---|---|---|
| P6 | 6.42 | 128.4 | Moderate |
| P7 | 10.82 | 306.21 | Moderate |
| P8 | 3.9 | 117 | Moderate |
| P9 | 4.13 | 48.32 | Low |
| P10 | 1.94 | 59.94 | Low |
| P11 | 3.04 | 61.71 | Moderate |
| P12 | 4.36 | 123.39 | Moderate |
| P13 | 7.17 | 129.06 | Moderate |
| P14 | 7.71 | 154.2 | Moderate |
| P15 | 3.64 | 93.91 | Moderate |

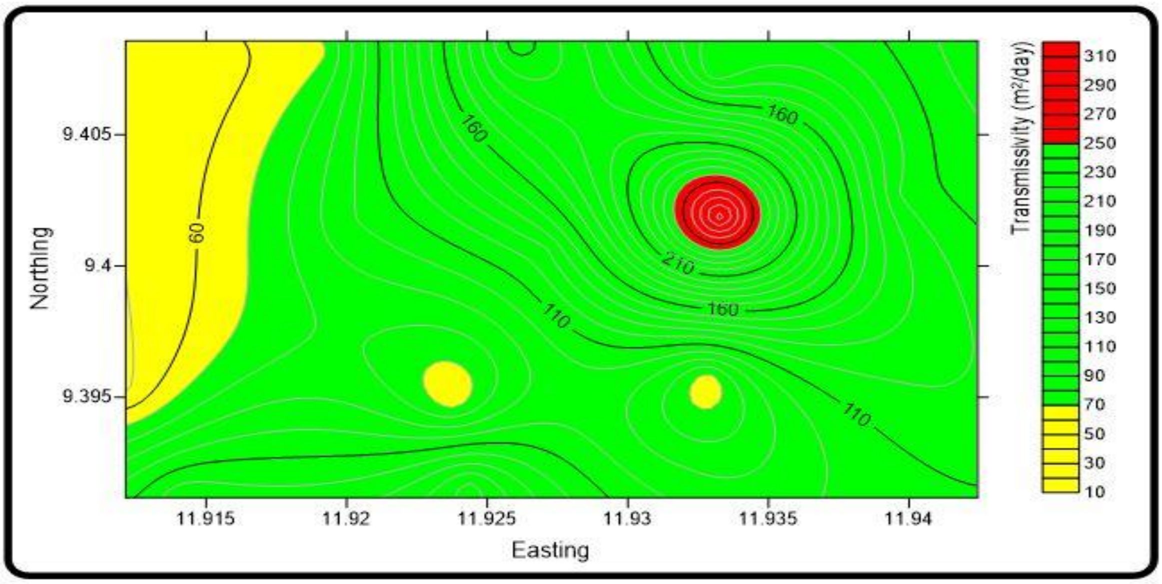
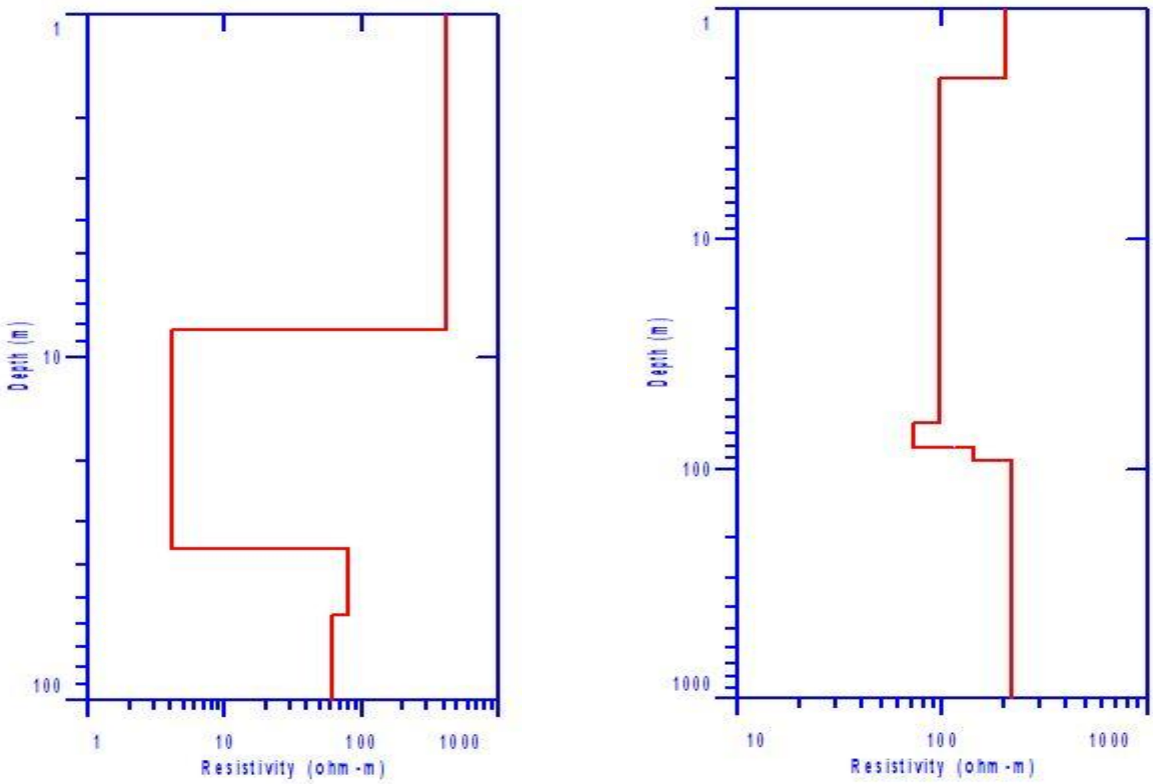



**Figure 5:**Aquifer transmissivity map of the study area

**Table 4:** Summary of aquifer longitudinal conductance values and protective capacity of the aquifer

| VES Point | Longitudinal conductance (mS) | Aquifer protective Capacity |
|---|---|---|
| P1 | 0.12 | Weak |
| P2 | 0.42 | Moderate |
| P3 | 0.23 | Moderate |
| P4 | 0.18 | Weak |
| P5 | 0.18 | Weak |
| P6 | 0.25 | Moderate |
| P7 | 0.61 | Moderate |
| P8 | 0.22 | Moderate |
| P9 | 0.09 | Poor |
| P10 | 0.11 | Weak |
| P11 | 0.11 | Weak |
| P12 | 0.23 | Moderate |
| P13 | 0.25 | Moderate |
| P14 | 0.30 | Moderate |
| P15 | 0.17 | Weak |




(a) VES P6 (b) VES P13

**Figure 6:** (a) Typical iterated KQ type in the study area. (b) Typical iterated KQQ type in the study area

The aquifer resistivity, thickness, hydraulic conductance and transmissivity contour maps (Fig. 2 - 5) were used to deduce and classify the groundwater potential in the study area into low and moderate zones. All the VES points in the present study revealed moderate groundwater potential zones with the exception of VES points P9 and P10. Thus about 86.66% of the entire area covered.

## IV. Conclusion

From the foregoing results and discussions, the authors of the present research thus concluded that;

a) The aquifer in around the study area is of moderate groundwater potential with relatively good protective capacity.

b) The aquifer can be explored to generate additional source of water around the study area in a bid to distinguish between water for grazing and that for cropping (irrigation). This has the capacity to minimize, if not completely eradicate the incessant clashes between farmers and herders around the area.

c) Electrical resistivity sounding (VES) method combined with Geographic Information System is a way to go in terms of groundwater exploration.

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**Conflict of interest:**
The authors have declared that no competing interests exist.

**Authors' contributions:**
SMB conducted the research, collected the data, analyzed it and drafted the manuscript. RHD supplied the hydrogeological history of the study area.

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SMB (M.Sc.) is an Assistant Lecturer in the Department of Physics, Yobe State University Damaturu Nigeria.RHD (B.Tech) is a Hydrogeologist with the Adamawa State Ministry of Water Recourses.

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