Nigerian Journal of Applied Physics (NJAP)
ISSN Print: 3115-5871
ISSN Online: 3115-588X
DOI: https://doi.org/10.62292/njap-v2i1-2026-70
Volume 2(1), March 2026

Assessment of Groundwater Potential and Vulnerability in Gurku-Gwari and Environs North-Central Nigeria, Using Electrical Resistivity Method

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ABSTRACT

Obtaining useful information regarding groundwater potential and vulnerability is essential for deciding whether groundwater can be used for drinking and for other purposes. Water remain one of the vital elements for sustaining any growing population; therefore, this research work is carried out around Gurku-Gwari community, Karu local government area, Nasarawa state, Nigeria; with the aim of evaluating groundwater potential and its vulnerability using vertical electrical sounding (VES) method. A total of fifteen (15) VES locations were surveyed using Omega 2.0 resistivity meter to measure subsurface resistivity variations. The acquired data were processed using WinRESIST 2.0 to determine layers apparent resistivity, thicknesses and to delineate geo-electric layers. Surfer 13, Geosoft, and ArcGIS 10.7.1 softwares were utilized for contouring and map production respectively. The interpreted field curves shows three to four geo-electric layers with model resistivity value ranging from 14.9 Ωm to 51,202.7 Ωm and thickness between 0.8 m to 20.6 m with a maximum depth to fresh basement of about 35.5 m. The aquifer units across the study area occurred predominantly within the weathered/fractured basement. Results of Dar-Zarrouk analysis revealed a longitudinal conductance values ranging from 0.0012 m/Ωm to 0.0436 m/Ωm, transverse resistance variation of 532.35 Ωm^2 to 11538.04 Ωm^2, hydraulic conductivity values of 1.0651 m/day to 9.9210 m/day and transmissivity values ranging from 7.79 m^2/day to 139.4 m^2/day. These results suggest that the study area has poor protective capacity which makes the area vulnerable to contamination and the aquifer potential yield is low to moderate. Based on these findings, the most favourable locations for borehole drilling are VES 4 south of Gurku-Gwari settlement and VES 6 and 12 south-west and north-west of Kubobbagi settlement respectively.

Keywords:
Gurku-Gwari,
Basement Complex,
Resistivity survey,
Groundwater potential,
Aquifer vulnerability.

INTRODUCTION

Groundwater remains one of the most crucial substances to human existence and one of the most natural resources that is indispensable for the survival of mankind as well as the survival of it natural environment. In a search for clean water, it is necessary to obtained useful information on the availability of groundwater, its quality as well as the aquifer protective capacity of that particular area in other to decide the usability of water for drinking and other applications. The availability of water has played a key role in the ancient civilisation. Since prehistoric times' water scarcity has limited the growth and sustainability of many civilizations (Stavros, 2015).

Throughout history, groundwater serves as the main source of water supply to many cities as well as the urban and villages (Barka & Kubbis, 2024)). Many developed and developing countries preferred groundwater because of it is relatively reliability during dry season and its better quality which require less treatment. In 2018, United Nations Water reported that 40% of water used for irrigation in agriculture and 1/3 of water supply required for industry are gotten from groundwater. However, due to the geological complexity of basement terrains groundwater are highly vulnerable to contamination, especially area where the topsoil and the weathered layer are not thick enough to protect the aquifer or the aquifer is directly connected to the surface though permeable layers with no confining layer in between (Kayode *et al.,* 2024).

The increase demand for groundwater across the world driven by population growth, urban development, climate inconsistency, and poor water management has placed significance pressure on the resource (Nzemeka *et al.,* 2023). In area where poor waste disposal occur and vis-à-vis rapid development the aquifer in such areas became more vulnerable to contamination from landfill leachates, sewage intrusion, flood recharge and agricultural chemicals (Agada & Abba, 2022; Jasechko *et al.,* 2017). The consequence of consuming contaminated groundwater is serious because it can lead to serious health condition such as constant headaches, insomnia, joint pains, cancer, renal failure and stomach disorder (Pareta *et al.,* 2024).

Aquifer protective capacity refers to the ability of the overburden material to impede and filter percolating contaminated fluid before they reach to the aquifer zone (Nzemeka *et al.,* 2023). Impermeable materials such as polycarbonate, clay and shale possess a good protective capacity while poor protective capacity material are often porous and permeable such as gravel and sand for aquifers. The quality of protection depends heavily on the context and intended use (Agada & Yakubu, 2022).

Gurku-Gwari, is part of the rapidly growing district in Karu Local Government Area in Nasarawa State, which is a major dormitory settlement for workers in the nearby Federal Capital Territory (FCT), Abuja (Damulak, 2015). There is no official population figure projected in the study area as at the national population census (NPC) of 2006. However, claim by (Rikko et al., 2019), state that approximate population of large ward (Mararaba Gurku-Gwari) is around 256,800 inhabitants.

With the outburst in population and urban growth across the study area which is dominantly underlain by Basement Complex rocks, there is a need to explore more area for groundwater exploitation. Therefore, for effective exploration and exploitation of Basement Complex terrains one need to have a proper understanding of the geology and hydrological characteristic of that area (Barka & Bassey, 2015).

Previous studies have evaluated groundwater potential and aquifer protective capacity in neighboring regions such as Keffi and Mararaba but the study area remains defectively studied despite its rapid growth. This exponential increase in the population of the entire metropolis due to urban migration has consequently caused water shortages in the area and necessitated the need to explore for more water resources to solve this menace.

The study area is largely underlain by rocks of the north-central Nigerian Basement Complex, which are variably fractured/weathered and metamorphosed. The groundwater resources here are restricted to the weathered and fractured basement rocks or confined in alluvial deposits as stated by some researchers (Wright, 1992; Olorunfemi & Fasuyi, 1993). This is promising for any geophysical survey of the groundwater development potential in the area since groundwater is mostly transmitted via secondary geologic structures like fractures.

Electrical resistivity method, specifically the vertical electrical sounding techniques has proven to be effective and reliable tool in locating groundwater potential zones in basement complex terrains. The method has been recognized across the world because it is cheap and easy to use. The method provides detailed information on surface resistivity variation, lithological changes, aquifer thickness, and basement topography and aquifer protective capacity through the application of Dar-Zarrouk parameters.

Therefore this research work utilized Schlumberger array configuration to explore the groundwater potential and determine the aquifer protective capacity of the Gurku-Gwari community.

Geology and Hydrogeology of the Study Area

Gurku-Gwari community is one of the major settlements in Karu Local Government Area that share common boundaries with the Federal Capital Territory (FCT) Abuja to the west, Kaduna to the north, Keffi Local Government Area to the east and Nasarawa LGA to the south. It fall within longitudes 7° 37′ 00″E to 7°39′30″E and latitudes 9° 05′ 00″ N to 9° 0′ 00″ N (figure 1). Gurku-Gwari, is located in the north central region of Nigeria sitting on the Precambrian Basement Complex terrain and consists predominantly of igneous and metamorphic rocks. The primary rock types are gneissic migmatites, granite, schists, and amphibolite schists, which have been intruded by porphyritic older granites and pegmatites (McCurry, 1976). The rock formation occurs in varying forms throughout the Karu-Abuja region. Geologically, the area features significant structure such as joints, fractures, faults, and folds. The depths of the weathering is generally shallow, meaning the overburden (soil and weathered rock) is not very thick (McCurry, 1976; Odedede & Ugbe, 2016; Ugwuonah *et al.,* 2017).

In terms of hydrology, the study area is largely dependent on the underlying geology, it is dominated by the Basement Complex rocks of north central Nigeria. The surface water is mainly streams and rivers that infiltrate sloppy terrains along the northern peripheral of the area. Gurku-Gwari is fed by the lower Gurara Dam. The occurrence of groundwater in the study area is controlled by the thickness of the overburden, rock type, composition, and textural variation of the rock, fracture density, and the degree of fracture network/interconnections and the aquifer here are characterized by low-moderate productive rates. The depth of water table is not homogenous in the area; it changes in the communities with maximum water level in the rainy season and minimum in dry season (Sunkari et al., 2021). The variation causes seasonal fluctuation in the storability of the underlying aquifers (Sunkari et al., 2021).

Therefore, this research work made an attempt to explore the study area for quantitative and qualitative groundwater resources that can meet up with its rapidly growing population.

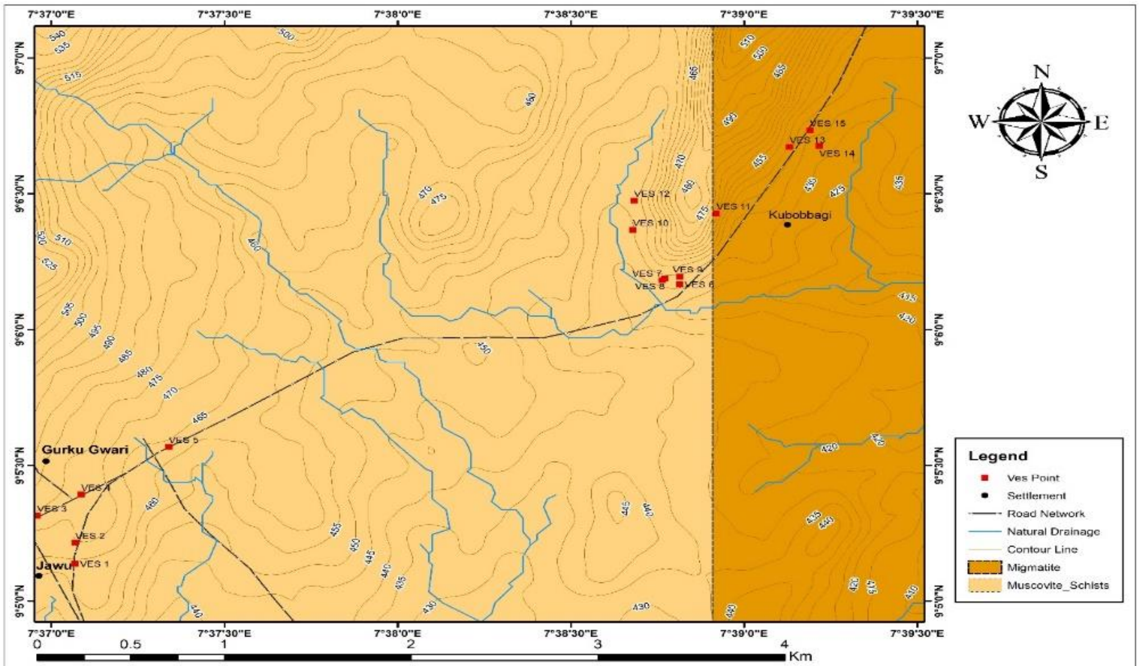

Figure 1: Geology Map of the Study Area showing VES Locations (Modified from NGSA 2016)

MATERIALS AND METHODS

Materials

Omega Terrameter version 2.0 geophysical equipment was used for electrical resistivity data acquisition and softwares such as Win Resist version 2, Surfer 1, ArcGIS version 10.7.1 and Microsoft excel were used for data processing and this aided in the interpretation of the results.

Methods

Fifteen (15) vertical electric sounding (VES) locations were occupied across the study area adopting the Schlumberger electrode configuration. The VES proceedings involved acquiring apparent resistivity data which is a function of the inhomogeneity of the earth. The apparent resistivity represents the resistivity of the isotropic half-space that would produce the measured potential difference for a given electrode arrangement and spacing. Therefore, it is calculated as a function of measured resistance value and the geometric factor, based on ohm's law (equation 1):

$$\rho = K\frac{\Delta V}{I} \quad (1)$$

Where: ρ Is the apparent resistivity in ohm's meters (Ωm), ΔV is the potential difference measured in millivolts (mV), I Is the current injected, measured in milli-amperes (mA) and K is the geometric factor.

The geometric factor *K* for each vertical electrical sounding (VES) point was determine from the spacing of the current and the potential electrodes and calculated using the (equation 2):

$$K = \pi\frac{\left(\frac{AB}{2}\right)^2 - \left(\frac{MN}{2}\right)^2}{MN} \quad (2)$$

Where: AB is the distance between the current electrodes, MN is the distance between the potential electrodes

The Schlumberger electrode configuration was employed for the measurements, with a maximum *AB/2* spacing of 150 meters. This configuration was selected due to its efficiency, accuracy, and slightly greater depth of penetration compared to other configuration, such as Wenner method.

Data Processing and Interpretation

The VES data were initially process using apparent resistivity curves matching, which involves plotting of the apparent resistivity values against $AB/2$ on a bi-logarithm sheet. A manual partial curve matching technique was adopted to obtain the initial layer parameters. The field data were later modelled using WINRESIST Software version 2.0 on a computer to obtain the apparent resistivity of the subsurface layers. Other software used for the analysis of the field data are surfer 13 which is used for the generation of contour maps and ArcGIS version 10.7.1 for map plotting respectively.

Dar-Zarrouk Parameters

Dar-Zarrouk parameter are hydrogeological values used to characterize the subsurface layers, by combining the layer resistivity (ρ) and layer thickness (h) to calculate the longitudinal conductance (S) and transverse resistance (Tr). Dar-Zarrouk parameter was introduced by Maillet (1947), in aquifer studies, evaluating groundwater potential and assessing aquifer protective capacity. They are derived from the geo-electric data and provide a way to understand the bulk properties of layered media.

Longitudinal Conductance (*S*):

The protective capacity of the overburden material was evaluated using longitudinal conductance (S) values. It represents the total current-c**a**rrying capacity parallel to the layer and is calculated using the formula (equation 3):

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

Where: ρ_i is the layer resistivity in (Ω), and $\boldsymbol{h_i}$ is the overburden layer thicknesses in (m) or (mho).

Transverse Resistance (T_r)

Transverse resistance (Tr) represents the total resistance to current flow perpendicular to the layers (Ωm^2). In this study, transverse resistance was obtained as the product of aquifer resistivity and aquifer layer thickness calculated using (equation 4):

$$T_r = \sum_{i=1}^{n} \rho_i h_i \quad (4)$$

Where: ρ_i Is the apparent resistivity in (Ω) and (h_i) is the layer thickness in (m^2).

Aquifer Protective Capacity

Aquifer protective capacity is the ability of a rock and soil layers above an aquifer to prevent surface pollutants from reaching it. It is determine by the thickness and the type of the overlying materials like clay and shale providing high protection, while sand and gravel offer low protection. The overburden protective capacity in the study area was evaluated using longitudinal unit conductance derived from the vertical electrical resistivity sounding results. The rating is categorized as poor, weak, moderate, good, very good and excellent depending on the magnitude of the total longitudinal conductance values (Table 1).

Table 1: Longitudinal Conductance/Protective Capacity Rating (Adapted from Henrient 1976, and Oladapo *et al.,* 2004)

Longitudinal Conductance (mhos)	Protective Capacity Rating
>10	Excellent
5 – 10	Very good
0.7 - 4.9	Good
0.2 - 0.69	Moderate
0.1 - 0.19	Weak
< 0.1	Poor

Hydraulic Conductivity (K)

In this work hydraulic conductivity is evaluate in other to measure how easily water move through soil and porous media. According to Heigoid et al., (1979), hydraulic conductivity of a porous medium can be determined using the formula in (equation 5):

$$\mathbf{K} = 386.40R_{rw}^{-0.93283} \quad (5)$$

Where: K is the hydraulic conductivity measure in meter per day (m/day) and R_{rw} is the aquifer resistivity in ohm's meter (Ωm).

Transmissivity (T)

Transmissivity refers to the capacity of an aquifer to transmit fluid (like groundwater) through it hydraulic gradient and is expressed as the product of the hydraulic conductivity (K) and the saturated aquifer thickness (h) using the formula in (equation 6):

$$\boldsymbol{T} = K \times h \quad (6)$$

Where: T is the Transmissivity, K is the hydraulic conductivity in (m/day) and h is the aquifer thickness in m. therefore, the SI unit is present as (m^2/day).

The classification of transmissivity value in the study was adopted from offodile 1983 classification as presented on table 2.

Table 2: Aquifer Classification Based on Transmissivity Values (Offodile, 1983)

Transmissivity (M^2/day).	Classification of Well
>500	High potential
50 – 500	Moderate potential
5 – 50	Low potential
<0.5	Negligible potential

RESULTS AND DISCUSSION

Analysis of Interpreted Field Curves

The vertical electrical sounding data obtained were interpreted and the summary of the geo-electrical parameters were presented on Table 3 while some selected interpreted field curves were presented as figure 2. The computed results in the study area revealed a minimum of three to a maximum of four geo-electric layers.

The first geo-electric layers are generally interpreted as the topsoil which in areas composed of sand, laterite, quartzite and clay. The first geo-electric layer in the study area has resistivity values ranging from 122.0 Ωm to 527.9 Ωm. Locally, The thickness vary between a minimum of 0.8 m to a maximum of 6.6 m.

Across the study area, the second geo-electric layer displays a noticeable variation in lithology unit composing of clayey to weathered basement, with low to moderate resistivity values of 14.8 Ωm to 1750.3 Ωm, and layer thickness ranging from 1.3 m to 14.2 m. In VES locations 4, 10 and 12 the second geo-electric layer were considered the aquifer zones.

The third geo-electric layers in some VES locations (VES 1, 2, 3, 5, 6, 7, 8, 9, 14, and 15) were interpreted as the main aquifer zone, consisting mainly of highly weathered and fractured basement materials. These layers show moderate to relatively high resistivity values 76.4 Ωm to 554.6 Ωm. While in other VES locations (VES 48, 10, 11. 12 and 13) the third layers with high resistivity values within the range of 22140.3 Ωm to 50508.7 Ωm are indicative of fresh and near surface crystalline or Basement Complex rocks. The thickness of the third layer varies between 5.4 m to 23.6 m and where the layer is sufficiently thick and contains high density fractures enhances groundwater storage

The fourth geo-electric layers in the study area are interpreted as the fresh basement rock, which are characterised by a very high resistivity values ranging between 4957.7 to 51202.7 Ωm, this indicate high resistive layer of crystalline basement rock.

The interpreted curve types across the study area as presented on Table 3, shows the H-type, KH-type, A-type, and HA–type however, the dominance of HA and H curve type suggests moderate to high groundwater potentials.

Table 3: Summary of Geo-Electric Parameters obtained from the Study Area

VES NO.	Resistivity of Layers (Ωm)	Thickness of Layers (m)	Depth of Layers (m)	Curve type	Inferred Lithology's
1	168.0, 33.6, 302.4, 28044.7	1.9, 2.8, 9.9	1.9, 4.7, 14.6	HA	Topsoil Weathered Basement Fractured Basement fresh Basement
2	134.0, 39.7, 488.9, 18558.3	1.1, 1.3, 23.6	1.1, 2.2, 26.0	HA	Lateritic Topsoil Clayey Weathered Basement Fractured Basement Fresh Basement
3	196.7, 14.8, 254.7, 43198.4	1.7, 1.8, 9.3	1.7, 3.5, 12.8	HA	Weathered Topsoil weathered Basement Fractured Basement Fresh Basement
4	122.0, 50.7, 6095.6	3.0, 10.5	3.0, 13.5	H	Sandy Topsoil Fractured Basement Fresh Basement
5	445.8, 20.3, 208.1,15552.3	2.6, 2.9, 11.4	2.6, 5.5, 17.0	HA	Gravelly sand topsoil Clayey Weathered Basement Dry sandy Basement Fresh Basement
6	353.8, 1750.3, 76.4, 7196.4	5.0, 6.9, 20.6	5.0, 11.9, 32.5	KH	Laterite Topsoil Weathered/Fractured Basement Fresh Basement
7	354.1, 87.4, 400.7, 39803.4	1.3, 1.7, 5.4	1.3, 3.0, 8.4	HA	Laterite Topsoil Thin weathered Basement Fractured Basement Fresh Basement

8	209.0, 134.2, 309.4,51202.7	3.1,1.9, 6.1	3.1, 5.0, 11.1	HA	Coarse-Grain Sand Weathered Basement Fractured Basement Fresh Basement
9	433.3, 132.0, 554.6,18333.7	0.9, 1.8, 9.9	0.9, 2.7, 12.5	HA	Rich quartzite Top soil Weathered Basement Fractured Basement Fresh Basement
10	386.3, 60.2, 7757.7	2.1, 13.2	2.1, 15.3	H	Sandy Clay Topsoil Weathered/Fractured Basement Fresh Basement
11	527.9, 102.2, 50508.7	0.8, 5.3	0.8, 6.1	H	Topsoil Weathered/Fractured Basement Fresh Basement
12	151.5, 100.1 , 5656.6	6.6 , 14.2	6.6, 20.8	H	Gravelly Topsoil Sandy Clay Layer Fresh Basement
13	233.5, 472.3 , 22140.3	4.1, 11.3	4.1, 15.4	A	Topsoil Fractured Basement Fresh Basement
14	314.7, 36.7, 408.1, 46068.4	1.5, 2.0, 11.1	1.5, 3.5, 14.6	HA	Sandy Topsoil Clayey Basement Fractured Basemen Fresh Basement
15	405.7, 29.2, 191.9, 4957.7	1.2, 4.1, 7.9	1.2, 5.3, 13.2	HA	Lateritic Soil Clayey Basement Weathered/Fractured Basement Fresh Basement

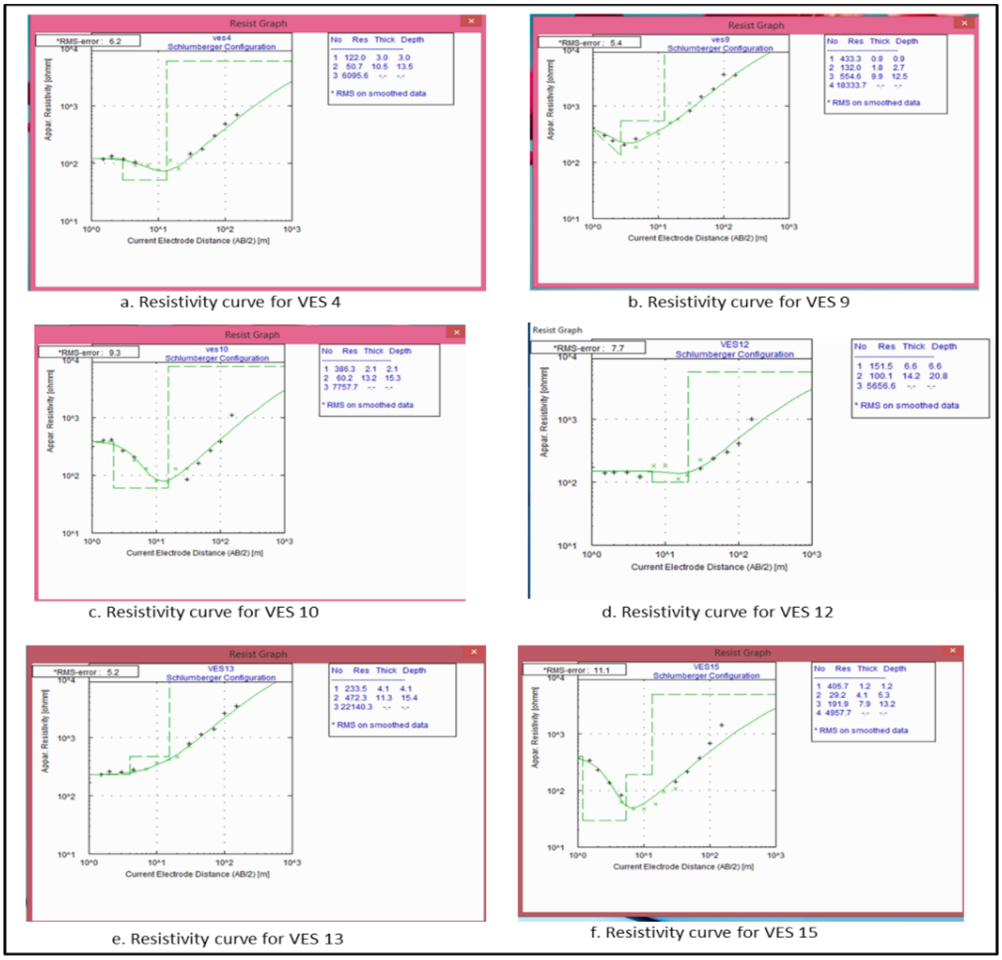

Figure 2: Resistivity Curves for Some Selected VES Locations in the Study Area

Dar-Zarrouk Parameter

The Dar-Zarrouk parameters were derived from the interpreted geo-electric layers to further evaluate the aquifer characteristic of the study area. A detailed summary of the results were presented on Table 4.

Table 4: Summary of Aquifer Parameters for the Study Area

VES No.	***Aquifer Thickness*** **(m)**	***Apparent*** **Resistivity (Ωm)**	**Longitudinal conductance S = *h*/ρ (m/Ωm)**	**Transverse resistance Tr = *h.ρ* (Ωm^2)**	**Hydraulic conductivity K=386.40$R_{rw}^{-0.93283}$ (m/day)**	**Transmissivity T = K*h* (m^2/day)**
1	9.9	302.4	0.0233	2993.76	1.8753	18.57
2	23.6	488.9	0.0138	11538.04	1.1980	28.27
3	9.3	254.7	0.0171	2368.71	2.2010	20.47
4	10.5	50.7	0.0246	532.35	9.9210	104.17
5	11.4	208.1	0.0118	2372.34	2.6576	30.30
6	20.6	76.4	0.0141	1573.84	6.7675	139.40
7	5.4	400.7	0.0068	2163.78	1.4423	7.79
8	6.1	309.4	0.0146	1887.34	1.8356	11.20
9	9.9	554.6	0.0048	5490.54	1.0651	10.54
10	13.2	60.2	0.0054	794.64	8.4523	111.57
11	5.3	102.2	0.0152	2661.66	5.2550	27.85
12	14.2	100.1	0.0436	1421.42	5.2598	74.69
13	11.3	472.3	0.01303	5336.99	1.2372	13.98
14	11.1	408.1	0.0100	4529.91	1.4179	15.74

15	7.9	191.9	0.0012	1516.01	2.8663	22.64
Minimum	5.3	50.7	0.0012	532.35	1.0651	7.79
Maximum	23.6	554.6	0.0436	11538.04	9.9210	139.40
Average	11.3	265.4	0.0146	3145.42	3.5635	42.50

Longitudinal Conductance (S) Map of the Study Area

The protective capacity of the overburden rock or layer overlying an aquifer zone is measured based on its longitudinal conductance, which is translated as the ability of these layers of rocks above the aquifer system to prevent surface pollutants from reaching the aquifer. These layers must possess significant amount of clayey, silty or perhaps shaley materials. The longitudinal conductance values for the study area were computed from (equation 3) and are presented on Tables 4 and 5. These values ranged from a minimum of 0.0012 m/Ωm to a maximum of 0.0436 m/Ωm with an average value of 0.0146 m/Ωm. These values obtained were transformed to produce the longitudinal conductance map of the study area (figure 3). From the analysis of this map, the entire study area was rated to fall within areas with poor protective capacity based on the classification given by Henrient 1976 and Oladapo et al., 2004 (Table 1). This anomaly can be attributed to the thin overburden layers in the study area which ranges from 0.9 to 6.9 m and their compositions mostly comprising of laterites, fragments of quartzite and coarse sand stone. The overburden material in the study area because of their grain sizes (medium to coarse), they tends to be porous in nature and could not inhibit the infiltration of pollutants from the surface into the aquifer system. Despite the general poor protective capacity rating of the study area, VES locations 1, 4 and 12 exhibits a near weak protective capacity rating.

Table 5: Protective Capacity Rating Of Aquifer in the Study Area

VES Point	Longitudinal Conductance Ω/Ωm	Protective Capacity
1	0.0233	Poor
2	0.0138	Poor
3	0.0171	Poor
4	0.0246	Poor
5	0.0118	Poor
6	0.0141	Poor
7	0.0068	Poor
8	0.0146	Poor
9	0.0048	Poor
10	0.0054	Poor
11	0.0152	Poor
12	0.0436	Poor
13	0.01303	Poor
14	0.01000	Poor
15	0.00120	Poor

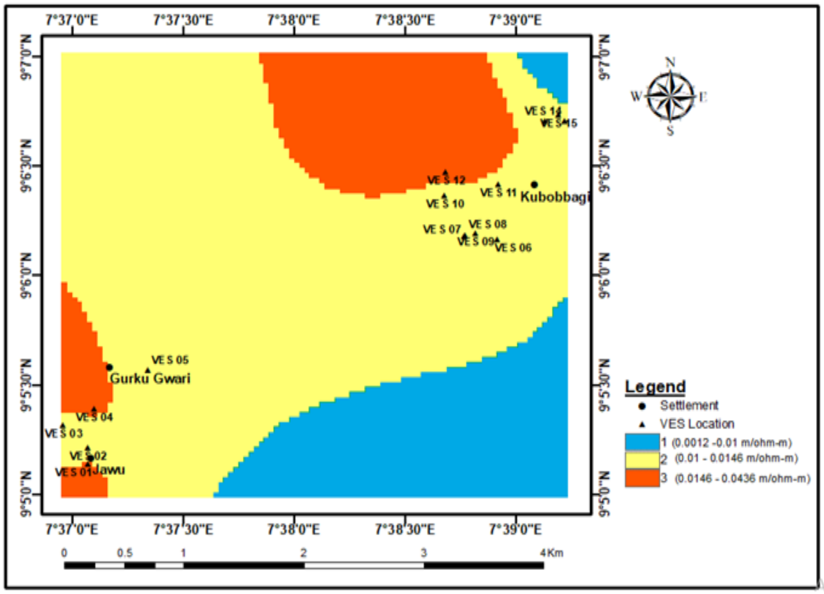

Figure 3: Reclassified Longitudinal Conductance Map of the Study Area

Transverse Resistance (Tr) Map of the Study Area

The ability of water to flow through a unit volume of an aquifer system is measured based on its transverse resistance. Opera et al., 2012 shows that zones with higher transvers resistance are expected to give higher borehole yield. Transverse resistance values on Table 4 were obtained using (equation 4) and the values ranges from a minimum of 532.35 Ωm^2 to maximum of 11538.04 Ωm^2 and an average of 3145.42 Ωm^2. These data were imaged to produce the transverse resistance map of the study area (figure 4) which revealed fairly high transverse resistance values at VES 1 and VES 2 at the southern part of Gurku-Gwari Gwari settlement and at VES 6 southwest of Kubobbaggi settlement. The remaining parts of the study area exhibits low to moderate transverse resistance with the moderate dominating the central parts.

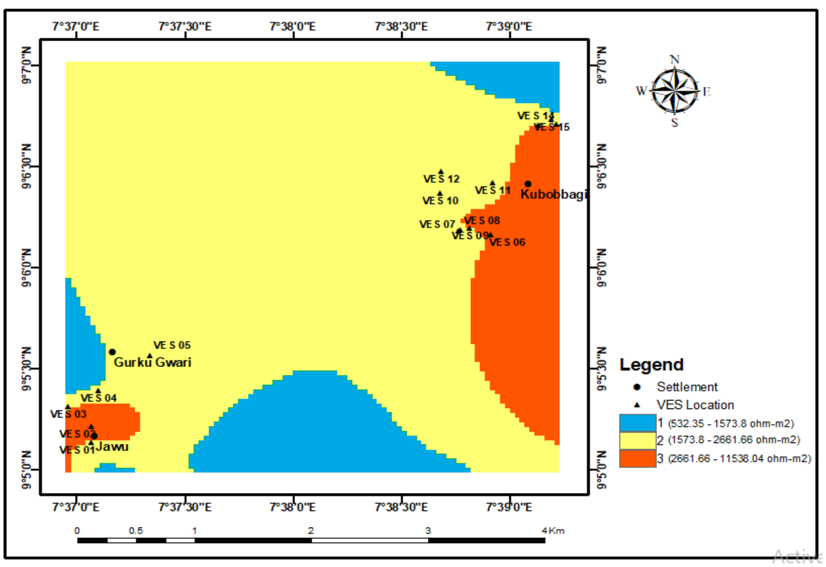

Figure 4: Reclassified Transverse Resistance Map of the Study Area

Hydraulic Conductivity (K) Map of the Study Area

The ease at which water can flow through the aquifer system either through pore spaces or fractures is refers to as hydraulic conductivity. The ease of flow of water through an aquifer system is aided primarily by interconnectivity of its pore spaces or fractures. The hydraulic conductivity values (Table 4) which displayed values ranging from a minimum of 1.0651 m/day to maximum of 9.9210 m/day with an average value of 3.5635 m/day were obtained using (equation 5). These values were transformed to produce the hydraulic conductivity map of the study area (figure 5). From figure 5, VES locations 4 and 5 south and north of Gurku Gwari Bwari settlement respectively and VES locations 6, 10, 11, and 12 falls within zones of fairly high hydraulic conductance. This implies that the fracture systems within the aquifer zones in these areas are interconnected therefore; the aquifers in these regions are permeable enough to allow the flow of groundwater through it. The central and south eastern part of the study area exhibits moderate to low flow of ground water.

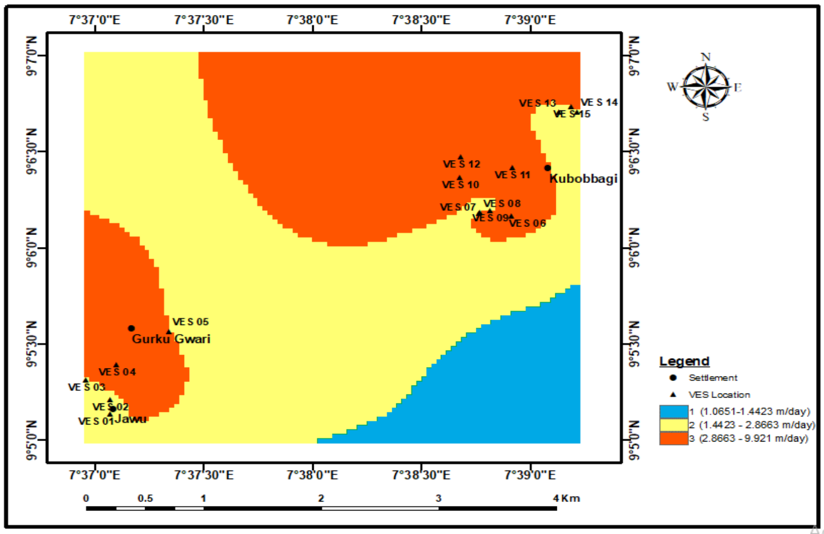

Figure 5: Reclassified Hydraulic Conductance Map of the Study Area

Transmissivity (T) Map of the Study Area

The measure of the rate at which groundwater is transmitted through a unit width of aquifer system is refers to as transmitivity. Research has shown that areas with high transmissivity are synonymous with areas of high hydraulic conductivity and vis-à-vis. Transmissivity values for the study area were computed using (equation 6) and are presented on Tables 4 and 6. The transmissivity values for the study area ranges from a minimum of 7.79 m^2/day to a maximum of 139.4 m^2/day with an average value of 42.50 m^2/day. Rating of the aquifer potential in the study area as presented on Table 6 was based on the work of Offodile, (1983) and the map representation of transmissivity values is presented as figure 6. From figure 6, VES 4 located southwest of Gurku-Bwari settlement and VES locations 6, 10 and 12 southwest of Kubobbaggi settlement with transmissivity values ranging from 74.69 to 139.4 m^2/day were classified as regions with moderate groundwater potentials. In these VES locations the third lithologic layers which were inferred to be the aquifer zones comprises of weathered to fractured basement rocks that are fairly thick (13.2 – 23.6 m). Other VES locations with transmissivity values falling below74.69 m^2/day were classified as areas with low groundwater potentials. Low groundwater potentials areas as observed around the central, north-eastern, north-western and south-eastern parts of the study area, were attributed to the relatively thin aquifer system (5.3 – 11.4 m) in these regions.

Table 6: Evaluation of Aquifer Potential Based on Transmissivity Rating

VES No.	Transmissivity m^2/day	Aquifer Potential
1	18.6	Low Potential
2	28.3	Low Potential
3	20.5	Low Potential
4	104.17	Moderate
5	30.3	Low Potential
6	139.4	Moderate
7	7.9	Low Potential
8	11.2	Low Potential
9	10.54	Low Potential
10	111.6	Moderate
11	27.34	Low Potential

12	68.83	Moderate
13	13.98	Low Potential
14	15.74	Low Potential
15	22.64	Low Potential

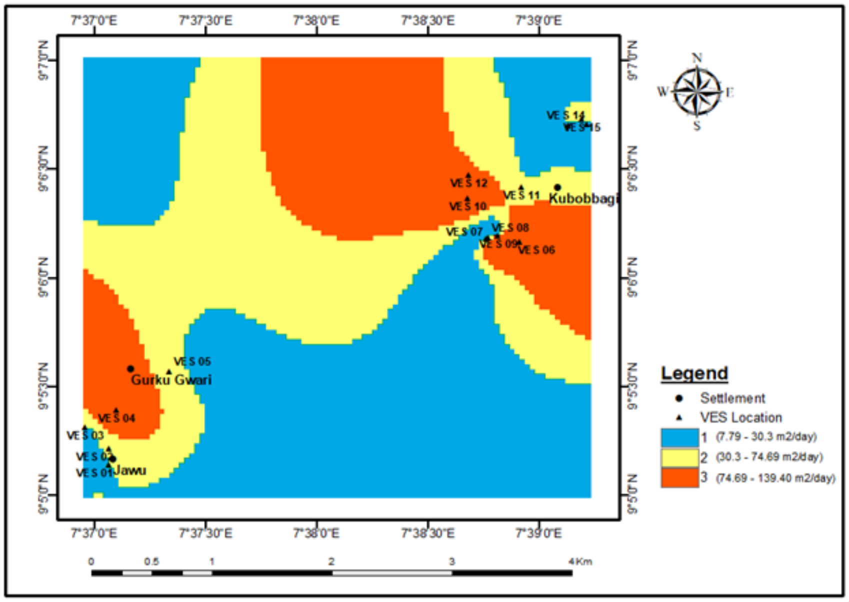

Figure 6: Reclassified Transmissivity Map of the Study Area

CONCLUSION

Findings from the study area revealed that the area is characterized by three to four geo-electric layers where the AH and H curves dominates. This suggests that, the area has moderate groundwater potentials and the aquifer zones are located within the weathered to fractured basement. From interpretation of the secondary geo-electric parameters using Dar-Zarrouk parameter, the aquifer system in the area are susceptible to contamination because of the poor protective capacity rating however, the groundwater potential in the study area is moderate this interpretation is also synonymous with that of the curve types analysis. Based on these findings, the most favourable locations for borehole drilling are VES 4 south of Gurku-Gwari settlement and VES 6 and 12 south-west and north-west of Kubobbagi settlement respectively. Considering the poor aquifer protective capacity of surface layers in the study area, it is therefore recommended that awareness campaigns should be conducted to educate the community on waste management disposal to curtail the effect of aquifer contamination from surface infiltration.

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