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Mapping of Aquifer Characteristics and Reservoir Protective Capacity Variation in Obafemi-Owode Local Government Area, Ogun State South-West Nigeria

***Ishola, S. A, Oyebolu, O. O. and Ikhane, P. R.**

Department of Earth Sciences, Olabisi Onabanjo University Ago-Iwoye, P.M.B 2002, Ago-Iwoye, Ogun State, Nigeria

*Corresponding author's email: ishola.sakirudeen@oouagoiwoye.edu.ng

ABSTRACT
Variation of Aquifer potential characteristics and its impacts on the groundwater subsurface protection of the aquiferous zone using electrical resistivity method was carried out at Obafemi-Owode Local Government Area, Ogun State South-West Nigeria with the principal purpose of assessing and rating aquifer protective capacity of the overburden units in the area. Twenty seven (27) vertical electrical sounding (VES) were conducted using Schlumberger configuration with the maximum electrode spacing of 100m at each point using Allied OMHEGA Resistivity meter. The data were interpreted using partial curve matching techniques and computer iteration program using WINRESIST. Parameters such as aquifer resistivity, aquifer thickness, overburden thickness, bedrock resistivity, reflection coefficient and longitudinal unit conductance were calculated and used for evaluating the groundwater yields and vulnerability of the aquiferous zone to contaminant seepages. The range of reflection coefficient is found to be between 0.02 and 0.98 while that of the protective capacity is between 0.00135 and 0.510. Groundwater potentials of the area were categorized as being high (overburden thickness >13m and reflection coefficient less than < 0.8); medium (overburden thickness ≥13m and with reflection coefficient ≥0.8) and low (overburden thickness < 13m and reflection coefficient $\geq or \leq$ 0.8. Also, the study area shows a very poor, poor, and moderate protective capacity rating. Seven (7) VES stations have very poor protective capacity, eighteen (18) VES stations shows poor protective capacity and only two (2) VES stations shows a moderate protective capacity rating. Since the illustration the longitudinal conductance revealed the impermeability of the confining layers which is generally < 1.0 Siemens; values >1.0 Siemens which indicates zones in which the confined aquifer is subject to protection by the overlying formation materials; these revelations in the study area were possible indications that the groundwater quality status may have been impaired which necessitated the urgent need for the groundwater to be randomly sampled for contaminant loads based on this investigation.

Keywords:
Aquifer potential characteristics,
Groundwater,
Contamination,
Ogun state.

INTRODUCTION

The significance of groundwater quality for the overall health and general wellness of any community cannot be overemphasized (WHO, 1996; WHO, 2009; Ufuogbune *et al.*, 2001). The seasonal experience of water scarcity by the dwellers of Obafemi-Owode Local Government Area mostly in dry season, led to the continuous search for surface water supply as readily alternative. Surface water, which principally occurs as rivers are widely subjected to varyng level of both internal and external pollution; the streams and rivers, may be highly polluted judging by the increasing wastes that emptied on them on daily basis. The first and natural option seemingly available to man is groundwater, which may be defined as "water in the zone of saturation and from which wells, springs and underground run off are supplied". Moreover, very minor water treatment method is mostly needed in making it usable and portable. Natural barriers have largely serve as a potent means of groundwater protection. However, in areas characterized by thin weathered layers with aquifers whose hydraulic continuity flow with the ground surface, groundwater could in this case be susceptible in one point or the other to pollution from surface water sources (Bayewu *et al.*, 2018). In the past centuries, studies have shown that high rate of commercialization, urbanization, industrialization and other labour cum income earning human activities could inadvertently result into the release of toxic substances into the ground which consequently migrate their ways as discharge materials and percolate the subsurface with unprecedented impacts on the aquiferous zone (Ishola, 2019; Ishola *et al.,* 2021). The shallowness of the groundwater reservoirs that predominates the Precambrian Basement Complex rocks enhances enhance the easy vulnerability to surface or near-surface contaminant seepages. As an integrated part of groundwater exploration programme, the task of assessing the protective capacity of groundwater system in the study area becomes very sacrosanct. Groundwater vulnerability assessment is not only vital for effective groundwater resource management but also for subsequent land use monitoring, control and urban planning thereby safeguarding the comfortability and general wellness of the dwellers (Rupert, 2001; Babiker *et al*., 2005; Ishola *et al*., 2021).

Obafemi-Owode is a fast growing area in Ogun State coupled with its proximity to Abeokuta; the ancient administrative city and Capital of Ogun State, South-West Nigeria. It lies in the basement terrain and decrease in the quality and quantity of water supply has been the daily experience of the dwellers. The continuous increase in population alongside the progressive infrastructural development within Obafemi-Owode Local Government Area necessitated the quest for further emphasis for the development of a sustainable water supply network. Groundwater exploration activities within the Basement Complex rocks of Africa are usually undertaken with the utilization of Vertical Electrical Sounding (VES) techniques (Omosuyi *et al.,* 2003; Olasehinde and Bayewu, 2011; Oloruntola and Adeyemi, 2014; Ishola *et al.,* 2016; Ishola, 2019). This is because the successful exploration and exploitation of groundwater in basement terrain often demands for a dependable knowledge and understanding of the fundamental hydrogeological properties of the Aquiferous units in relation to their vulnerability levels to contaminant seepages and overall consequent environmental pollution. Also, many dug wells that were sunk in the study area failed due to lack of proper preliminary investigation and so were abandoned. Several reasons that have been attributed to this aforementioned failure of boreholes were inadequate or lack of pre drilling investigation, lack of expertise on the part of personnel handling the drilling and sometimes lack of proper development of a successfully dug hole among others. Consequently, a detailed geoelectric survey and mapping of the study area was undertaken to determining the geoelectric parameters (resistivities, thicknesses, number of layers) of subsurface layers and the corresponding hydrogeological inferences. The study is equally targeted at assessing the groundwater potentials of the area, rating the aquifer protective capacity of the overlying formations (insulating the subsurface reservoir rocks from possible pollution) as well as recommending appropriate points for groundwater abstraction. Geophysical approach using electrical resistivity techniques with contouring was used for the interpretation of resistivity data for the groundwater characterization and distribution of the selected parts of Obafemi-Owode.

Study Area

Location and Climate

Obafemi-Owode is situated in Ogun State and lies within the southwestern part of the Nigerian Precambrian basement complex rocks and lies within longitudes 3^0 20 617’ with 3^0 45 236’E and latitudes 7^0 00 102’ and 7^0 11 897’ N . The map of surveyed and sampled locations for the study area is shown in (Figure. 1**).** The study area is accessible via Lagos-Abeokuta express road; two major roads, few minor roads and footpaths making conveyance and mobility accessible and convenient. The study areas fall within the humid tropical region which is in turn characterized by two distinct seasons typical of the tropics in the southern part of Nigeria namely; the wet and dry seasons. The wet season regularly occurs from March to October and widely predominated by moisture laden southwest winds from the Atlantic Ocean that produces heavy rainfall. The dry season occurs from November to March as the area response to the influence of North-easterly winds (Ishola et al., 2019). The average rainfall annually noticed is estimated to be about 963mm to 1600 mm as recorded by Nigerian Meteorological Agency (Ishola, 2019). The mean monthly temperature varies between 25.7°C in July and 32°C in February, and the average annual temperature is 26.6°C. The effects of high humidity which is generally expressed as above 50% and long wet season ensure adequate and continuous presence of moisture in the air and water supply (Onaikomaiya *et al.,* 1992; Ogunrayi *et al.,* 2016; Ishola et al., 2019).

Physiography and Hydrogeology

The past geomorphic processes were responsible for the shaping of the terrain resulting to the current physiography of the area (Akanni, 1992); the topography is undulating and ranges from high to low relief. The crystalline basement complex rocks of Nigeria are represented in specified areas of Ogun State (Kehinde-Phillips, 1990). These rocks belong to the youngest of the three major provinces of the West African Craton recognized by Hurley and Rank (1976). This source of water supply is not sufficient and therefore does not meet the demand of the populace. This surface water, which serves as the major source of water for consumption in the identified locations of the study area, has a very low productivity during the dry season due to low evaporation rate and consequent lower precipitation than annual average. Though, most sachet water industries rely heavily on the supply from state water corporations; this has overtime increased the challenge of water scarcity due to the overriding higher demand for the water over the corresponding supply. Furthermore, some inhabitants use hand dug wells, but this also creates similar painful effect during dry season because the depth of the aquiferous zone is not being reached due to the nature of the terrain and the cost of drilling of standard borehole is capital intensive. For these reasons, groundwater stands to be the best considered option but there is a huge challenge of delineating high productive aquiferous zones in different investigated locations.

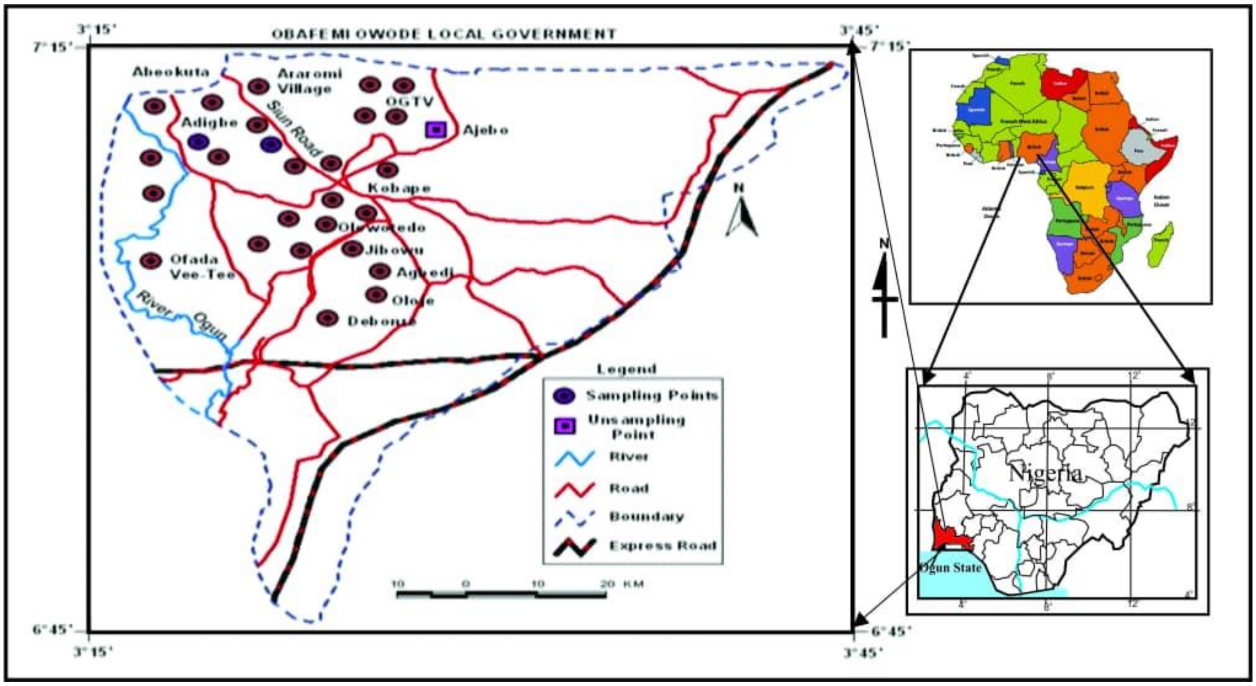

Figure 1: Map showing the Sampled Location in Obafemi-Owode Study Area (Ishola, 2016).

MATERIALS AND METHODS

Effect of Anisotropy on Resistivity

In any given geological environment, layering and fracturing is an indispensable parameters affecting resistivity measurement. Thus, the flow of electric current is not uniform in the study area (Bayewu et al., 2018)

Anisotropy coefficient is a geoelectrical parameter used in measuring the inhomogeneity of a given medium (Olorunfemi *et al.*, 1999); its increase linearly follows the increase in groundwater yield. In stratified conductors, identifiable parameters are of basic importance for the understanding and consequent interpretation of the geoelectrical model of stratified conductors. Different combinations of the thickness and resistivity of each geoelectrical layer in the model are related to these parameters (Olayinka (1996) and Ishola (2019). The integration of the thickness and resistivity of the geoelectric layers into single variables; the Dar-Zarouk parameters of Transverse unit resistance (R) and Longitudinal unit conductance (S), can be efficiently utilized as a fundamental requirement for the assessment of aquifer properties such as hydraulic conductivity (K), transmissivity (T) as well as the protective capacity (*Pc*) of the overburden rock materials in the course of geo-electrical section with a unit crossectional area.

For a geologic layer that is not only horizontal but also homogenous and isotropic, the Dar-Zarouk parameters of transverse unit resistance and longitudinal unit conductance can be mathematically derived as follows:

$H = \sum_{i=1}^{n} h_i \ldots$ (1)

The longitudinal conductance 'S' is given as

$S_I = \sum_{i=1}^{n} h_{i/\rho_i} \ldots$ (2)

Where H represents the summation of thickness while the transverse unit resistance 'R' is given as

$R_i = \sum_{i=1}^{n} h_i p_i \ldots$ (3)

From equation (1) and (3) the longitudinal resistivity is

$\rho_l = H/S = \sum h_i / \sum h_i / p_i$ (4)

Where $H = \sum_{i=1}^{n} h_i$ and $S_i = \sum_{i=1}^{n} h_{i/\rho_i}$

From equation (1) and (3) the transverse resistance is
$\rho_t = R/H = \sum h_i p_i / \sum h_i$ (5)
Where T = $\sum \rho_i h_i$
H = $\sum_{i=1}^{n} h_i$
The Anisotropic coefficient $(\lambda) = \sqrt{\rho_t/\rho_l}$
$(\lambda) = \sqrt{\frac{T}{H} \cdot \frac{S}{H}}$.... (6)
T and S are represented as Dar-Zarrouk parameters.
For an isotropic medium
$\rho_t = \rho_l$ such that $\lambda = 1$
For an anisotropic medium
$\rho_t > \rho_l$ such that $\lambda > 1$
Equation (6) is used for layered rocks such as sedimentary rocks and can also applied to basement complex rocks that exhibits layered structured (Keller and Friskcknecht, 1966; Ishola, 2016). This was systematically estimated using the method of Bhattacharya and Patra (1968), Loke (1999), Olayinka (1996) and Ishola (2019).
The reflection coefficient between the sub-basement and basement layer was calculated which is an indication that the fracture within the bedrocks are filled with water.
$K_n = \frac{\rho_n - \rho_{n-1}}{\rho_n + \rho_{n-1}}$ (7)
Where Kn is the reflection coefficient
n is the no of layers
ρ_n *is the layer resistivity of the* nth layer
$\rho_n - 1$ is the layer resistivity overlying the nth layer.
The layer resistivity and thickness of the ith layer are respectively given as ρ_i and h_i are. The aquifer transmissivity (T) can therefore be expressed as the hydraulic conductivity (k) multiplied by the layer thickness (h),
$T = Kh$ … (8)
For pure saturated aquifers whose natural fluid properties are fairly constant (that is, no significant effect on the general subsurface water quality by surface contaminant loads), the hydraulic conductivity is therefore proportional to the aquifer resistivity. This implies that, the aquifer hydraulic conductivity K can be approximated to the true resistivity of the aquifer derived from geoelectric investigation even in the absence of a pumping test data (Olorunfemi and Okhue, 1992; Hubbard and Robin, 2002). Therefore,
$T = Kh = \rho h$… (9)
But the transverse resistance (R) represents the product of the resistivity to its thickness which is numerically equal to the transmissivity (T) as given in equation 10.
$T = R$ … (10)
The aquifer protective capacity characterization is based on the values of the longitudinal unit conductance of the overburden rock units. The longitudinal conductance (S) serves as a measure of the impermeability of a confining layer which principally comprises of clayey/shaly overburden. Such layers are characterized by low hydraulic conductivity (k) and low resistivity. Protective capacity (P_C) of the overburden layers is there unit proportional to its longitudinal conductance(S) (Henriet, 1976; Olayinka and Yaramanci, 2008; Ishola, 2019).
P_{OC} = S = $\sum_{i=1}^{n} h_{i/\rho_o}$ (11)
(Olayinka and Yaramanci, 2008; Oborie and Nwankoala, 2012; Ishola et al., 2016).

Data Acquisition and interpretation
Twenty Seven (27) VES soundings data were principally acquired with Allied Ohmega Resistivity meter using the Schlumberger configuration with maximum electrode separation (AB/2) is restricted to 100 m. The Schlumberger configuration consists of a linear electrodes array (AMNB) as shown in Figure 2. Potential electrodes M and N were kept fixed at the centre of the array while current electrodes A and B were systematically moved outward in a symmetrical fashion (Telford, 1990; Pirttijärvi, 2009). The operational principle lay on the fact that ground injection of current through current electrodes A and B enabled the measurement of the potential drop between potential probes M and N. The current penetrated deeply into the ground as the electrode A and B spacing increased**.** The interpretation of result was carried out both qualitatively and quantitatively the qualitative interpretation was achieved by plotting the obtain Resistivity data on the log-log paper which relate the resistivity data to the geology of the study area while quantitative interpretation refers to a curve matching and computer assisted program called iteration The 1-D forward modeling adopted for the VES interpretation is called WinRESIST version 1. 0 program. I-D forward modeling (1DF) is a computer program that provides a way for the user to interactively model vertical electrical sounding data by changing the geologic conditions and parameter that control earth resistivity responses (Loke, 1999; Ishola *et al.*, 2021). This provides a comparison of real resistivity data to synthetic data in other to make geologic interference from the features observed in the real data. The user iteratively changed the model to enhance a sufficient match with the real data so that the model becomes a possible representation of the geologic condition that produced the real resistivity data. The acquired geoelectric parameters output from the partial curve matching qualitative interpretation therefore provided an input model for computer-assisted iteration of the Vander Velpen, (2004) utilizing WINRESIST version 1.0 program both for the iteration and presentation of the curves. From the analysis of the values obtained from the sounding, aquifer parameters were calculated from the Geometric computations of Dar-Zarrouk parameter for each location using sing the classification (Oladapo and Akintorinwa, 2007; Ishola et al., 2016; Olasehinde and Bayewu, 2011; Bayewu *et al.*, 2018).

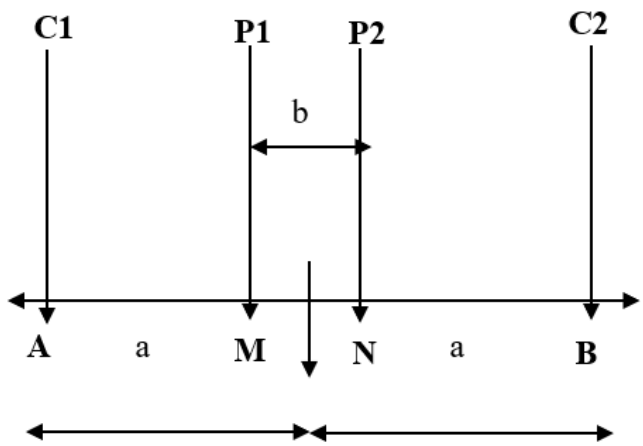

Figure 2: Field illustration showing Schlumberger arrays (Ishola *et al.*, 2016)

RESULTS AND DISCUSSION

The output and distinct features of the acquired field data from the electrical resistivity soundings were interpreted quantitatively with the inferred lithologies from the geoelectric section shown in Table 1, aquifer properties in their confined and unconfined status were shown in Table 2 while Aquifer layer resistivity map, aquifer layer thickness map, overburden thickness, Bedrock relief map are shown in (Fig. 3 – Fig. 11).

Table 1: Geoelectric Interpretation and Inferred Lithologies of the Study Area

VES Points	No of Layers	Resistivity (ohm-m)	Thickness (m)	Depth (m)	Reflection Coefficient	Inferred Lithology	Aquifer Type
VESOB1	1	278.4	0.9	0.9	0.3509	Lateritic Top Soil	Confined
	2	45.0	2.5	3.4		Sandy Clay	
	3	101.1	7.85	11.25		Clayey Sand	
	4	673.0	–	–		Fractured Basement	
VESOB2	1	567.8	0.5	0.5	0.1438	Lateritic Top Soil	Confined
	2	1033	1.3	1.8		Sandy Clay	
	3	139.8	6.5	8.3		Clayey sand	
	4	2138.3	–	–		Fresh Basement	
VESOB3	1	488.7	2.7	2.7	0.1869	Lateritic Top Soil	Unconfined
	2	55.6	10.8	20.6		Sandy Clay	
	3	372.9	–	–		Fractured Basement	
VESOB4	1	207.8	1.8	1.8	0.1983	Lateritic Top Soil	Unconfined
	2	24.3	13.7	15.5		Sandy Clay	
	3	155.3	–	–		Fractured Basement	
VESOB5	1	1081.2	1.1	1.1	0.0296	Lateritic Top Soil	Unconfined
	2	44.8	11.3	12.4		Sandy Clay	
	3	1061.2	–	–		Fractured Basement	
VESOB6	1	570.1	1.0	1.0	0.0875	Lateritic Top Soil	Unconfined
	2	452.2	1.6	2.6		Sandy Clay	
	3	16.7	3.1	5.7		Clayey sand	
	4	1301.8	–	–		Fresh Basement	
VESOB7	1	347	1.0	1.0	0.2225	Lateritic Top Soil	Unconfined
	2	295.2	1.8	2.8		Sandy Clay	
	3	36.5	15.3	18.1		Clayey sand	
	4	408.4	–	–		Fractured Basement	

VES Points	No of Layers	Resistivity (ohm-m)	Thickness (m)	Depth (m)	Reflection Coefficient	Inferred Lithology	Aquifer Type
VESOB8	1	60.6	0.31	0.31	0.3682	Lateritic Top Soil	Unconfined
	2	16.71	4.36	4.67		Sandy Clay	
	3	840.58	29.3	33.97		Clayey sand	
	4	35.7	–	–		Fractured Basement	
VESOB9	1	118.7	3.3	3.3	0.7666	Lateritic Top Soil	Confined
	2	161.7	4.6	7.9		Sandy Clay	
	3	168.9	9.36	17.26		Clayey sand	
	4	2122.3	–	–		Fresh Basement	
VESOB10	1	553.2	0.9	0.9	0.0303	Lateritic Top Soil	Confined
	2	984.7	2.1	3.0		Sandy Clay	
	3	1282.5	12.3	15.5		Coarse Sand	
	4	685.5	69.3	84.7		Clayey sand	
	5	1634	–	–		Fresh Basement	
VESOB11	1	453.2	0.7	0.7	0.0736	Sandy Top Soil	Confined
	2	958.5	9.8	10.5		Sand	
	3	271.4	86.4	96.8		Clayey sand	
	4	1635.9	–	–		Fresh Basement	
VESOB12	1	285.7	0.4	0.4	0.6542	Sandy Top Soil	Confined
	2	2236.7	1.4	1.8		Sand	
	3	422	7.8	9.6		Sandy Clay	
	4	55.5	39.55	49.15		Clayey sand	
	5	527	–	–		Fresh Basement	
VESOB13	1	331.1	0.7	0.7	0.2225	Lateritic Top Soil	Confined
	2	697.9	6.4	7.1		Sandy Clay	
	3	39.6	83.8	90.8		Clayey sand	
	4	654.4	–	–		Fresh Basement	
VESOB14	1	1019.9	0.6	0.6	0.2378	Lateritic Top Soil	Confined
	2	4543.7	2.1	2.7		Sandy Clay	
	3	113.9	7.5	10.2		Shale/Clay	
	4	10876.2	–	–		Fresh Basement	
VESOB15	1	7959.2	0.6	0.6	0.4355	Lateritic Top Soil	Confined
	2	2161.9	1.9	2.5		Sandy Clay	
	3	274.3	14.5	17.0		Shale/Clay	
	4	11627.9	–	–		Fresh Basement	
VESOB16	1	1647.3	1.0	1.0	0.5427	Lateritic Top Soil	Confined
	2	4989.5	2.2	3.2		Sandy Clay	
	3	181.4	23.0	26.2		Shale/Clay	
	4	22388.7	–	–		Fresh Basement	
VESOB17	1	1035.2	1.1	1.1	0.3179	Lateritic Top Soil	Unconfined
	2	281.9	11.7	14.3		Sandy Clay	
	3	2733.3	–	–		Fresh Basement	

VES Points	No of Layers	Resistivity (ohm-m)	Thickness (m)	Depth (m)	Reflection Coefficient	Inferred Lithology	Aquifer Type
VESOB18	1	24.6	1.2	1.2	0.9682	Lateritic Top Soil	Confined
	2	261.6	1.4	2.6		Sandy Clay	
	3	437.97	19.2	21.8		Clayey Sand	
	4	492.8	23.5	45.3		Shale/Clay	
	5	17710.9	–	–		Fresh Basement	
VESOB19	1	48.0	1.9	1.9	0.9280	Lateritic Top Soil	Confined
	2	401.8	2.1	4.0		Sandy Clay	
	3	396.13	29.2	33.2		Shale/Clay	
	4	12037.3	–	–		Fresh Basement	
VESOB20	1	103.2	1.1	1.1	0.8914	Lateritic Top Soil	Confined
	2	614.27	6.03	7.13		Sandy Clay	
	3	346.53	11.43	18.56		Clayey Sand	
	4	1003.2	22.5	41.06		Shale/Clay	
	5	12495.8	–	–		Fresh Basement	
VESOB21	1	112.5	2.0	2.0	0.4370	Lateritic Top Soil	Confined
	2	57.08	6.1	8.3		Sandy Clay	
	3	199.43	9.13	17.43		Shale/Clay	
	4	432.8	–	–		Fresh Basement	
VESOB22	1	238.7	1.7	1.7	0.1725	Lateritic Top Soil	Confined
	2	4084.2	11.53	32.3		Sandy Clay	
	3	309.8	14.17	46.47		Shale/Clay	
	4	6125.6	–	–		Fresh Basement	
VESOB23	1	83.5	1.3	1.3	0.4544	Lateritic Top Soil	Unconfined
	2	464.7	1.8	3.1		Clayey Sand	
	3	1281	24.3	27.4		Clay	
	4	205.1	46.0	73.4		Shale/Clay	
	5	686.2	–	–		Fractured Basement	
VESOB24	1	15.5	0.3	0.3	0.5644	Lateritic Top Soil	Confined
	2	5545.6	3.5	3.8		Sandy Clay	
	3	202.63	20.7	24.5		Shale/Clay	
	4	1548.6	–	–		Fresh Basement	
VESOB25	1	54.3	7.2	7.2	0.9878	Lateritic Top Soil	Unconfined
	2	350.0	27.9	35.1		Sandy Clay	
	3	8834.9	–	–		Fresh Basement	
VESOB26	1	14.4	6.2	6.2	0.9946	Lateritic Top Soil	Unconfined
	2	180.2	26.4	32.6		Sandy Clay	
	3	5289	–	–		Fresh Basement	
VESOB27	1	161.5	2.3	2.3	0.1027	Lateritic Top Soil	Unconfined
	2	474.5	9	11.3		Sandy Clay	
	3	1742.5	19.9	31.2		Clayey Sand	
	4	134	29.8	61.0		Shale/Clay	
	5	781.6	–	–		Fresh Basement	

Table 2: Summary of Aquifer Properties in Obafemi-Owode

VES Stations	Aquifer Resistivity ρ_a (Ωm)	Aquifer Thickness (m)	Aquifer Depth (m)	Lithology	Aquifer Type
VES OB1	101.1	2.5	11.25	**Weathered Basement**	**Confined**
VES OB2	139.8	6.5	8.3	**Weathered Basement**	**Confined**
VES OB3	55.6	10.8	20.6	**Weathered Basement**	**Unconfined**
VES OB4	24.3	3.7	15.6	**Sandy Clay**	**Unconfined**
VES OB5	44.8	11.3	12.4	**Weathered Basement**	**Unconfined**
VES OB6	16.7	3.1	4.7	**Weathered Basement**	**Unconfined**
VES OB7	36.5	15.3	18.1	**Weathered Basement**	**Confined**
VES OB8	840.58	29.3	15.7	**Weathered Basement**	**Confined**
VES OB9	168.9	9.36	17.26	**Weathered Basement**	**Confined**
VES OB10	688.5	69.3	84.7	**Weathered Basement**	**Confined**
VES OB11	271.4	86.4	96.8	**Weathered Basement**	**Confined**
VES OB12	55.5	39.55	49.15	**Clayey Sand**	**Confined**
VES OB13	39.6	83.8	90.8	**Clayey Sand**	**Confined**
VES OB14	113.9	7.5	10.2	**Shale/Clay**	**Confined**
VES OB15	274.3	14.5	16.1	**Shale/Clay**	**Confined**
VES OB16	181.4	23	26.2	**Shale/Clay**	**Confined**
VES OB17	281.9	11.7	14.3	**Sandy Clay**	**Unconfined**
VES OB18	437.97	19.2	21.8	**Sandy Clay**	**Confined**
VES OB19	396.13	10.2	14.2	**Shale/Clay**	**Confined**
VES OB20	346.53	11.43	18.56	**Shale/Clay**	**Confined**
VES OB21	199.43	9.13	17.43	**Shale/Clay**	**Confined**
VES OB22	309.8	14.17	46.47	**Shale/Clay**	**Confined**
VES OB23	205.1	46	73.2	**Sandy Clay**	**Unconfined**
VES OB24	202.63	20.7	20.5	**Shale/Clay**	**Confined**
VES OB25	350	27.9	35.1	**Weathered Basement**	**Unconfined**
VES OB26	180.2	26.4	32.6	**Weathered Basement**	**Unconfined**
VES OB27	134	29.8	61	**Shale/Clay**	**Unconfined**

Contour Maps

One of the fundamental techniques often used for the interpretation of resistivity data is contouring. Groundwater characterization and distribution in the selected parts of Obafemi-Owode was prepared and contoured using surfers software.

Aquifer Resistivity Map

The resistivity contour map revealed the spatial distribution of resistivity across the study areas, thereby showing the groundwater potential zones and their ranking levels across at each VES station. Low to moderate grades of resistivity values were identified between 16**Ω**m and 84 **Ω**m. it is observed that VES 0B3, 0B4, 0B5, 0B7 and 0B13 have much higher groundwater potential values since the layer resistivity is between 0 and 100 **Ω**m. This is seen with a ridge which steeps downwards at the extreme of Northwestern part of the map while the area with resistivity values between 400 **Ω**m and 1000 **Ω**m seen in VES 0B 8, VES OB10 and VES 0B18 are of higher resistivity values and consequently have lower groundwater potentials. In the 3-D map, the peaks correspond to the areas with higher resistivity values in 2D (Fig. 3). This study area underlain by granitic gneiss and migmatite gneiss with various quartzite intrusions and grades into the transition zone with the sedimentary basin and is duely characterized by fairly satisfactory hydrogeological history that is less porous. The area can sometimes be highly problematic and it is prone to low yield groundwater supply (Ishola *et al.*, 2016; Ishola, 2019; Ishola, 2021). It is worthy of emphasis that weathered layer resistivity alone cannot be outrightly used to infer groundwater potential zone, other maps such as overburden thickness map and aquifer unit thickness map need to be considered.

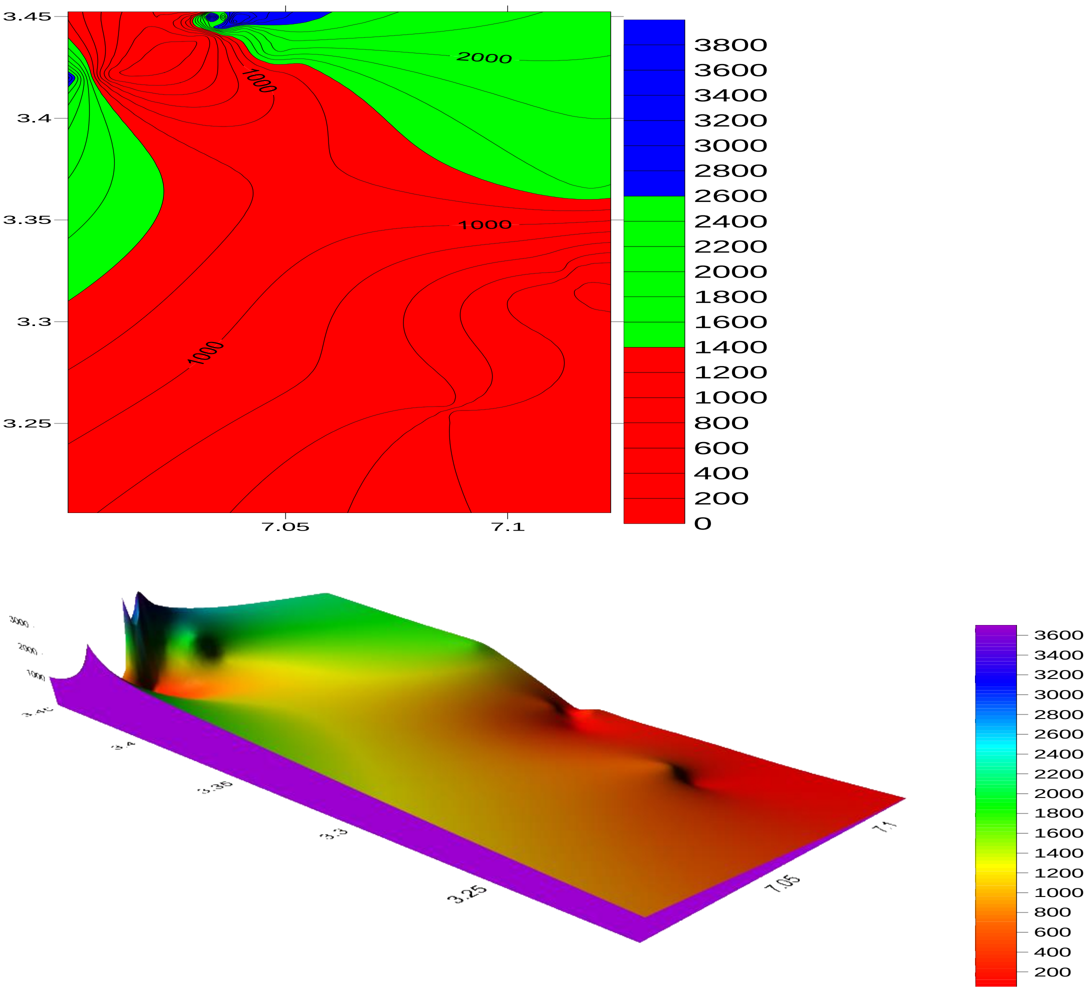

Figure 3: 2D/ 3D-View Aquifer Resistivity Map of Obafemi Owode LGA

Aquifer Unit(s) Thickness Map

The aquifer unit(s) thickness map can be used in placing geology formation in ranks because groundwater productivity as inferred from each VES station depends on the aquifer thickness. This in turn reveals the different types of aquifer found in all sounded VES locations. Locations depicted by widely spaced closed contour lines are the region of possible fractures/deep-seated faults. The entire study areas can be classified as good, moderate and poor groundwater potential zones (Coker *et al.*, 2009; Ishola *et al.*, 2016). The highest recorded thickness value is 86.4m at VES 0B11 and the lowest 2.5m at VES 0B1 (Table 1). The study area revealed the water-bearing zone graded as potential zone occur at the South-eastern part (VES 0B8, 0B10, 0B11, 0B12, 0B13, 0B16, 0B23, 0B24, 0B25, 0B26, and 0B27) while the most prolific water bearing zone is VES OB11 with a pronounced and conspicuous bulging spike displayed by 3-D map. A moderate groundwater potential zone ranges in aquifer thickness values of 10m to 20m found in VES 0B3, 0B5, 0B7, 0B15, 0B19, 0B20, and 0B22). The other locations were demarcated to be very low saturation zone with an aquifer thickness less than 10m classified as a poor potential water bearing zone; VES 0B1, 0B2, 0B4, 0B6, 0B9, 0B14 and 0B21) with less pronounced valley pattern shown by the 3D map (Fig. 4).

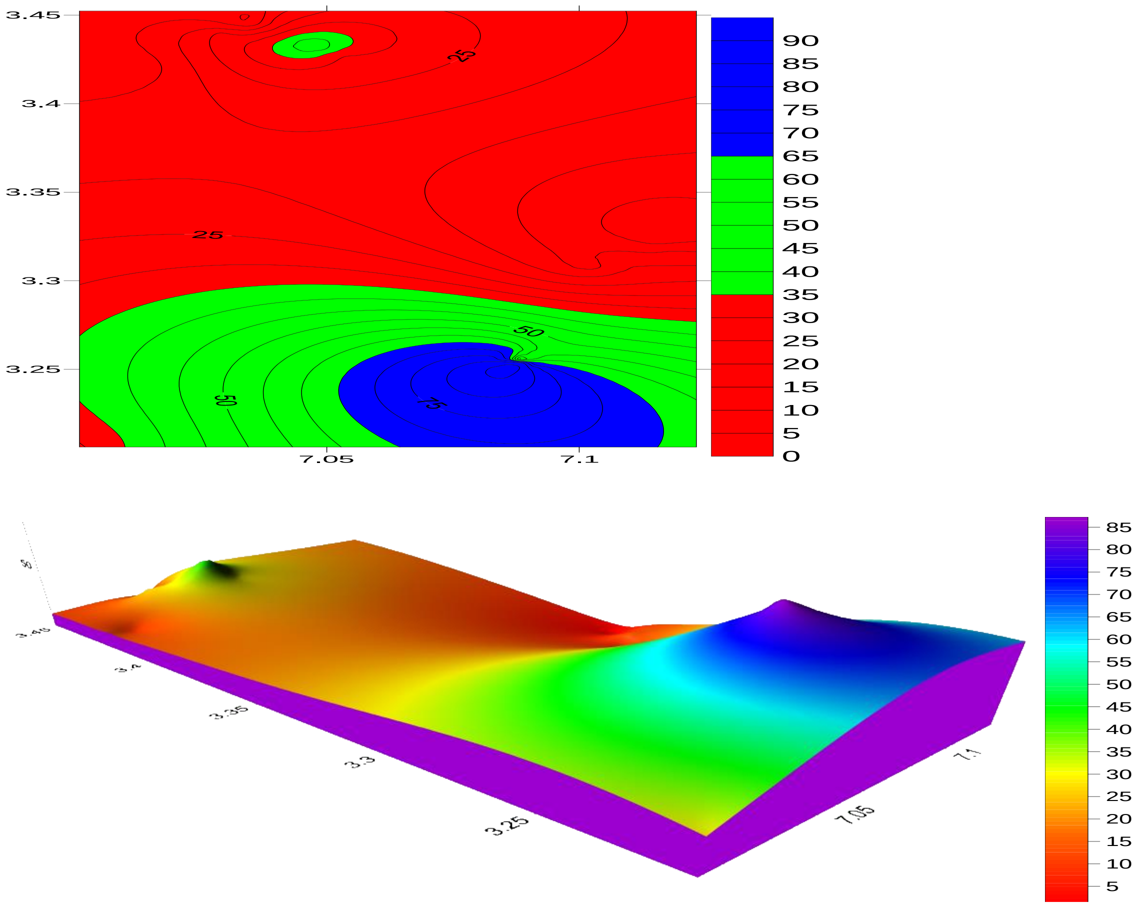

Figure 4: 2D/3D- View of Aquifer Thickness of Obafemi Owode

Overburden Thickness Map

The term overburden refers to all formative materials overlying the basement. Overburden thickness map revealed the overburden/depression along different sections which conspicuously the depth to the aquifer. The dense contour closures revealed the area of thick overburden as indicated (Fig. 5). The cost effectiveness of the area in terms of drilling and efficiency in terms of performance can be evaluated using the overburden thickness (Aucken and Christiansen, 2004; Coker *et al,* 2009; Ishola *et al.*, 2016; Ishola *et al.*, 2021). The depth to overburden is greatest at VES 0B22 which is located at the extreme Northeastern part of the map with a conspicuous “shoot-out”, it embraces VES 0B27 with the overburden thickness value of 32.3m and 31.2m respectively while the areas with the thinnest overburden is observed in VES 0B1 with the overburden thickness value of 0.9m. Areas with VES stations whose value is greater than 26.0m is considered to be of good groundwater potential than other areas with lower overburden thickness. Large sections of this study area is depicted by very low to moderately low overburden thickness values that are between 1m to 10m as shown in the 3-D map (Fig. 5).

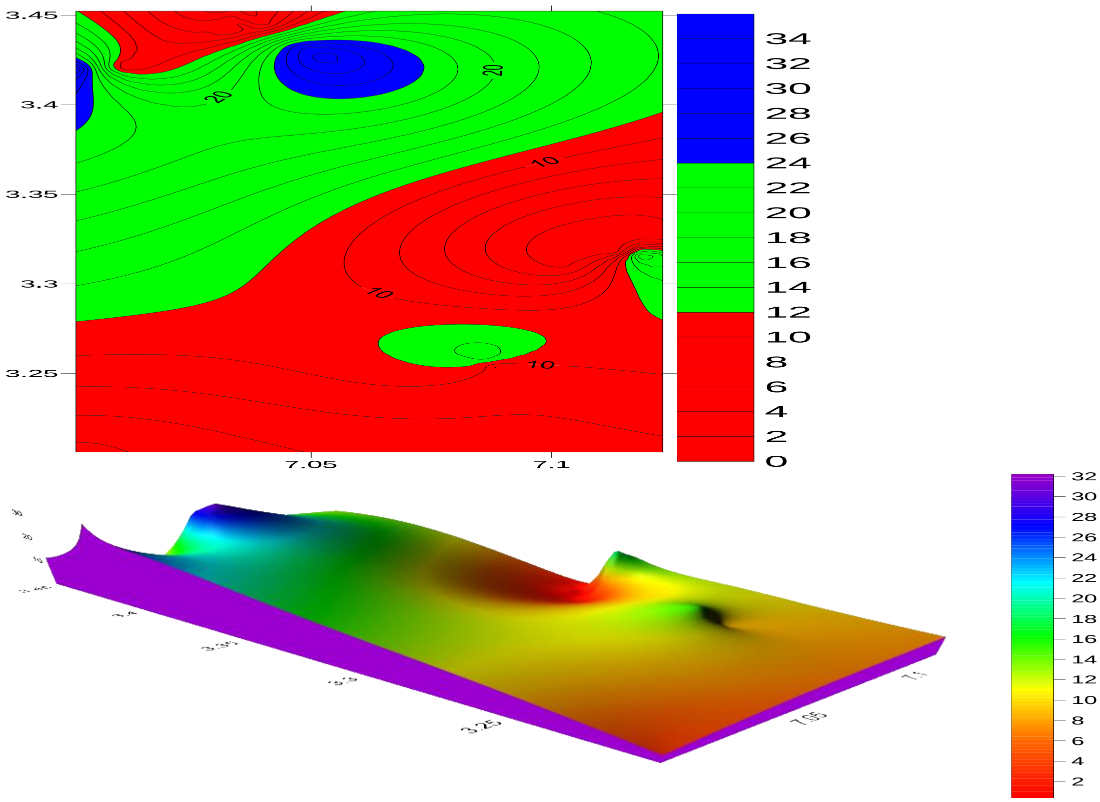

Figure 5: 2D/3D-View of Overburden Thickness Map of Obafemi-Owode

Bedrock Relief Map

The area with low resistivity values (less than 1000Ωm) is called fractured basement; while the area with basement resistivity value greater than 4000 Ωm are thus, called fresh basement (Ishola, 2016). It shows the topography of the bedrock of the study area obtained by subtracting the overburden thickness from each elevation at each VES point and subsequently shows series of bedrock depressions and ridges. The variation in elevation is a reflection of groundwater potential. Most zones in the sounding points are characterized by closures except VES 0B10, 0B12 and 0B13 that are characterized by widely spaced contours. These areas around the zones that showed evidence of close contour have better groundwater potentials compared with other VES point that are associated with ridges because of their elevation. These areas are found in the Northern part of the map (Fig. 6).

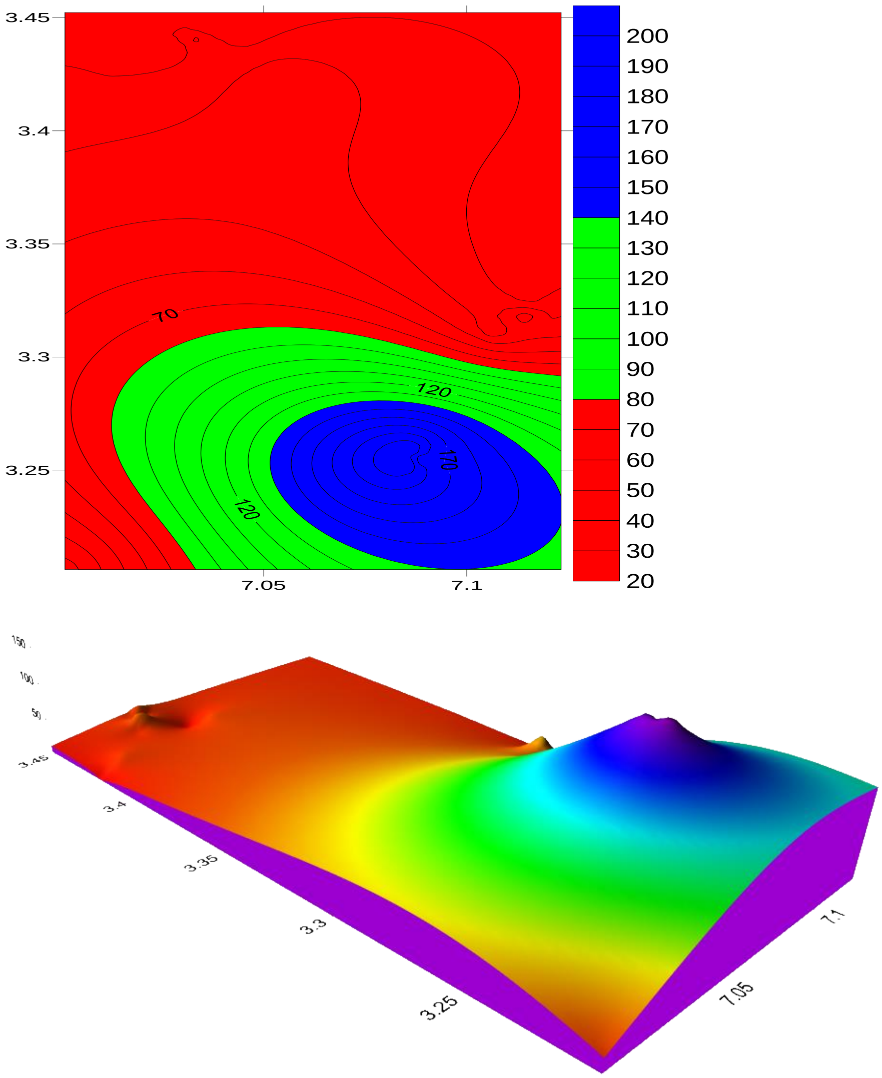

Figure 6: 2D/ 3D- View of Bedrock Relief Map of Obafemi Owode

Longitudinal Unit Conductance Map

Based on the reciprocal relationship of resistance and conductance i.e. $\boldsymbol{\sigma} = {}^{1}/_{\rho}$, it is understood that the more conductive a geological formation is, the less resistive it becomes indicating a permeable formation (Devi *et al.*, 2001). As the conductance increases the resistivity naturally decreases pointing towards groundwater potential aquifer (Gowd, 2004; Ishola *et al.*, 2016; Ishola, 2019).

Furthermore, the protective capacity of the overburden layer can be expressed through the map of longitudinal conductance. Judging by the illustration, when the values of S >1.0 Siemens, it depicts zones of protection for the confined aquifer as the geophysical survey permits to obtain lithological identification and equally characterize the conditions of the subsurface flow of water at the respective investigated locations. The variation of the longitudinal conductance in the study area is displayed both in 2D and 3D contour representation in Fig. 7. The map of longitudinal conductance also grants explanation to the impermeability clay layers in their confined state; the confined aquifer would be protected in comparisons when the values of S > 1.0 siemens while zones in which values of S <1.0 Siemens would indicate zones of high vulnerability to contaminat seepages. The longitudinal unit conductance is less than unity (S < 1.0 Siemens) in all the investigated locations of the study area, which ultimately revealed that the sttudy area is vulnerable to external invasions

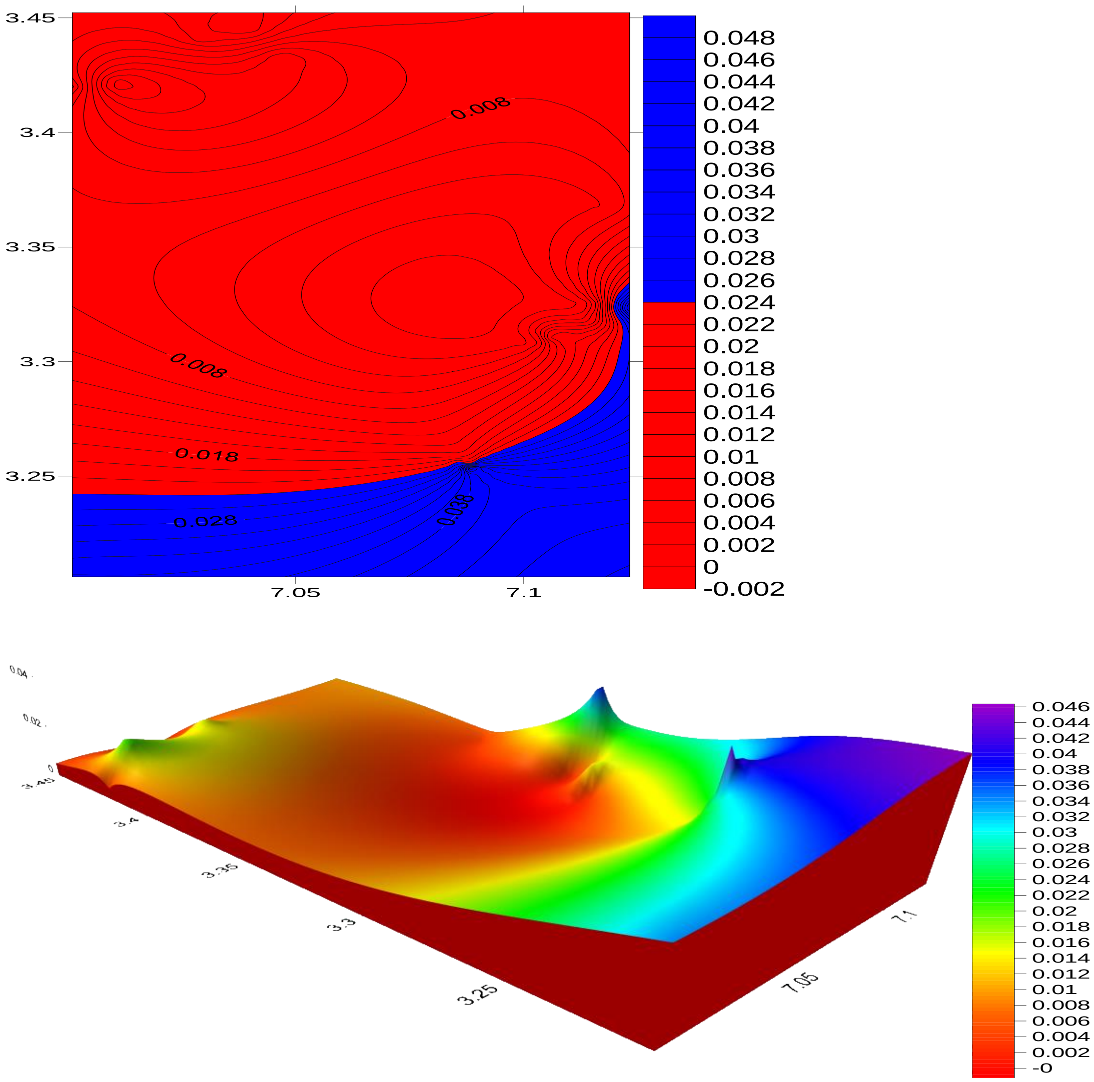

Figure 7: 2D/ 3D-View of Longitudinal Unit Conductance Map of Obafemi Owode

Reflection Coefficient

This map explains the spatial distribution of the reflection coefficient obtained between the sub-basement and basement layer. This secondary parameter is an indication that the fractures within the bedrocks are filled with water. It is often denoted with K_n (Gowd, 2004; Coker, 2009; Ishola *et al.*, 2016; Ishola, 2019). In Obafemi-Owode, VES OB5 has the lowest reflection coefficient value of 0.0296 while VES OB26 has the highest reflection coefficient value of 0.9946. The reflection coefficient is spatially distributed at various sites in the study areas are shown as peaks and slight depressions depicting areas with higher and lower reflection coefficient values respectively (Fig. 8).

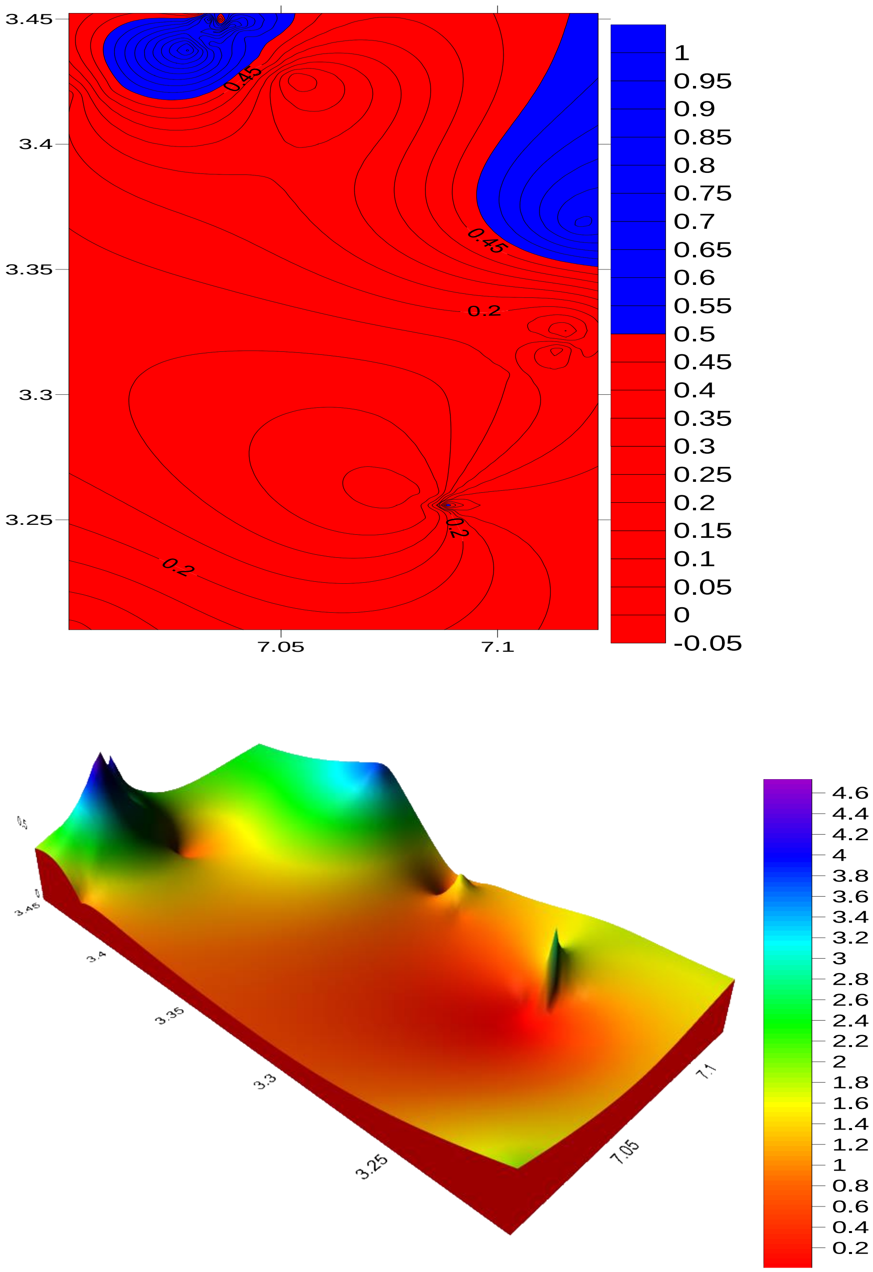

Figure 8: 2D/3D View of Reflection Coefficient Map of Obafemi- Owode

Transmissivity

The Lowest transmissivity value is observed in VES OB4 which embraces OB6 with the value of $0.01\times10^4 m^2/s$ while the highest transmissivity value is observed in VES OB10 with the value of $4.80\times10^4 m^2/s$. In this study area different VES points exhibited similar pattern of transmissivity rate. This is seen in VES OB2 and OB14 with *T* value of $0.09\times10^4 m^2/s$, VES OB5 and OB7 with the *T* value of $0.05\times10^4 m^2/s$,VES OB4 and OB6 with the T value of $0.01\times10^4 m^2/s$. VES OB13 and OB17 with the *T* value of $0.33\times10^4 m^2/s$ and VES OB15,OB16,and OB19 with the T value of $0.40\times10^4 m^2/s$ .The rate of transmissivity increases towards the southern part of the map with a conspicuous and prominent bulging peak showing the areas with transmissivity as shown in the 3D map (Fig. 9). Points of drilling and installations of monitoring wells for unconfined aquifer are best suggested for zones of high transmissivities. Also, high transmissivities suggest that the aquifer materials in that area are permeable to fluid mobility within the aquifer which possibly may enhance the migration and circulation of contaminant in the groundwater system (Gowd, 2004; Ishola *et al.*, 2016; Coker *et al*., 2019; Ishola, 2019).

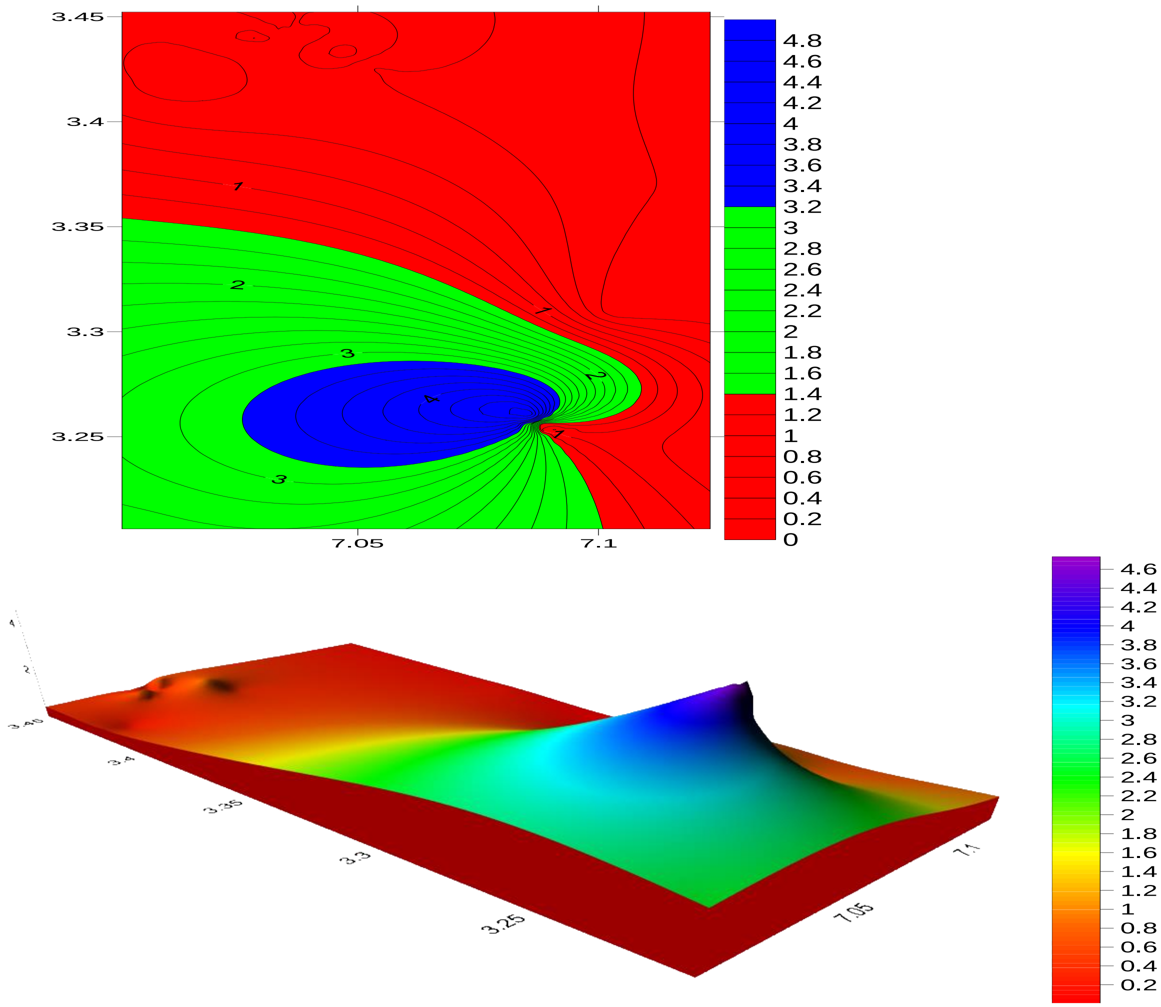

Figure 9: 2D/3D-View of Transmissivity map Obafemi-Owode

Hydraulic Conductivity

The hydraulic conductivity value varies from 11.55×10^{-3} m/s and 373.00×10^{-3} m/s. It increases slightly to the northern part and both the north eastern and south-eastern part has low hydraulic conductivity. VES OB1 in the extreme eastern part exhibited a very high conductivity with a conspicuous and prominent peak while the areas with low hydraulic conductivity are shown with a slight depression or near-valley distribution pattern displayed by the 3D map (Fig. 10)

It should be noted that hydraulic conductivity *(K)* is directly proportional to resistivity ***(ρ)*** that is as *K* increases; ***ρ*** also increases whereas reverse is the case in longitudinal conductance (Gowd, 2004; Ariyo and Adeyemi, 2009; Ishola *et al.*, 2016; Ishola, 2019).

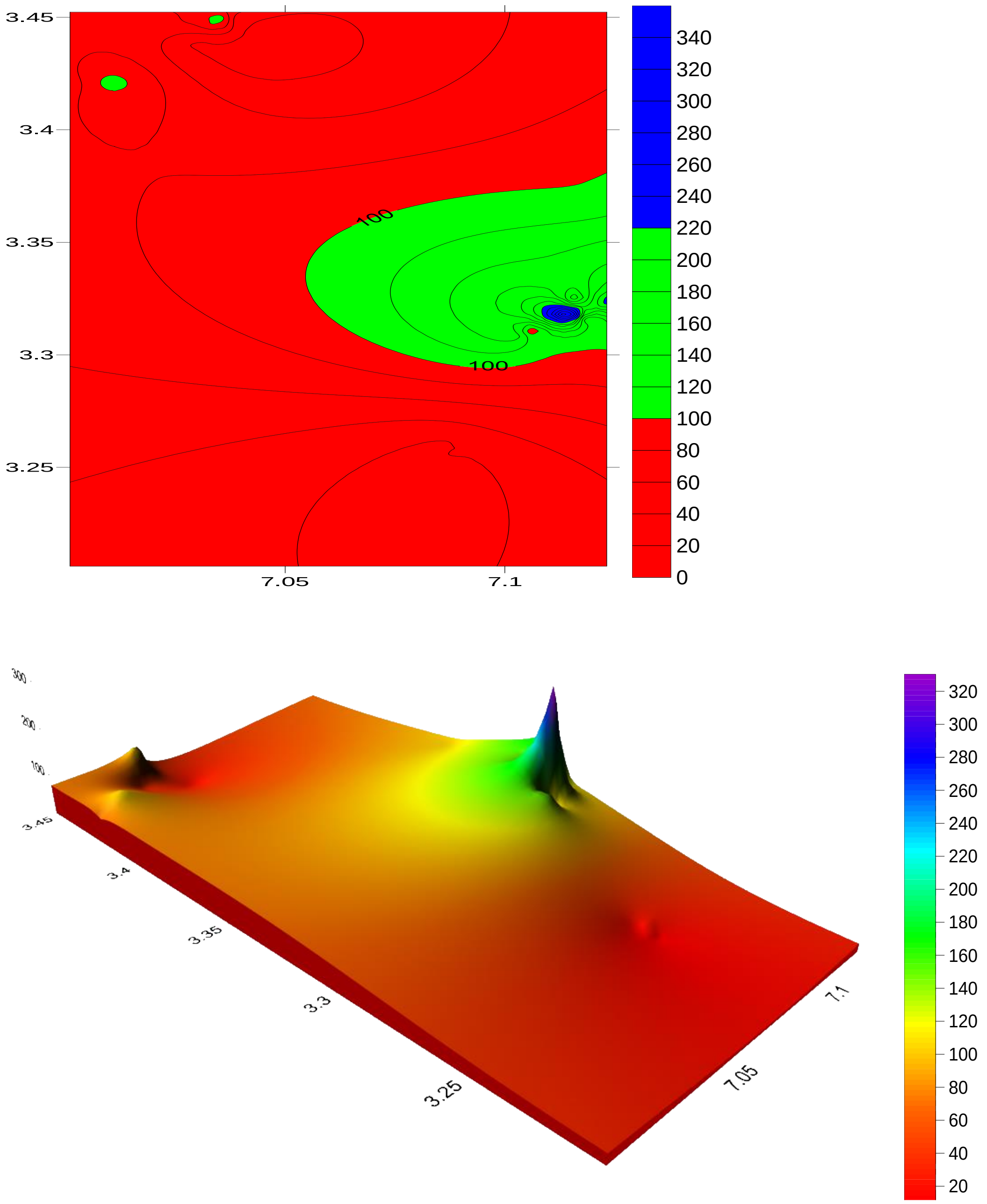

Figure 10: 2D/3D-View of Hydraulic Conductivity map of Obafemi-Owode

Evaluation of the Groundwater Potentials of the Reservoir Rocks

The principal factor and cardinal focus on the groundwater potential assessment in the crystalline basement area is where the overburden and the fractured basement aquifers are interconnected or complementary (Meju *et al.*, 1999; Omosuyi, 2000; Ishola *et al.*, 2016; Bayewu *et al.*, 2018; Ishola *et al.*, 2021). Olayinka (1996) once observed that the resistivity of the basement cannot be solely relied on for the identification of promising and prolific aquifer within the basement terrain. Hence, the consideration of its reflection coefficient as a determining factor of aquifer parameter is highly significant in evaluating the groundwater potential zones in the study area. Instead of depending solely on the resistivity values, reflection coefficients can equally serve as the determinant of degree of fracturing of the underlying basement. In the basement terrain, good aquiferous zones are usually located where the overburden is relatively thick and/or where the reflection coefficient is low (< 0.8). In this study, three basic criteria were later considered in assessing the prospective points for groundwater potential in a given reservoir (Omosuyi, 2000; Ishola *et al.*, 2016; Bayewu *et al.*, 2018).

i. Locations where the overburden thickness displayed greater than or equal to (>13m) and with reflection coefficient less than (< 0.8) are categorized as areas with high groundwater yield.
ii. Locations where the overburden thickness displayed greater than or equal to (≥13m) and with reflection coefficient greater than or equal to (≥0.8) are categorized as areas with medium groundwater yield.
iii. Locations where the overburden thickness displayed less than 13m and with reflection coefficient either greater than, less than or equal to 0.8 are categorized as areas with low groundwater yield.

Based on these classifications, the aquifer parameters obtained from the study area; overburden thickness, aquifer unit thickness, reflection coefficients and others were used for the protective capacity rating (Table 3) as complements for categorizing groundwater potential yields into grades of high, medium and low.

Table 3: Groundwater Potentials across the VES Points

VES Points	Overburden Thickness (m)	Reflection Coefficient	Remarks	Longitudinal Conductance (Siemens)	Protective Capacity Rating
VESOB1	**11.25**	**0.3509**	**Low**	7.73×10^{-3}	**Very poor**
VESOB2	**8.3**	**0.1438**	**Low**	4.06×10^{-3}	**Very poor**
VESOB3	**20.6**	**0.1869**	**High**	2.21×10^{-2}	**Poor**
VESOB4	**15.5**	**0.1983**	**High**	1.78×10^{-2}	**Poor**
VESOB5	**12.4**	**0.0296**	**Low**	$\mathbf{1.05\times10^{-2}}$	**Poor**
VESOB6	**5.7**	**0.0875**	**Low**	3.03×10^{-2}	**Poor**
VESOB7	**18.1**	**0.2225**	**High**	2.38×10^{-2}	**Poor**
VESOB8	**33.97**	**0.3682**	**High**	3.79×10^{-1}	**Moderate**
VESOB9	**17.26**	**0.7666**	**High**	3.34×10^{-2}	**Poor**
VESOB10	**84.7**	**0.0303**	**High**	2.46×10^{-2}	**Poor**
VESOB11	**96.8**	**0.0736**	**High**	6.12×10^{-2}	**Poor**
VESOB12	**49.15**	**0.6542**	**High**	1.34×10^{-2}	**Poor**
VESOB13	**90.8**	**0.2225**	**High**	$\mathbf{8.14\times10^{-2}}$	**Poor**
VESOB14	**10.2**	**0.2378**	**Low**	1.35×10^{-3}	**Very Poor**
VESOB15	**17.0**	**0.4355**	**High**	1.43×10^{-3}	**Very Poor**
VESOB16	**26.2**	**0.5427**	**High**	3.47×10^{-3}	**Very Poor**
VESOB17	**14.3**	**0.3179**	**High**	1.13×10^{-2}	**Poor**
VESOB18	**45.3**	**0.9682**	**Medium**	6.71×10^{-2}	**Poor**
VESOB19	**33.2**	**0.9280**	**Medium**	2.27×10^{-2}	**Poor**
VESOB20	**41.06**	**0.8914**	**Medum**	1.59×10^{-2}	**Poor**
VESOB21	**17.43**	**0.4370**	**High**	5.38×10^{-2}	**Poor**
VESOB22	**46.47**	**0.1725**	**High**	3.28×10^{-3}	**Very Poor**
VESOB23	**73.4**	**0.4544**	**High**	2.51×10^{-2}	**Poor**
VESOB24	**24.5**	**0.5644**	**High**	3.72×10^{-3}	**Very Poor**
VESOB25	**35.1**	**0.9878**	**Medium**	5.10×10^{-1}	**Moderate**
VESOB26	**32.6**	**0.9946**	**Medium**	1.83×10^{-2}	**Poor**
VESOB27	**61.0**	**0.1027**	**High**	5.63×10^{-2}	**Poor**

Longitudinal conductance/protective capacity rating (Oladapo et al., 2004; Oladapo and Akintorinwa, 2007 and Abiola et al., 2009; Ishola et al., 2016).

Evaluation of Aquifer Protective Capacity

The computation of longitudinal conductance of the layers can be achieved by utilizing the combination of the resistivity and layer thickness (Golam *et al.*, 2014; Oborie and Udom, 2014; Ishola *et al.*, 2016; Ishola *et al.*, 2021). The high longitudinal conductance observed indicated relatively high protective capacity and identified vulnerable zones which could help to protect groundwater resources and also evaluates the aquiferous zones for water quality improvement. The computed longitudinal conductance for the study area is therefore presented in Table 2. These computed values are favourably compared with the standard rating by (Oladapo and Akintorinwa, 2007 and Ishola *et al.*, 2016). It is observed from Table **3** that the study area shows a very poor, poor, and moderate protective capacity rating. Seven (7) VES stations have very poor protective capacity, eighteen (18) VES stations shows poor protective capacity and only two (2) VES stations shows a moderate protective capacity rating. This is expressed in a bar chart in Fig. 11. Altogether, the results reveal that the protective capacity rating of the hydrogeological formation of the study area is generally low except for VESOB8 and VESOB25 that displayed moderate protective capacity rating (Fig. 11). Zones of high infiltration rates mostly from precipitation are reflections of areas are classified as very poor and poor protective capacity rating (Table 3); such areas are vulnerable to leachate infiltrations and other surface contaminant loads that could migrate through the porous and permeable rock layers with unprecedented lethal impacts on the subsurface groundwater system of the study area.

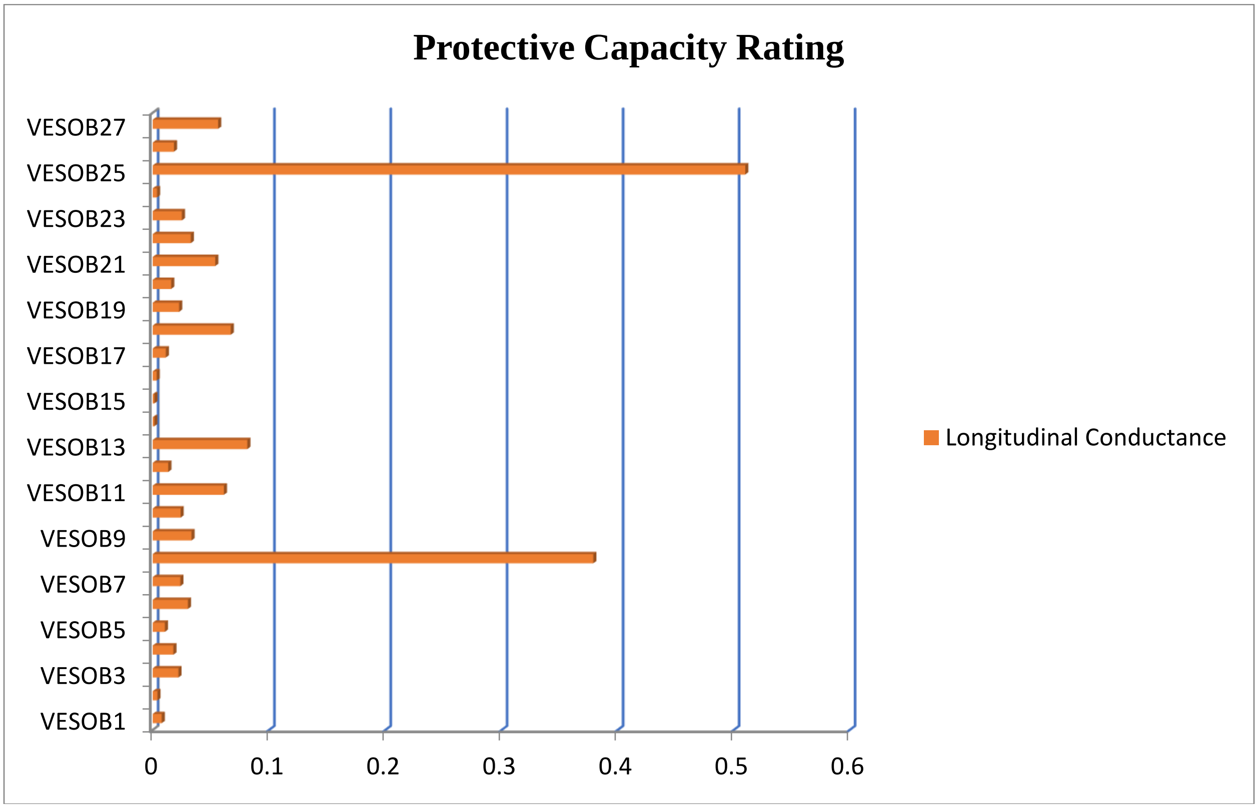

Figure 11: Protective Capacity Rating of Obafemi-Owode

CONCLUSION

It can be concluded from the qualitative and quantitative data interpretation of the study area that 63% of the investigated locations possesses high groundwater potentials, 18% have moderate or medium investigated and 19% have low groundwater potentials in terms of yield. The study area is overlain by materials of weak protective capacity and only small area is of moderate protective capacity. It is therefore evident that groundwater in most part of the area is vulnerable to pollution that may arise from runoff water, sewage system, effluent and indiscriminate waste disposal in the study area.

Therefore, the revelations in the study area are possible indications that the groundwater quality may have been impaired which necessitated the need for borehole water to be randomly sampled for contaminant loads based on this analysis.

REFERENCES

Akanni, C.O. (1992). Aspects of Climate in "Ogun State in Map". in Onakomanya, S.O, Oyesiku, K., Jegede, F. J (Eds).

Ariyo, S.O. and Adeyemi, G.O. (2009). Role of Electrical Resistivity Method for Groundwater Exploration in Hard Rock Areas: A case Study from Fidiwo/Ajebo Areas of Southwesten Nigeria. Pacific Jour. of Sciences and Technology, Vol.10 (1) 483-486.

Auken, E and Christiansen, A.V. (2004). Layered and laterally constrained 2-D Inversion of Resistivity Data.Geophysics 69, 752-761.

Bayewu, O.O., Moroof O.O., Ganiyuo.M., Lanyan T.A., S.O Ariyo And Fatoba, J.O. (2018). Assessment of Groundwater Prospect and Aquifer Protective Capacity using Resistivity Method in Olabisi Onabanjo

University Campus Ago-Iwoye, Southwestern Nigeria. NRIAG Journal of Astronomy and Geophysics, 7:2, 347-360, DOI:10.1016/J.NRJAG.2018.05.002

Coker J.O, Makinde V., Olowofela J.A (2009). Geophysical Investigation of Groundwater Potentials of Oke-Badan Estate, Ibadan, Southwestern, Nigeria. Proceedings of 3rd International Conference on Science and National Development University of Agric. Abeokuta, p. 119.

Gowd S.S (2004). Electrical Resistivity Surveys to delineate Groundwater Potential Aquifers in Peddavanka Watershed, Anantapur District, Andhra Pradesh, India. J.Envir. Geol., 46: 118-131.

Henriet, J.P. (1976). Direct Applications of the Dar-Zarrouk Parameters in Groundwater Survey. Geophys. Prospect 24, 344-353.

Ishola S.A., Makinde V., Aina J.O., Ayedun H., Akinboro F.G.,Okeyode I.C., Coker J.O., and Alatise O.O (2016). Aquifer Protection Studies and Groundwater Vulnerability Assessment in Abeokuta South Local Government Area, South-West Nigeria, Journal of Nigerian Association of Mathematical Physics, © J.of NAMP Vol 33, (January, 2016), pp 347-362

Ishola S.A (2019). Characterization of Groundwater Resource Potentials using Integrated Techniques in Selected Communities within Ewekoro Local Government Area South-West Nigeria. Depatment of Physics, FUNAAB Ph.D Thesis.

Ishola, S.A., Makinde, V., Gbadebo, A.M., Mustapha, A.O and Orebiyi E.O (2021). Quality Assessment of Groundwater System in Itori Community of Ewekoro Local Government Area, South-West Nigeria. International Journal of Science and Technology in Science and Technology Publishing (SCI & TECH) ISSN: 2632-1017, Vol. 5, Issue 12 December-2021 pp 1060-1061. www.scitechpub.org

Kehinde-Phillips, O. (1990). Geology of Ogun State. In: Ogun State In Maps (Eds: Onakomaiya, S. O, Oyesiku, K., Jegede, J.). Rex Charles Publication. Ibadan. pp. 12-13.

Keller, G.V., and Frischknecht, F.C., (1996). Electrical Methods in Geophysical Prospecting. Pergamon-press, Oxford, New York, Toronto, Sdney, Branumsckweig.

Loke, M.H (1999). Time Lapse Resistivity Imaging Inversion. Inc Proceedings of the Meeting of the Environmental and Engineering Geophysical Society European Section, Emi. Pp. 90.

Meju, M.A., Fonts, S.L., Oliveira, M.F.B., Lima, J.P.R., Ulugerger, E.U., Carrasquilla, A.A., (1999). Regional Aquifer Mapping Using Combined VES-TEM-AMT-EMAP Methods in the Semi-Arid Eastern Margin of Parnaiba Basin, Brazil. Geophysics 64(2), 337-356.

Oborie E.A and Nwankoala H.A. (2012). Relationship between Geoelectrical and Groundwater parameters in parts of Ogbia , Bayelsa state, central Niger Delta. Wilolud Continental Journals of Earth Sciences. Vol. 7, pp. 29- 32.

Ogunrayi, A.O., Akinseye, F.M, Goldberg, V., Bernhofer, C . (2016). Descriptive Analysis of Rainfall and Temperature Trends Over Akure, Nigeria. Journal of Geography and Planning. 9(11), 195-202.

Oladapo, M.I., and Akintorinwa, O. J. (2007). Hydrogeophysical Study Of Ogbese Southwestern, Nigeria, Glob. Journ. of Pure Applied. Sci. 13(1), 55-61.

Olasehinde, P.I., Bayewu, O.O., (2011). Evaluation of Electrical Resistivity Anisotropy in Geological Mapping: A Case Study of Odo Ara, West Central Nigeria, African Journal of Env. Sci. and Technology. 5(7), 553-556.

Olayinka, A.I. and Yaramanci, U. (2008). Use of block inversion in the 2-D Interpretation of Apparent Resistivity data and its comparism with smooth inversion. Jour of Applied Geophysics 45, 63-81.

Olayinka, A.I. (1996). Non-uniqueness in the interpretation of bedrock resistivity from sounding curves and its hydrological implications. Water resources. NAH 7(1&2), 55-60.

Olayinka, A.I. Abimbola, A.F., Isibor, R.A., Rafiu, A.R. (1999). A Geoelectrical Hydrogeochemical Investigation of Shallow Groundwater Occurrence in Ibadan, Southwestern Nigeria, Environ. Geol. 37(1-2), 31-39.

Olayinka, A.I. and Olorunfemi, M.O. (1992). Determination of Geoelectrical characteristics in Okene Area and implication for Borehole sitting. *Journal of Mining and Geology*, Vol.28 (2) pp. 403-412.

Olorunfemi, M.O; Ojo, J.S., Akintunde, O.M., (1999): Hydrogeophysical Evaluation of the Groundwater Potentials of Akure Metropolis, Southwestern Nigeria. Journ. of Mining. Geol. 35(2), 207-228.

Olorunfemi, M.O and Okhue, E.T. (1992): Hydrogeologic and Geologic significance of a Geoelectric Survey at Ile-Ife *Nig. Journal of Mining* (Ecology, Vol. 28, No.2, pp.221-229).

Olorunfemi, M. O, Olanrewaju, V. O and Alade, O. (1991). The Electrical Anisotropy and Groundwater Field in a Basement Complex Area of Southwestern Nigeria. Journal of African Earth Sciences, Vol.12 Pp 467-472.

Omosuyi, G.O. (2010). Geoelectric Assessment of Groundwater Prospect and Vulnerability of Overburden Aquifers at Idanre, Southwestern Nigeria. Ozean Journal of Applied Science. 3(1). 19-28.

Omosuyi, G.O., Ojo, J.S., and Erinkanselu, P.A. (2003). Geophysical Investigation for Omosuyi, G.O. (2000). Investigation of the Geoelectric Parameter, Dar-Zarrouk Parameters and Aquifer Characteristics of Some Parts of North-Central Nigeria. Journal of Sci. Eng. and Tech. 7(4), Pp. 2835−2848.

Onakomaiya, S.O, Oyesiku, K., and Jegede, F.J., (1992). Ogun State in Maps. Rex Charles Publications, pp. 128.

Pirttijärvi, M (2009) “Joint Interpretation of Electromagnetic and Geoelectrical Soundings Using 1-D Layered Earth Model, User’s Guide to Version 1.3,” Oulu, 2009, 48 p.

Telford, W. M.. Geldart L. P and. Sheriff, R. E (1990). “Applied Geophysics,” Cambridge University Press, Cambridge, 1990, 870 p. doi:10.1017/CBO9781139167932

Ufoegbune G.C; Lamidi K.I; Awomeso J.A; Eruola A.O. (2009). Hydrogeological characteristics and groundwater quality using assessment in some selected communities of Abeokuta,Vol 1 pp10-22.

Vander Velpen, B.P.A. 2004. WinRESIST Version 1.0 Resistivity Depth Sounding Interpretation Software. M.Sc Research Project, ITC, Delft Netherland.

World Health Organization, WHO (1996). Guidelines for Drinking Water Quality. Health Criteria and other Supporting Information. 2nd Edition, WHO, Geneva, p. 271.

World Health Organisation WHO. (2009). Arsenic in drinking water. Fact Sheet No.210. Retrieved from http://www.who.int/mediacentre/factsheets/fs210/cn/. Accessed on 06/ 06/2009.