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# Assessment of Groundwater Potential and Vulnerability Using Electrical Resistivity Method in the University of Delta, South-South Nigeria

**Irunkwor Thompson Chinedum[1], Abanjo Nkonyeasua[2], Okobia Chuks[3], Maduaka Pascal Ifeanyi[4]**
[1]Department of Environmental Management and Toxicology, Faculty of Science, University of Delta, Agbor, Delta State, Nigeria
[2,3]Department of Geology, Faculty of Science, University of Delta, Agbor, Delta State, Nigeria
[4]Engineering Directorate, Hydrogeology Department, Benin-Owina River Basin Development Authority, Obayantor, Edo State, Nigeria
thompson.irunkwor@unidel.edu.ng[1], nkonyeasua.abanjo@unidel.edu.ng[2], chuks.okobia@unidel.edu.ng[3],pascalify@yahoo.com[4]

**Corresponding Author's Email***:* thompson.irunkwor@unidel.edu.ng

## ABSTRACT

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Groundwater potential and the strength of the aquifer overburden protective layer to prevent contaminants into groundwater aquifer within the University of Delta Main Campus were assessed with Vertical Electrical Sounding (VES). Ten sounding points were carried out using Petrozenith PZ-02 Terrameter with the Schlumberger array. The VES data were processed with IPI2WIN software and delineated eight to nine geoelectric layers of lateritic topsoil, clayey sand, sandy clay, fine grained sand, fine to medium grained sand, medium grained sand, medium to coarse grained sand, coarse grained sand and sandy clay/clay. The aquiferous layer located between the sixth and eighth layer exhibited varying resistivity (2037Ωm to 300098Ωm), thickness (59.93m to 88.92m) and depth (106.75m to 140.80m). Dar-zarrouk hydraulic parameters were derived from values of aquifer resistivity and thickness. Hydraulic conductivity ranged from 6.90m/day to 9.70m/day, transmissivity from 413.65$m^2$/day to 850.11$m^2$/day, longitudinal conductance from 0.0002892 mho to 0.040411 mho and transverse resistance from 122,118.15Ω$m^2$ to 263, 000588.72Ω$m^2$.The aquifer storativity ranged from 0.0001798$m^{-1}$ to 0.0002668$m^{-1}$. Aquifer overburden protective layer was rated poor and highly vulnerable to contaminants. However, aquifer showed high potential of portable water sufficient to meet the needs of the University community. Hydrogeochemical study is recommended to determine the water portability.

**Keywords:** Aquifer, Contaminants, Hydraulic Conductivity,Protective Overburden Capacity, Vulnerability

## INTRODUCTION

Clean water is essential for maintaining good health and national development in order to achieve the United Nations' (UN) sustainable Development Goals (SDGs) of availability and access to clean and safe water [1]. Contaminated water is associated with waterborne diseases that can cause health problems in humans. According to report an estimated 1.1 billion people worldwide do not have access to clean water, 67% of the rural population do not have access to clean water supply, about only 9.7 billion people will live on fresh water while 3.9 billion or over 40% of the world population will live in highly water-stressed river basins by 2050 [2], [3], [4].

Portable water source for human consumption are ground waters that are stored in aquifers beneath the ground surface that are porous saturated permeable rocks. The viability of the aquifer depends on its porosity, storativity, permeability and capability to transmit large volumes of water to wells, springs and streams [5], [6]. Groundwater improves living standards, economic growth, food security and livelihood, but less than 5% of the population has access to this resource and many depend on untreated water from shallow boreholes and hand dug wells [7], [8], [9]. Agbor metropolis is fast in population growth which can be attributed to the existence of tertiary institutions such as the University of Delta, Agbor, Delta State School of Nursing and Midwifery, and the various companies like Camelite Paints, Apaco Foam, Palm oil producing companies, e.t.c in the area. This rapid population growth has increased the need for clean drinking source of water for educational, domestic, business and industrial purposes. To meet the needs of the growing local population, groundwater aquifer must be porous and permeable with the potential to transmit very high groundwater yield to meet the needs of individuals living in the area.

However, the continuous indiscriminate disposal of liquid, municipal, agricultural, mining and industrial wastes in Agbor metropolis poses a serious threat to groundwater quality. This is because such indiscriminately disposed wastes infiltrates, percolates and permeates into the soil and enters the groundwater during rainfall, making the groundwater aquifer susceptible to contaminants from the surface topsoil. Hence the need to investigate the overburden capacity in preventing contaminant intrusion to fresh water aquifer.

Electrical resistivity geophysical method has found its credence in groundwater environmental studies to investigate and delineate subsurface potential geologic units containing groundwater to avoid drilling unproductive and failed boreholes and to identify subsurface layers that are prone to contaminants intrusion into groundwater aquifers. Many authors such as [10], [11], [12-14] and [15] have employed electrical resistivity survey to delineate contaminant leachate plume and investigate aquifer's vulnerability to contaminants. Cases of failed borehole drills have been reported in Agbor-Obi and Alihami communities where the main campus of University of Delta is located and has been attributed to the complex nature of the geology of the area [14]. Therefore before the start of borehole drilling operations, geophysical investigations are necessary to determine the characteristics of the aquifer and the strength of the overburden layer to prevent contaminants' intrusion into the underlying aquifer. This is to ensure abstraction of safe and clean fresh water devoid of waterborne diseases.

The University of Delta main campus is located in Agbor, the headquarter of Ika South Local Government Area of Delta State and lies within Latitude 6º 07' and 6º 20' North of the Equator and Longitude 6º 05' and 6º 20' East of the Greenwich meridian (Figure 1). The area sits in the sedimentary Basin that is underlain by the Miocene-Recent Benin Formation. The equatorial climate of the area is characterized by high rainfall, so groundwater is in abundance ensuring proper aquifer recharge and storage of the recharging waters due to the existence of impervious sediments [16]. Groundwater is the main source of water for domestic, commercial and agricultural purposes in Agbor town. This is because surface water is scarce and the few available water sources are contaminated with solid and liquid wastes. The Benin sedimentary Formation that consists of Agbor town where the University of Delta main campus is located is reported to have good aquifers comprising coastal plain sands, unconsolidated and friable sandy beds with intercalations of gravely units and clay lenses that are probably the most prolific water producers in southern Nigeria [17, 18] and [16]. The sediments in the area comprises lateritic topsoil, clayey sand, sandy clay, fine grained sand, with a mixture of fine to medium grained sand, medium grained sand, medium to coarse grained sand, coarse grained sand, and sandy clay with intercalation of discontinuous lenses of clay of varied thickness that settle in fluvial tidal environment. Hence the reason why the Benin Formation has always been described as consisting of massive continental/fluvial sands and gravels [19]. The main aquifer that is explored in Agbor town is the medium to coarse grained and coarse grained sandy beds.

The hydrogeology of the University of Delta main campus is affected by the geology of the region. The porous and permeable sedimentary Formation in the region facilitates the movement and recharge of groundwater by rain water, surface run off and Iyi-Ama stream which is about 300metres away from the University of Delta (Unidel) main campus. [12] and [16] reported that the area is generally made up of unconfined phreatic aquifer and that this aquifer quality is an important characteristic of the Benin Formation that constitutes in area. Due to the characteristic unconfined nature of aquifers in the area, serious concerns have arisen regarding the entry of contaminants from large stream of wastes generated by agricultural, domestic and industrial activities associated with poor sanitation practices in the area. Therefore, to maintain sustainable groundwater resource and ensure access to clean, portable and sufficient water to meet the economic needs of the University community, it is necessary to investigate the groundwater potential yield and the vulnerability of the aquifer overburden protective layer to shield or prevent contaminants into the groundwater aquifer.

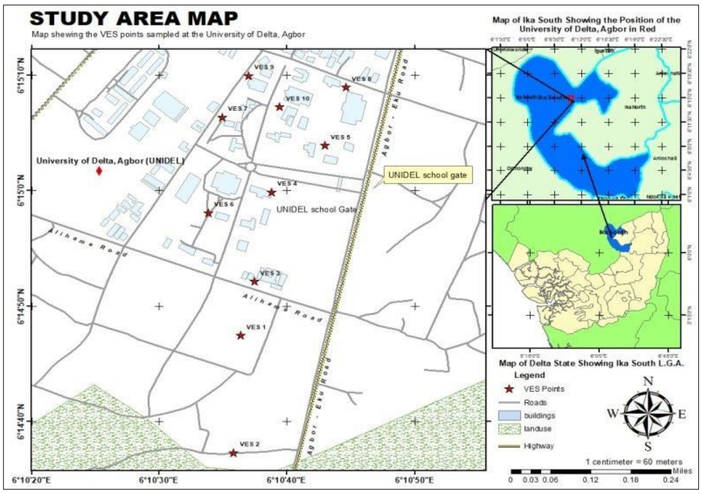


**Fig. 1:** Map of the Study Area Showing VES Sampling Points in the University of Delta Main Campus, Agbor

## MATERIALS AND METHOD

### *Data Acquisition*

Electrical resistivity geophysical method was employed in this investigation. The method is non destructive and requires injecting current into the ground through two current electrodes, AB and the potential difference created from the passage of the electric current into the earth materials is measured across a pair of potential electrodes, MN. The Schlumberger array was used and the data was obtained with the *Petrozenith PZ-02 resistivity Meter.* This device is very sensitive and has the capacity of automatically taking successive readings whose results are averaged continuously. The consistently updated running average is displayed as resistance automatically.

### *Vertical Electrical Sounding*

The vertical electrical sounding (VES) was randomly performed at ten locations in the Northeast-Southwest and Northwest-Southeast direction. Maximum current electrode spacing (AB/2) of 800m was adopted with the Schlumberger array. The Schlumberger array was chosen because it is faster, more cost effective and less sensitive to vertical heterogeneity. At each location where measurements were made, a resistance R reading of the volume of the earth material within the electrical field of the electrode configuration was obtained. The measured resistance values (R) were converted into apparent resistivity ($\rho_a$) by multiplying with a geometric factor (K), and is given by:

$$\rho a = \pi R \frac{[(AB/2)^2 - (MN/2)^2]}{MN} = \pi RK \quad (1)$$

Where K is the geometric factor and is represented as:

$$\frac{(AB/2)^2-(MN/2)^2}{MN} \quad (2)$$

The resulting apparent resistivity values were used to generate sounding curves that was qualitatively and quantitatively interpreted with the one-dimensional resistivity inversion IPI2WIN software to obtain geo-electric section of the resistivity model for the area with minimal root mean square error. This software uses the least-squares optimization technique to continuously adjust the initial model until the difference between the field data and the output model is reduced to a minimum. The software also converts the resulting apparent resistivities as a function of electrode separation in the field to true resistivities as a function of depth so that the true resistivities represent the best average volume resistivity for a given layer.

***Dar-Zarrouk Parameters of Aquifers***

For effective groundwater management, it is important to understand aquifer hydraulic properties. The hydraulic properties of an aquifer such as hydraulic conductivity, transmissivity, permeability, longitudinal conductance and transverse resistance make up the Dar-Zarrouk parameters. They are calculated from field values of the resistivity and thickness of the subsurface layered units. The Dar-Zarrouk parameters are used to estimate aquifer hydraulic properties of an area.

**(i)** The longitudinal conductance ($S_L$) of a geologic formation is its ability to slow down and filter percolating fluid which is considered as the protective overburden layer of the aquifer and is expressed as:

$$\text{Longitudinal unit conductance, } S_L = \sigma h_i = \frac{h_i}{\rho_i} \quad (3)$$

Where σ is the aquifer conductivity, $h_i$ is the aquifer thickness and ρ is the aquifer resistivity

**(ii)** The transverse resistance of a subsurface Formation is the parameter that indicates areas with high potential for groundwater exploration such that a high value of transverse resistance implies a high potential for groundwater exploration in the area [20], [21]. [22] and [5] opined that aquifer units exhibiting high transverse resistance also implies high aquifer permeability that are characterized by more electrically resistive Earth materials like sand, gravel and sandstone which are standard materials for aquifers in sedimentary domains. The transverse resistance ($T_r$) in this study was calculated by this relationship:

$$T_r = h.\rho \quad (4)$$

Where h is the thickness of the aquifer and ρ is the aquifer resistivity.

**(iii)** The hydraulic conductivity (k) of a hydrogeologic medium is the ease with which a fluid can flow through the medium. The ease or difficulty of fluid flow through a medium is influenced by the level of porosity (the number and size of interconnected pores or spaces) within the medium and the properties of the flowing fluid such as its viscosity and density. It was confirmed from studies by [23] and [24] that hydraulic conductivity also influences the yield of wells and contaminant spread.

In areas of few or sparse pumping test information, [25, 26] and [27] adduced that applying surface resistivity method in such areas can provide useful information on aquifer properties. Thus, due to dearth of pumping test data in the study area, the hydraulic conductivity data in this study were estimated according to the relationship based on the exponential law function by [28, 29] and it is given as:

$$Ln k = 0.068 ln \rho_i + 6.02 \quad (5)$$

Where $\rho_i$ is the aquifer resistivity, K is the hydraulic conductivity

**(iv)** Transmissivity is another Dar-zarrouk parameter that is used to estimate the ability of the subsurface formations to store and transmit groundwater. It is used to indicate the groundwater abstraction capacity of an aquifer depending on the properties of the porous matrix and the fluid passing through the Formation [30, 31]. Transmissivity serves as a key indicator of the aquifer's quality and quantity leading to fewer unsuccessful water well projects [7]. The transmissivity values used in this study were extrapolated by applying the relationship:

$$T = Kh \quad (6)$$

Where K is the hydraulic conductivity measured in m/day, and h is the aquifer thickness measured in meters (m).

The above relationship was employed to extrapolate the transmissivity data because of lack of pumping test data and this method is consistent with the study of [32] who reported that the relationship in equation 6 should be applied to extrapolate transmissivity data in areas with sparse pumping test information or where boreholes do not exist.

***Aquifer Storativity***

Aquifer storativity is also referred to as aquifer storage capacity. [33] defined the storativity of an aquifer as the amount of water that is absorbed by or realeased from an aquifer per unit change in hydraulic head within the aquifer. [33] also stated that unconfined aquifers have larger storage capacity than confined aquifers due to the contraction and expansion of the aquifer material and the vertical movement of the water table. The data for the storativity (S) of the unconfined aquifers used in this study was estimated from the empirical relationship by [5]:

$$S = 3x10^{-6}b \ldots \qquad (7)$$

Where b is the aquifer saturated thickness measured in meters (m).

***Aquifer Diagnostic Parameter***
This parameter is used to identify areas with almost the same geologic properties according to [32] and [5]. The aquifer diagnostic parameter (δ) for this study was calculated using the empirical relationship:

$$\delta = K\sigma \qquad (8)$$

Where K is the hydraulic conductivity and σ is the electrical conductivity.

## RESULTS AND DISCUSSION

***Layer Lithology***
The number of layers at each VES data location was identified using the results of the geoelectric curves. The pseudo-sections and curves types obtained at the surveyed areas are KHA, HKH and HAK (Figure 2) which indicates heterogeneity in the lithology of the area. Their respective lithologies are shown in Table 1. The VES result delineated eight to nine geoelectric layers comprising lateritic topsoil, clayey sand, sandy clay, Fine grained sand, Fine to Medium grained sand, Medium grained sand, Medium to Coarse grained sand, Coarse grained sand, and Sandy clay/clay. This confirms that the geology of the area is the Benin Formation.

Except for Faculty of Computing (VES 3) and the Administrative Block (VES 4) with eight layers the other VES stations have nine subsurface layers. Generally, the resistivity values of the area varied from 7.05Ωm (VES 4) to 300098Ωm (VES 3) with varying thickness (0.5m to 104.42m) and depth (0.5m to 212.7054m). A very keen observation from the geoelectric sections showed that the study area consists of unconfined aquifers which agree with the studies of [16] and [12].

***Aquifer Parameters***
The key aquifer parameters (resistivity and thickness) were extracted from Table 1 and used to estimate the Dar-Zarrouk parameters (Table 2). The aquiferous layer consists of medium-coarse sand and coarse sand with resistivity, thickness and depth respectively ranging from 2037Ωm (VES 2 and VES 8) to 3000098Ωm (VES 3), 59.93m (VES 7) to 88.92m (VES 4), and 106.75m (VES 8 and VES 10) to 140.8m (VES3). The low conductivity of the aquifer layers confirms that it is a very good aquiferous layer. Studies and findings by [5] revealed that aquifer thickness determines the ability of that unit to store large quantity of water. Thus, the aquifer unit at the Administrative Block (VES 4) has the maximum storage capacity value of 0.0002668m$^{-1}$ and the maximum aquifer thickness value of 88.92m. While the aquifer unit at Unidel business centre (VES 7) has the lowest storage capacity of 0.0001798m$^{-1}$ and aquifer thickness of 59.93m.

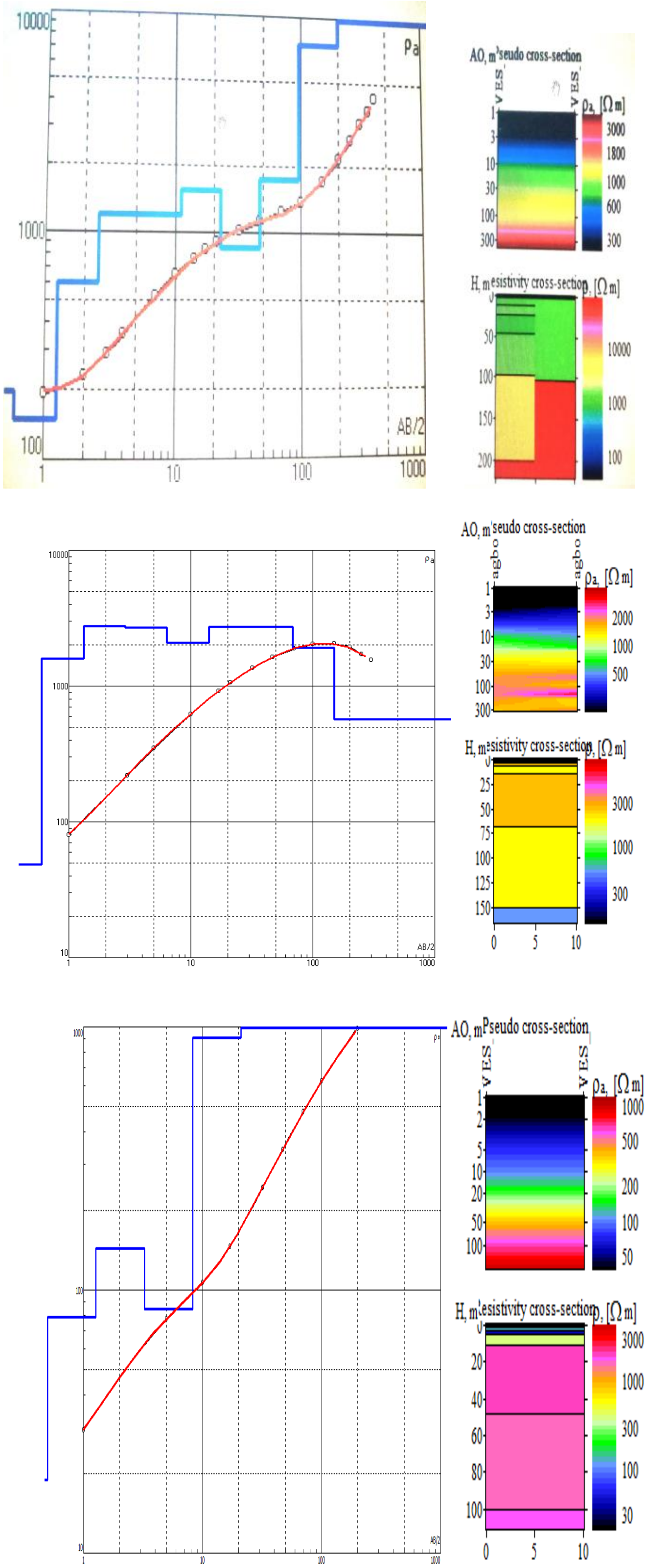

**Fig. 2:** VES Field Curves and Pseudo-sections of the 1-D Resistivity Model

**Table 1:** Lithologic Delineation of the 1D Inversion Model from the VES Stations

| Location | | VES Locations | Layer | Resistivity (Ωm) | Thickness (m) | Depth (m) | Inferred Lithology |
|---|---|---|---|---|---|---|---|
| Northings | Eastings | | | | | | |
| 06º 14.791' | 006º 10.607' | VES 1 (Proposed School of Postgraduate Studies Block) | 1 | 188.2 | 0.6 | 0.6 | Lateritic topsoil |
| | | | 2 | 151.4 | 0.6510 | 1.251 | Clayey Sand |
| | | | 3 | 865.2 | 1.346 | 2.597 | Sandy Clay |
| | | | 4 | 1040 | 2.756 | 5.353 | Fine grained Sand |
| | | | 5 | 803.50 | 5.755 | 11.108 | Fine to medium grained Sand |
| | | | 6 | 1987 | 11.81 | 22.918 | Medium grained Sand |
| | | | 7 | 856.20 | 24.18 | 47.098 | Medium to Coarse grained Sand |
| | | | 8 | 2048 | 82.76 | 129.858 | Coarse grained Sand |
| | | | 9 | 1875 | - | - | Sandy Clay/Clay |
| 06º 14.622' | 006º 10.598' | VES 2 (Faculty of Science Block) | 1 | 186.7 | 0.6 | 0.6 | Lateritic topsoil |
| | | | 2 | 150.4 | 0.6403 | 1.24 | Clayey Sand |
| | | | 3 | 862.2 | 1.323 | 2.564 | Sandy Clay |
| | | | 4 | 1039 | 2.736 | 5.299 | Fine grained Sand |
| | | | 5 | 802.5 | 5.655 | 10.95 | Fine to medium grained Sand |
| | | | 6 | 1988 | 11.69 | 22.64 | Medium grained Sand |
| | | | 7 | 851.9 | 24.16 | 46.81 | Medium to Coarse grained Sand |
| | | | 8 | 2037 | 81.95 | 128.75 | Coarse grained Sand |
| | | | 9 | 1878 | - | - | Sandy Clay/Clay |
| 06º 14.869' | 006º 10.625' | VES 3 (Faculty of Computing) | 1 | 388.8 | 0.6 | 0.6 | Lateritic topsoil |
| | | | 2 | 321.5 | 0.6461 | 1.246 | Clayey Sand |
| | | | 3 | 486.7 | 1.342 | 2.588 | Sandy Clay |
| | | | 4 | 211.5 | 2.787 | 5.375 | Fine grained Sand |
| | | | 5 | 189.5 | 5.788 | 11.16 | Medium grained Sand |
| | | | 6 | 11758 | 42.02 | 53.18 | Medium to coarse grained Sand |
| | | | 7 | 300098 | 87.64 | 140.8 | Coarse grained Sand |
| | | | 8 | 38138 | - | - | Sandy Clay/Clay |
| 06º 14.998' | 006º 10.647' | VES 4 (Administrative Block) | 1 | 847 | 0.5 | 0.5 | Lateritic topsoil |
| | | | 2 | 768 | 0.701 | 1.2 | Clayey Sand |
| | | | 3 | 840 | 1.82 | 3.02 | Sandy Clay |
| | | | 4 | 844 | 14.95 | 17.97 | Fine grained Sand |
| | | | 5 | 699 | 21.93 | 39.90 | Medium grained Sand |
| | | | 6 | 4123 | 88.92 | 128.82 | Medium to coarse grained Sand |
| | | | 7 | 3126.04 | 79 | 207.82 | Coarse grained Sand |
| | | | 8 | 7.05 | - | - | Sandy Clay/Clay |
| 06º15.065' | 006º10.717' | VES 5 (Former Registrar's Block/Faculty of Basic Medical Sciences{Dept. of Nursing Sciences}) | 1 | 187.40 | 0.6 | 0.6 | Lateritic topsoil |
| | | | 2 | 152.40 | 0.662 | 1.262 | Clayey Sand |
| | | | 3 | 865.20 | 1.341 | 2.603 | Sandy Clay |
| | | | 4 | 1040 | 2.821 | 5.424 | Fine grained Sand |
| | | | 5 | 804.5 | 5.453 | 10.877 | Fine to medium grained Sand |
| | | | 6 | 1989 | 11.65 | 22.527 | Medium grained Sand |
| | | | 7 | 861.9 | 24.22 | 46.747 | Medium to Coarse grained Sand |
| | | | 8 | 2152 | 60.95 | 107.697 | Coarse grained Sand |
| | | | 9 | 188936 | - | - | Sandy Clay/Clay |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 06º 14.968’ | 006º 10.565’ | **VES 6** (1000 Capacity Hall Block) | 1 | 865 | 0.5 | 0.5 | Lateritic topsoil |
| | | | 2 | 767 | 0.721 | 1.221 | Clayey Sand |
| | | | 3 | 845 | 1.67 | 2.891 | Sandy Clay |
| | | | 4 | 847 | 4.08 | 6.971 | Fine grained Sand |
| | | | 5 | 700 | 9.75 | 16.721 | Fine to medium grained Sand |
| | | | 6 | 752 | 24.30 | 41.021 | Medium grained Sand |
| | | | 7 | 4232 | 78.9 | 119.921 | Medium to Coarse grained Sand |
| | | | 8 | 6.07 | 80.2 | 200.121 | Coarse grained Sand |
| | | | 9 | 7.09 | - | - | Sandy Clay/Clay |
| 06º 15.106’ | 006º 10.583’ | **VES 7** (Unidel Business Centre) | 1 | 1850 | 0.6 | 0.6 | Lateritic topsoil |
| | | | 2 | 812.50 | 0.6504 | 1.2504 | Clayey Sand |
| | | | 3 | 1781 | 1.433 | 2.6834 | Sandy Clay |
| | | | 4 | 639.40 | 2.747 | 5.4304 | Fine grained Sand |
| | | | 5 | 1582 | 5.665 | 11.0954 | Fine to medium grained Sand |
| | | | 6 | 50980 | 37.26 | 48.3554 | Medium grained Sand |
| | | | 7 | 16846 | 59.93 | 108.285 | Medium to Coarse grained Sand |
| | | | 8 | 4945 | 104.42 | 212.7054 | Coarse grained Sand |
| | | | 9 | 6981 | - | - | Sandy Clay/Clay |
| 06º 15.149’ | 006º 10.744’ | **VES 8** (Faculty of Education Block) | 1 | 186.7 | 0.6 | 0.6 | Lateritic topsoil |
| | | | 2 | 150.4 | 0.6403 | 1.24 | Clayey Sand |
| | | | 3 | 862.2 | 1.323 | 2.564 | Sandy Clay |
| | | | 4 | 1039 | 2.736 | 5.299 | Fine grained Sand |
| | | | 5 | 802.5 | 5.655 | 10.95 | Fine to medium grained Sand |
| | | | 6 | 1988 | 11.69 | 22.64 | Medium grained Sand |
| | | | 7 | 851.9 | 24.16 | 46.81 | Medium to Coarse grained Sand |
| | | | 8 | 2037 | 59.95 | 106.75 | Coarse grained Sand |
| | | | 9 | 187837 | - | - | Sandy Clay/Clay |
| 06º 15.166’ | 006º 10.617’ | **VES 9** (Faculty of Arts Block) | 1 | 1800 | 0.6 | 0.6 | Lateritic topsoil |
| | | | 2 | 810.5 | 0.6403 | 2.34 | Clayey Sand |
| | | | 3 | 1591 | 1.323 | 2.564 | Sandy Clay |
| | | | 4 | 628.4 | 2.736 | 5.299 | Fine grained Sand |
| | | | 5 | 1531 | 5.655 | 10.95 | Fine to medium grained Sand |
| | | | 6 | 50970 | 36.26 | 47.22 | Medium grained Sand |
| | | | 7 | 15836 | 59.95 | 107.17 | Medium to Coarse grained Sand |
| | | | 8 | 4947 | 103.2 | 210.4 | Coarse grained Sand |
| | | | 9 | 6872 | - | - | Sandy Clay/Clay |
| 06º 15.121’ | 006º 10.658’ | **VES 10** (Library Block) | 1 | 188.2 | 0.6 | 0.6 | Lateritic topsoil |
| | | | 2 | 152.5 | 0.6403 | 1.24 | Clayey Sand |
| | | | 3 | 863.10 | 1.323 | 2.564 | Sandy Clay |
| | | | 4 | 1044 | 2.736 | 5.299 | Fine grained Sand |
| | | | 5 | 805.6 | 5.655 | 10.95 | Fine to medium grained Sand |
| | | | 6 | 1986 | 11.69 | 22.64 | Medium grained Sand |
| | | | 7 | 865.9 | 24.16 | 46.81 | Medium to Coarse grained Sand |
| | | | 8 | 2087 | 59.95 | 106.75 | Coarse grained Sand |
| | | | 9 | 187943 | - | - | Sandy Clay/Clay |

The aquifer units at the Faculty of Education block (VES 8), Faculty of Arts block (VES 9) and the Library block (VES 10) have almost the same lowest storage capacity with the aquifer unit at Unidel business centre (VES 7). The average regional storage capacity in the area (Unidel Community) is $0.0002163m^{-1}$ and the average regional aquifer thickness is 72.09m. A shallow aquifer unit of 107.17m depth was found at the Faculty of Arts block while a deep lying aquifer unit at depth 140.80m was found in the Faculty of Computing. The average aquifer depth recorded in the main campus of the University of Delta was 118.48m which is consistent with the study of [16] who reported that the depth of groundwater aquifer in Agbor generally occurs at a depth greater than 60metres and has medium-coarse sandy beds that make up the main aquifer tapped in the area.

***Dar-Zarrouk Parameters***

The hydraulic conductivity, transmissivity, longitudinal conductance and transverse resistance are the key constituents of the Dar-Zarrouk parameters of an aquifer. These parameters were estimated from the aquifer resistivity values (Table 2). The transverse resistance of aquifer units in this study ranged from $12118.15\Omega m^2$ to $26300588.72\Omega m^2$ which indicates that the aquifer unit at Faculty of Computing (VES 3) has the highest porosity and permeability, making it the most suitable for groundwater exploration and yielding a greater amount of groundwater compared to the aquifer unit at the Faculty of Education block, which has the lowest potential for groundwater exploration and groundwater yield. This implies that high transverse resistance translates to high potential yield of groundwater and high groundwater transmissivity.

The transmissivity values in the area ranged from $413.65m^2$/day to $850.11m^2$/day with the highest value at the Faculty of Computing (VES 3). The high transmissivity value means that the probability of obtaining good groundwater yield from the aquifer is very high and therefore gives a good hope of successfully drilling effective boreholes in the area. [34] reported that the transmissivity of an aquifer is a function of its thickness, such that transmissivity increases with the thickness of the aquifer. The transmissivity of aquifers in the study area was rated high and withdrawal of lesser regional importance (Table 4) when compared to the standards for transmissivity rating by [30] and [35]. Therefore, high transmissivity values mean that a relatively thick aquifer unit is underlain in the area. The study also found that VES stations with high hydraulic conductivity and transmissivity such as at VES 1, VES 2, VES 3, VES 4, VES 6, VES 7 and VES 9 have good aquifer productive potential, although has poor overburden protective layer and making the aquifer units in the area of extremely high vulnerable to ingress of surface contaminants from topsoil (Table 6).

The hydraulic conductivity of this study ranged from 6.90m/day to 9.70m/day. These values falls within the range of 4.6m/day to 8.8m/day recorded in other parts of Delta State in the studies of [36] and [37]. However, the hydraulic conductivity in this study area was rated high when compared to the standard transmissivity rating by [35] since the values ranged between $100m^2$/day and $1000m^2$/day (Table 3). This is consistent of the studies of [23] and [24] where they opined that hydraulic conductivity affects the yield of wells and contaminant spread.

The longitudinal conductance of an aquifer unit defines its ability to slow down and filter percolating fluid. An impermeable earth material such as clay is considered a good aquifer protective layer. The higher and thicker the clay volume of the soil, the better the strength of the protective layer. High and increasing longitudinal conductance values indicates good aquifer protective capacity or strength. The longitudinal conductance in the area varied between $0.0002892\Omega^{-1}$ and $0.040411\Omega^{-1}$. These values are found to be very low when compared to the standards for aquifer protective capacity and vulnerability ratings (Table 5) adopted by [38] and [39]. The overburden protective capacity of the aquifer was rated poor and extremely high vulnerability (Tables 5 and 6) to contaminant risk from surface contaminants. Thus, low values of longitudinal conductance imply low clay volume to prevent/retard percolating contaminants. Since the direction and magnitude of groundwater velocity is controlled by the hydraulic conductivity, high hydraulic conductivity would therefore affect groundwater flow and contaminant spread to the extremely high vulnerable aquifer. The aquifer protective layer in the entire surveyed area was rated 90% poor and extremely high vulnerability, and 10% moderate and high vulnerability to contaminants (Figure 3).

This study revealed that the proposed school of Postgraduate studies block (VES 1), Faculty of Science block (VES 2) and Faculty of Education block (VES 8) have the same diagnostic parameters and therefore have similar geologic characteristics while the Administrative block (VES 4) and the 1000 Capacity Hall block share similar geologic diagnostic features.

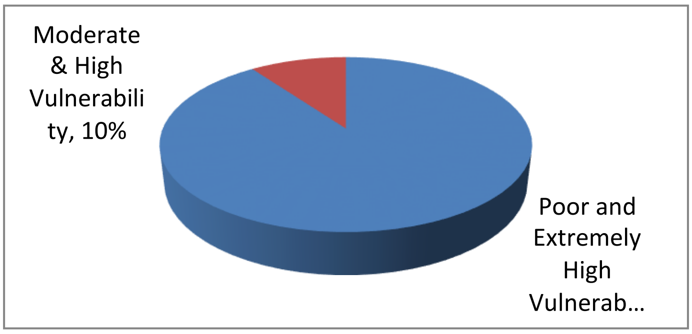


**Fig. 3:** Percentage of Aquifer Overburden Protective Layer Vulnerability Rating in the Study Area

**Table 2:** Aquifer Hydraulic Parameters in the Study Area

| VES Points | Aquifer Resistivity, ρ (Ωm) | Aquifer Thickness, h (m) | Aquifer Depth, d (m) | Aquifer Conductivity, σ = 1/ρ $(\Omega m)^{-1}$ | Longitudinal Conductance, S = σh $(\Omega^{-1})$ | Transverse Resistance, R = hρ $(\Omega m^2)$ | Hydraulic Conductivity, K (m/day) | Transmissivity, T = Kh $(m^2/day)$ | Storativity $(m^{-1})$ | Aquifer Diagnostic Parameter $(\Omega day)^{-1}$ | Inferred Lithology |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **VES 1 (Proposed School of Postgraduate Studies Block)** | **2048** | **82.76** | **129.86** | **0.0004883** | **0.040411** | **169492.48** | 6.91 | 571.872 | **0.0002483** | **0.003374** | **Coarse grained Sand** |
| **VES 2 (Faculty of Science Block)** | **2037** | **81.95** | **128.75** | **0.0004910** | **0.040237** | **166932.15** | 6.90 | 565.46 | **0.0002459** | **0.003388** | **Coarse grained Sand** |
| **VES 3 (Faculty of Computing)** | **300098** | **87.64** | **140.80** | **0.0000033** | **0.0002892** | **26300588.72** | 9.70 | 850.11 | **0.0002629** | **0.000032** | **Coarse grained Sand** |
| **VES 4 (Administrative Block)** | **4123** | **88.92** | **128.82** | **0.0002425** | **0.0215631** | **366617.16** | 7.25 | 644.67 | **0.0002668** | **0.0017581** | **Medium to Coarse grained Sand** |
| **VES 5 (Former Registrar's Block/Faculty of Basic Medical Sciences{Dept of Nursing Sciences})** | **2152** | **60.95** | **107.69** | **0.0004647** | **0.0283234** | **131164.40** | 6.93 | 422.38 | **0.0001829** | **0.003220** | **Coarse grained Sand** |
| **VES 6 (1000 Capacity Hall Block)** | **4232** | **78.90** | **119.92** | **0.0002363** | **0.0186440** | **333904.80** | 7.26 | 572.81 | **0.0002367** | **0.0017155** | **Medium to Coarse grained Sand** |
| **VES 7 (Unidel Business Centre)** | **16846** | **59.93** | **108.28** | **0.00005940** | **0.0035598** | **1009580.78** | 7.98 | 478.24 | **0.0001798** | **0.000474** | **Medium to Coarse grained Sand** |
| **VES 8 (Faculty of Education Block)** | **2037** | **59.95** | **106.75** | **0.0004910** | **0.0294354** | **122118.15** | 6.90 | 413.65 | **0.0001799** | **0.003388** | **Coarse grained Sand** |
| **VES 9 (Faculty of Arts Block)** | **15836** | **59.95** | **107.17** | **0.00006314** | **0.0037852** | **949368.20** | 7.94 | 476.00 | **0.0001799** | **0.0005013** | **Medium to Coarse grained Sand** |
| **VES 10(Library Block)** | **2087** | **59.95** | **106.75** | **0.0004792** | **0.0287280** | **125115.65** | 6.92 | 414.85 | **0.0001799** | **0.0033161** | **Coarse grained Sand** |
| **Mean Value** | | **72.09** | **118.48** | | | | | | **0.0002163** | | |

**Table 3:** Summary of Results of Aquifer Properties of VES Stations in the Study Area

| VES Stations | Hydraulic Conductivity, K (m/day) | Transmissivity, T = Kh ($m^2$/day) | Transmissivity ($m^2$/day) [30] | Designation | Groundwater Supply Potential |
|---|---|---|---|---|---|
| **VES 1 (Proposed School of Postgraduate Studies Block)** | **6.91** | **571.872** | | **High** | **Withdrawal of Lesser Regional Importance** |
| **VES 2 (Faculty of Science Block)** | **6.90** | **565.46** | | **High** | **Withdrawal of Lesser Regional Importance** |
| **VES 3 (Faculty of Computing)** | **9.70** | **850.11** | | **High** | **Withdrawal of Lesser Regional Importance** |
| **VES 4 (Administrative Block)** | **7.25** | **644.67** | | **High** | **Withdrawal of Lesser Regional Importance** |
| **VES 5 (Former Registrar's Block/Faculty of Basic Medical Sciences{Dept of Nursing Sciences})** | **6.93** | **422.38** | **100-1000** | **High** | **Withdrawal of Lesser Regional Importance** |
| **VES 6(1000 Capacity Hall Block)** | **7.26** | **572.81** | | **High** | **Withdrawal of Lesser Regional Importance** |
| **VES 7(Unidel Business Centre)** | **7.98** | **478.24** | | **High** | **Withdrawal of Lesser Regional Importance** |
| **VES 8(Faculty of Education Block)** | **6.90** | **413.65** | | **High** | **Withdrawal of Lesser Regional Importance** |
| **VES 9(Faculty of Arts Block)** | **7.94** | **476.00** | | **High** | **Withdrawal of Lesser Regional Importance** |
| **VES 10(Library Block** | **6.92** | **414.85** | | **High** | **Withdrawal of Lesser Regional Importance** |

**Table 4:** Standards for Transmissivity [30] and [35]

| Transmissivity ($m^2$/day) | Designation | Groundwater Supply Potential |
|---|---|---|
| 1000 | Very High | Withdrawal of great regional importance |
| 100-1000 | High | Withdrawal of lesser regional importance |
| 10-100 | Intermediate | Withdrawal of local water supply (Small community, plants, e.t.c) |
| 1-10 | Low | Smaller Withdrawal for local water supply (Private consumption) |
| 0.1-1 | Very Low | Withdrawal for Local water supply (Private consumption) |
| <0.1 | Impermeable | Sources of Local water supply are difficult |

**Table 5:** Standards for Aquifer Overburden Protective Capacity and Vulnerability Ratings

| Sum of Longitudinal Conductance (mho or $\Omega^{-1}$) | Overburden Protective Capacity Rating [38] | Vulnerability Rating [39] and [37] |
|---|---|---|
| >10 | Excellent | Extremely low Vulnerability |
| 5-10 | Very good | Low Vulnerability |
| 0.7-0.49 | Good | Moderate Vulnerability |
| 0.2-0.69 | Moderate | High Vulnerability |
| 0.1-0.19 | Weak | Extremely High Vulnerability |
| <0.1 | Poor | |

**Table 6:** Aquifer Overburden Protective Capacity to Surface Contaminants in the Study Area

| VES Points | Aquifer Resistivity, ρ (Ωm) | Aquifer Thickness, h (m) | Aquifer Depth, d (m) | Longitudinal Conductance, S = σh ($\Omega^{-1}$) | Transverse Resistance, R = hρ ($\Omega m^2$) | Aquifer Protective Capacity Rating | Aquifer Vulnerability Rating |
|---|---|---|---|---|---|---|---|
| **VES1 (Proposed School of Postgraduate Studies Block)** | **2048** | **82.76** | **129.86** | **0.040411** | **169492.48** | **Poor** | **Extremely High Vulnerability** |
| **VES 2 (Faculty of Science Block)** | **2037** | **81.95** | **128.75** | **0.040237** | **166932.15** | **Poor** | **Extremely High Vulnerability** |
| **VES 3 (Faculty of Computing)** | **300098** | **87.64** | **140.80** | **0.002892** | **26300588.72** | **Poor** | **Extremely High Vulnerability** |
| **VES 4 (Administrative Block)** | **4123** | **88.92** | **128.82** | **0.0215631** | **366617.16** | **Poor** | **Extremely High Vulnerability** |
| **VES 5 (Former Registrar's Block/Faculty of Basic Medical Sciences{Dept of Nursing Sciences})** | **2152** | **60.95** | **107.697** | **0.0283234** | **131164.40** | **Poor** | **Extremely High Vulnerability** |
| **VES 6 (1000 Capacity Hall Building)** | **4232** | **78.90** | **119.921** | **0.0186440** | **333904.80** | **Poor** | **Extremely High Vulnerability** |
| **VES 7 (Unidel Business Centre)** | **16846** | **59.93** | **108.285** | **0.0035598** | **1009580.78** | **Poor** | **Extremely High Vulnerability** |
| **VES 8 (Faculty of Education Block)** | **2037** | **59.95** | **106.750** | **0.294354** | **122118.15** | **Moderate** | **High Vulnerability** |
| **VES 9 (Faculty of Arts Block)** | **15836** | **59.95** | **107.17** | **0.0037852** | **949368.20** | **Poor** | **Extremely High Vulnerability** |
| **VES 10 (Library Block** | **2087** | **59.95** | **106.75** | **0.0287280** | **125115.65** | **Poor** | **Extremely High Vulnerability** |

## CONCLUSION

The VES data revealed that the subsurface lithology of the area consists of eight to nine geoelectric layers of lateritic topsoil, clayey sand, sandy clay, fine sand, fine-medium sand, medium sand, medium-coarse sand, coarse sand, and sandy clay/clay. The study finds that the aquifer unit at the Faculty of Computing block possesses the best hydraulic conductivity and transmissivity in the University of Delta Main campus. Generally, groundwater can be harnessed within a depth range of 107m to 140m in the main campus of the University of Delta and the aquifer layers are highly productive, thick, and ideal for drilling wells to supply water commercially. Besides rainfall, the Iyi-Ama stream which is about 300 metres away from the University also recharges the groundwater aquifer in the area. The aquifer protective capacity was rated 90% poor and extremely high and 10% moderate and highly vulnerable to contaminants intrusion. However, the aquifers in the university community have high hydraulic pressure and high transmissivity thus shows very high potentials for providing portable water to meet the needs of the University community. It is advised that abstracted groundwater be treated before consumption to prevent the spread of water borne diseases due to the weak/poor nature of the strength of the overburden protective layers. Hydrogeochemical investigation of the portability of the pumped water is also recommended.

### Conflict of Interests

The authors declared no potential conflict of interests with respect to the research authorship and/or publication of this article.

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