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Geoelectric assessment of groundwater prospect and vulnerability of overburden aquifers at Adumasun Area, Oniye, Southwestern Nigeria

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ABSTRACT

Adumasun lies on a Precambrian basement complex of Southwestern Nigeria. Some kilometers away from the study area especially at Igangan is characterized by outcrops of crystalline basement rocks. Inadequate municipal water supply from State Water Corporation, coupled with hydrogeologically difficult nature of the terrain, individuals and corporate bodies indiscriminately sink tube wells and boreholes within the unconsolidated overburden materials, with glaring lack of concerns for the vulnerability status of aquifers, and possible environmental risk. Vertical Electrical Sounding method was used to map Adumasun area, Oniye, Oyo State with a view to assessing the groundwater prospect, focused on the thickness of the unconsolidated materials overlying the crystalline bedrock. The resistivity parameters of the geoelectric topmost layer across the area were also used to assess the vulnerability of the underlying aquifers to near-surface contaminants. The thickness of the unconsolidated overburden varies from 3.1m to 20.1m, where about 60% falls within the 10m-14.9m brackets. This shows that unconsolidated materials are not thick and hence averagely low groundwater prospect. 80% of the topmost geoelectric layer in the study area has resistivity mostly within the range of 1-100 Ω m. Resistivity values within these brackets tend to indicate silt or clay sequence, which can constitute effective protective geologic barriers for the underlying aquifers. This suggests that aquifers within the unconsolidated overburden at Adumasun are mostly capped by impervious/semi-pervious materials, geologically protecting the underlying aquifers from near-surface contaminants.

Keywords: Vertical Electrical Sounding, Layers Parameters, Geoelectric Sections, Overburden Thickness, Fractured Bedrock, Aquifer Vulnerability.

INTRODUCTION

Groundwater has become immensely important for human water supply in urban and rural areas in developed and developing nations alike. In Sub-Saharan Africa, groundwater is well suited to rural water supply. The resource is relatively cheap to develop, since large surface reservoirs are not required and water sources can usually be developed close to the demand [1]. To have successful and sustainable rural water supply projects, it is essential to understand the hydrogeological environment of the project area [2]. The importance of groundwater as a supply source to the socio-economic development of a country is tremendous. Despite its importance, there is gross inadequate supply of water at Adumasun, the study area.

Adumasun lies within the Precambrian basement complex terrain of Southwestern Nigeria [3, 4]. From the experience acquired from the field work of this research, the crystalline basement rocks are extensively exposed at Igangan which is some kilometers away from Adumasun the study area. In basement terrains, groundwater is generally believed to occur within the overlying unconsolidated materials derived from the in-situ weathering of rocks, and fractured/faulted bedrock [5, 6, 7, 8]. MacDonald and Davies (2000) [2] also reported that groundwater generally occurs in the top few meters of weathered rocks. Since the intrinsic resistivity of the unconsolidated overburden and that of the crystalline basement differs by orders of magnitude, geoelectric methods are suitable to map the thickness and extent of the overburden [9, 10]. The electrical resistivity depth sounding is useful in locating areas of maximum aquifer thickness and serves as a good predictive tool for estimation of borehole depth.

Omosuyi (2010) [11] reported that aquifers in basement complex terrains often occur at shallow depths, thus exposing the water within to environmental risks that is, vulnerable to surface or near-surface contaminants. Omosuyi (2010) [11] and Omosehin (2008) [12] have geoelectrically delineated aquifers and assessed the vulnerability of aquifers in Idanre, Southwestern Nigeria. From the knowledge acquired through the field work of this research, it was discovered that the people around Adumasun area abstract water from the unconsolidated materials overlying the crystalline basement through unconsolidated sinking of tube wells, with glaring lack of concern for aquifer vulnerability to near-surface contaminants and quality status of the groundwater.

This work is to assess the groundwater prospect of the unconsolidated materials in the area, the geoelectric parameters of the near-surface aquifers to near-surface contaminants. The work is anticipated to enlighten the populace on groundwater potential of the unconsolidated materials in the area, and the vulnerability of the aquifers within.

1.1 SITE DESCRIPTION AND GEOLOGICAL SETTING.

Adumasun area is underlain by the Precambrian basement complex of Southwestern Nigeria [2, 3, 13]. Precambrian basement comprise of crystalline and metamorphic rocks over 550million years old [2]. Unweathered basement rock contains negligible groundwater. Significantly aquifers however, develop within the weathered overburden and fractured bedrock.

The study area is located between latitude 07^0 $37'$ $55.37''$ to 07^0 $38'$ $00''$ North and longitude 003^0 $11'$ $10.2''$ to 003^0 $11'$ $16.8''$ East. The entire study area is a suburb of Oniye, Oyo State, Nigeria. It is located at some kilometers away from Igangan (Figure 1). Accessibility of the area can be best described in terms of its road network. Several roads dissect the area. These include the major road that link Tapa, Igbo-Ora, and Igangan. Other minor roads and footpaths link the area with other places (like Oniko and Alagbado) (Figure 2). With these roads, the accessibility is very easy.

Two major rock formations exist within the study area. Each formation generally has different petrophysical properties, which will impact different capacities to store and transmit fluid. These two rocks are grouped as Migmatite Gneiss complex (e.g. granite gneiss) and Older Granite complex (e.g. granite) [14]. The granite in the region forms the country rock for granite gneiss and banded gneiss. The outcrops are highly weathered and exfoliated, sometimes found with displaced boulders. The granite gneiss is of light and dark mineral layers. Visible minerals include quartz, feldspar and biotite. The rock is highly weathered with potholes resulting from differential weathering. On most locations of gneiss, there is occurrence of folding that is probably due to differential stress. The banded gneiss consists of parallel light and dark coloured bands [14]. Gneiss frequently exists together in outcrops and because of their intimate association, it is not possible to show them as separate units on the geologic map. Figure 3 shows the geologic map of Oniye and the study area.

MATERIALS AND METHODS

The vertical electrical soundings (VES) were conducted on 14th to 16th December, 2011 using the Schlumberger electrode array [15]. R 50 Resistivity meter was used for the data acquisition. The geoelectric survey comprised of ten depth soundings (Figure 4), with maximum current electrode spacing (AB) of 200m. The field curves were interpreted through partial curve matching [9], engaging master curves and auxiliary point charts [16].

The manually derived geoelectric parameters were subjected to an inversion [17], which successfully reduced the interpretation error to acceptable levels [18].

The electrical resistivity contrasts existing between lithological sequences in the subsurface [19, 20] were used in the delineation of geoelectric layers, identification of aquiferous materials [21] and assessment of groundwater prospect of the area. Also, the resistivity parameters of the uppermost geoelectric layer (topsoil) was used to evaluate, in quantitative terms, its permeability to surface/near surface contaminants, and hence the vulnerability of the underlying aquifers, as demonstrated in Draskovits et al. (1995) [22] and Omosuyi (2010) [11].

RESULTS AND DISCUSSION

The results were discussed under geoelectric sections, assessment of groundwater prospect in terms of overburden thickness and assessment of aquifer vulnerability sub-headings. The Schlumberger depth soundings produced a short range of sounding curves: three-layer type A (40%), H type (50%), and four-layer curves of type KH (10%) were recorded. Typical curves are shown in Figure 5 (a-j). Summary of the formation of layer parameters and classification of the resistivity sounding curves are presented in Table 1 and 2 respectively. Field curves were mirror-image (geoelectrically) in three traverses of SE to NW and SW to NE directions. The nature of the successive lithologic sequence in a place can be used in qualitative sense to assess the groundwater prospect of an area [23]. Type H and KH curves are often associated with groundwater possibilities while type A may typify a rapid resistivity progression, indicative of shallow, resistive bedrock.

1.1.1 Geoelectric Sections

The aquifers in Adumasun were delineated through geoelectric sections. From figure 4, the 10 VES stations were grouped into 3 profiles (A, B and C) according to how convenient they can be located on a straight line to see an image representation of the subsurface. The results of the interpreted VES curves were used to draw 2D geoelectric sections (figures 6a–c) along profiles A, B and C to show the vertical distribution of resistivities within the volume of the earth in the investigated area. The sections consist of sequence of uniform horizontal (or slightly inclined) layers (horizons). Each layer (horizon) in a geo-electrical section may completely be characterized by its thickness and true resistivity. The geoelectric sections show both vertical and lateral variations in layer resistivity. One of the importances of 2D geoelectric sections is that it helps someone to see clearly where there is thin overburden as well as thick overburden within the sounding locations.

The presence of groundwater in any rock presupposes the satisfaction of two factors: adequate porosity and adequate permeability. On account of their crystalline nature, the metamorphic and igneous rocks of the Basement Complex satisfy neither of these requirements. Basement complex rocks are thus considered to be poor aquifers because of their low primary porosity and permeability necessary for groundwater accumulation [24]. However, secondary porosity and permeability imposed on them by fracturing, fissuring, jointing, and weathering through which water percolates make them favourable for groundwater storage [25].

Electrical resistivity contrasts exist across interfaces of lithologic units in the subsurface. These contrasts are often adequate to delineate discrete geoelectric layers and identify aquiferous or non-aquiferous layers [26]. The geoelectric parameters of the aquifer units were determined from the interpretation of the sounding curves. Resistivity of earth materials is strongly affected by water saturation and water quality [27]. The resistivity paramenter of a geoelectric layer is an important factor to adjudge an aquifer or otherwise [11]. The electrical resistivity of the saprolite layer overlying the basement is controlled by the parent rock type, climatic factors, as well as the clay content. A low resistivity of the order of less than 20 ohm-m is indicative of a clayey regolith [28, 29]. This reduces the permeability and thus lowers the aquifer potential. Weights are assigned to the weathered layer resistivity values according to Wright, (1992) [30]. Table 3 summarized the optimum aquifer potentials associated with the saprolite resistivities. However, study shows that the resistivity value of fresh bedrock often exceeds 1000 Ω m, beside, where it is fractured/sheared and saturated with fresh water, the resistivity often reduces below 1000 Ω m [31].

1.1.1.1 Profile A

A maximum of three-to-four subsurface geoelectric units were delineated beneath this profile (figure 6a). These include the topsoil which lies above the water table, the clay/partially weathered rock with resistivities ranging from 9.4 to 105.9 Ω m, and the fresh bedrock under VES 6 and VES 10 while VES 9 showed fractured bedrock. According to Wright (1992) [30], the most promising locations beneath this profile are VES 9 and VES 10. Though VES 10 is A-type but due to thick regolith and weathered layer resistivity of 82.5 Ω m present beneath this location, it is considered suitable for groundwater exploration [30, 32, 33]. VES 9 is another location for groundwater prospect in

this profile because of the weathered layer resistivity of 48.2 Ω m [30] and fractured bedrock [30, 34]. Though overburden of VES 9 is thin, it could still serve for domestic purposes [7, 11].

1.1.1.2 Profile B

A maximum of three-to-four subsurface geoelectric units were delineated beneath this profile (figure 6b). These include the topsoil which lies above the water table, the clay/partially weathered rock with resistivities ranging from 9.4 to 132.6 Ω m, and fresh bedrock underlain VES 5, VES 6 and VES 7 while VES 8 showed fractured bedrock. VES 8 is the only fair location that could be explored for groundwater under this profile but VES 8 is A-type curve which could just depict a rapid resistivity progression. However, groundwater developers in the area may give this location try an error approach if it could yield at the end of the day.

1.1.1.3 Profile C

A maximum of three subsurface geoelectric units were delineated beneath this profile (figure 6c). These include the topsoil which lies above the water table, the clay/partially weathered rock with resistivities ranging from 11.1 to 56.7 Ω m, and fractured bedrock underlain VES 1, VES 2 and VES 3 while VES 4 showed resistive bedrock. VES 1 and VES 3 are promising locations for groundwater prospect because of the weathered layer resistivities which fall above 20 Ω m [30] and the fractured bedrock [30, 34]. Though the overburden of VES 1 and VES 2 are thin, it could serve for domestic purposes [7, 11].

1.1.2 Assessment of Groundwater Prospect in Terms of Overburden Thickness

The approach of Lenkey et al (2005) [33] and Omosuyi (2010) [11] have been employed under this sub-heading. Figure 7 is a contour map produced by Surfer 8 software [35] while figure 8 is the numerical value distribution, showing the thickness of unconsolidated materials overlying the crystalline basement in Adumasun produced by Microsoft Excel software. The thickness ranges from 3.1 to 20.1m with an average of 10.63m. Figure 7 shows that overburden thickness is averagely thin while figure 8 shows that the overburden thickness of 1-4.9m constitutes 20%, 5-9.9m constitutes 10%, 10-14.9m constitutes 60%, 15-19.9m constitutes 0%, and 20-24.9m constitutes 10% in the study area. Overburden thickness ranging from 10-14.9m that covered 60% of the study area confirms that the overburden is averagely thin but not too thin (i.e. overburden less than 15m) as reported by Olayinka et al. (1997) [29], thus suggesting that the water-bearing horizon [33] across the study area is generally not significantly thick.

1.1.3 Assessment of Aquifer Vulnerability

Due to shallow depth of occurrence, aquifers in crystalline basement terrain are often exposed to environmental risks. An effective groundwater protection is given by protective geologic barriers with sufficient thickness [36] and low hydraulic conductivity. Laterite, silt or clay often constitutes protective geologic barriers. When found above an aquifer they constitute its cover [33].

The resistivity parameters of the uppermost geoelectric layer in the study area have been used to assess the vulnerability of the underlying aquifers. Figure 9 is a contour map of resistivity of the first layer while figure 10 shows the numerical resistivity distribution across the first layer in the area. About 80% of the resistivity values of the topmost geoelectric layer fall within 1-100 Ω m range. In Nigerian geological circumstances, this suggests considerable clayey or silt sequences (aquitard), with effective capacity to constitute impervious/semi-impervious barriers.

Figure 1: Location map of the study area.

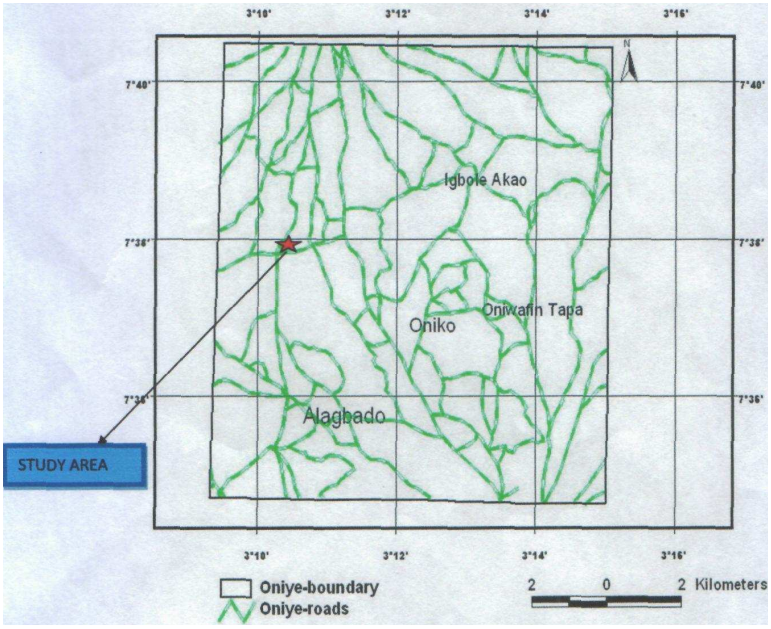

Figure 2: Accessibility map of Oniye showing the study area.

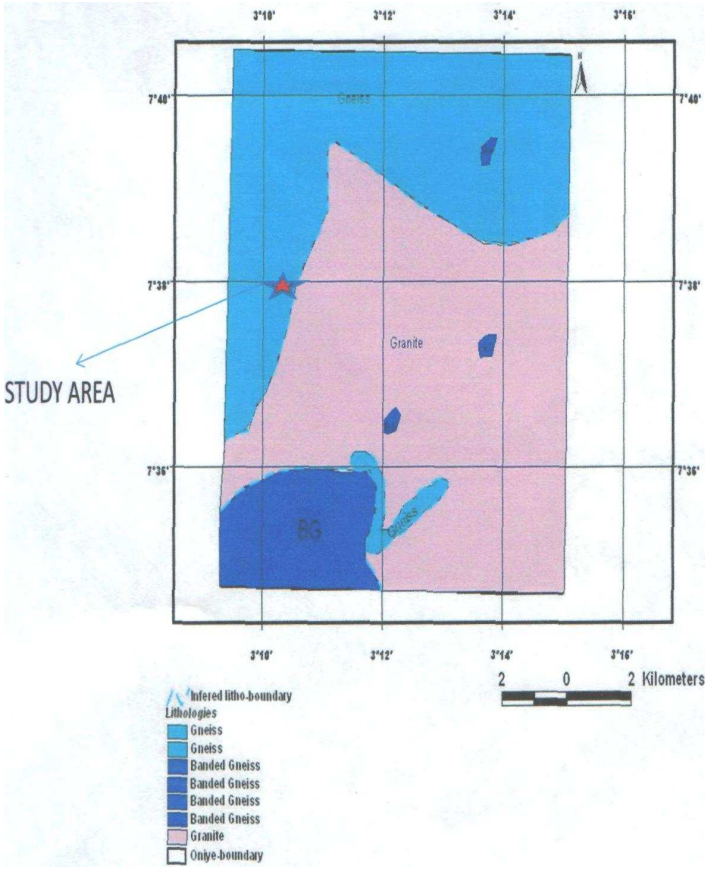

Figure 3: Geologic map of Oniye (after Azeez, 2010).

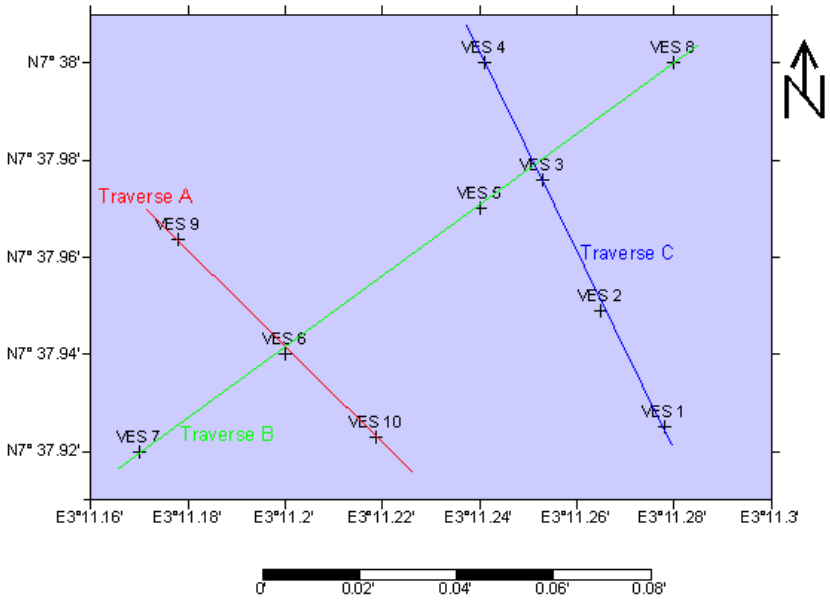

Figure 4: Layout map of VES locations at the study area.

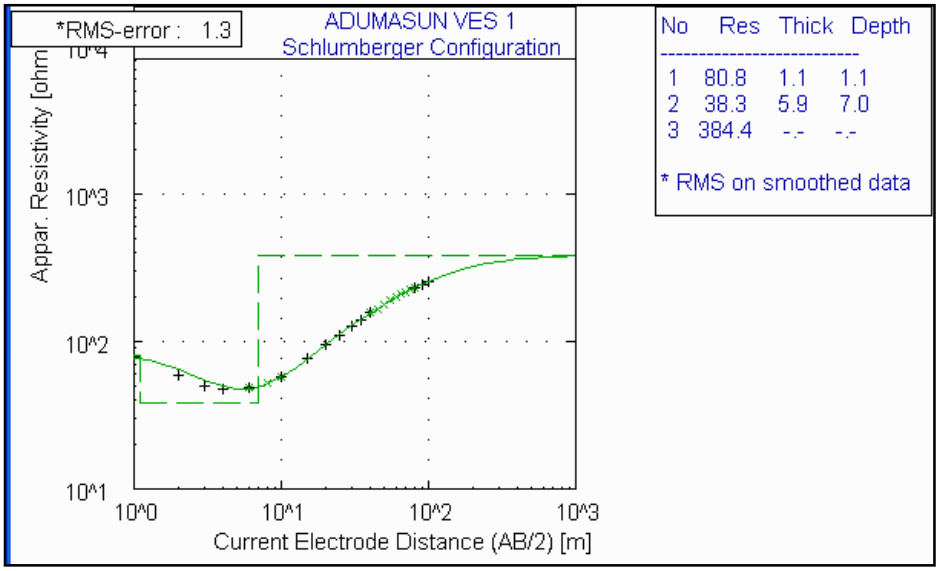

Figure 5(a): The modeled curve for VES 1.

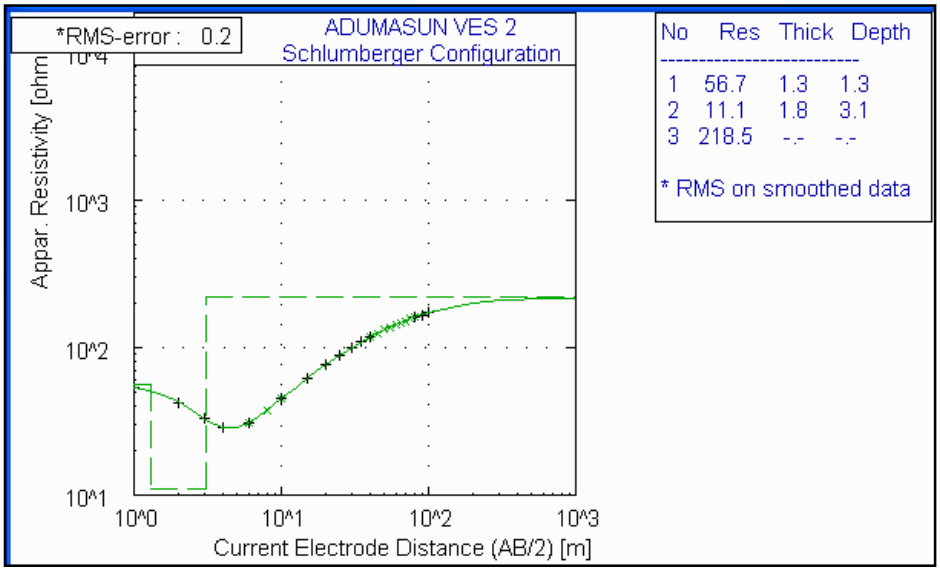

Figure 5(b): The modeled curve for VES 2.

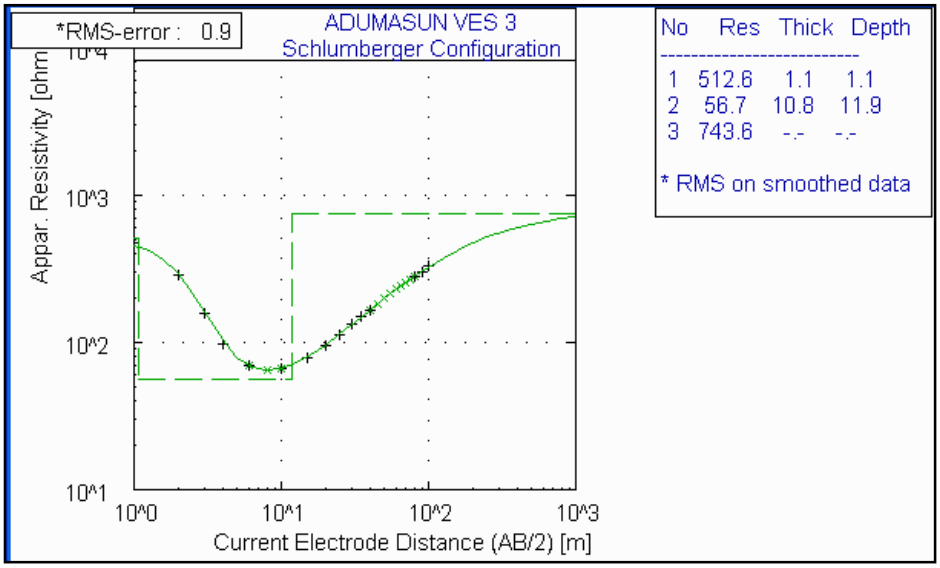

Figure 5(c): The modeled curve for VES 3.

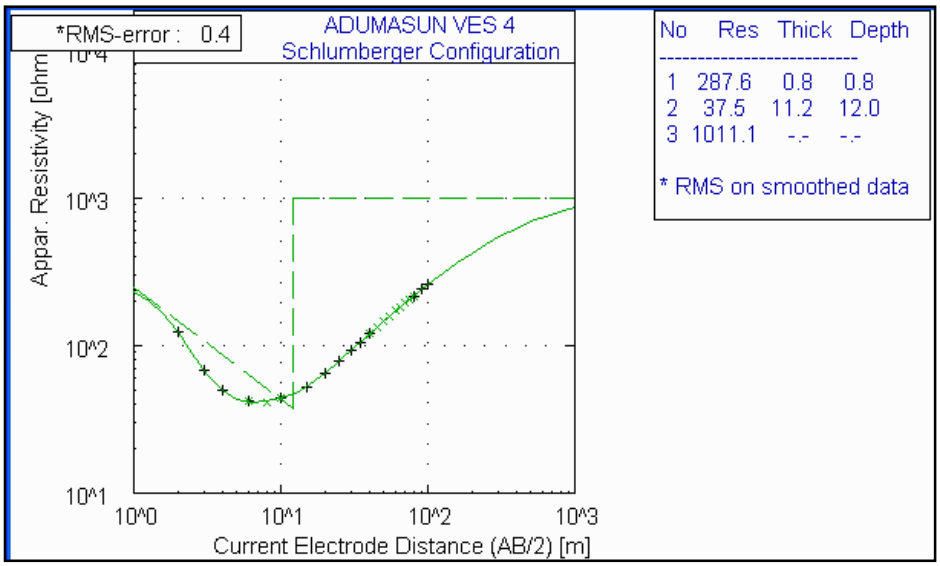

Figure 5(d): The modeled curve for VES 4.

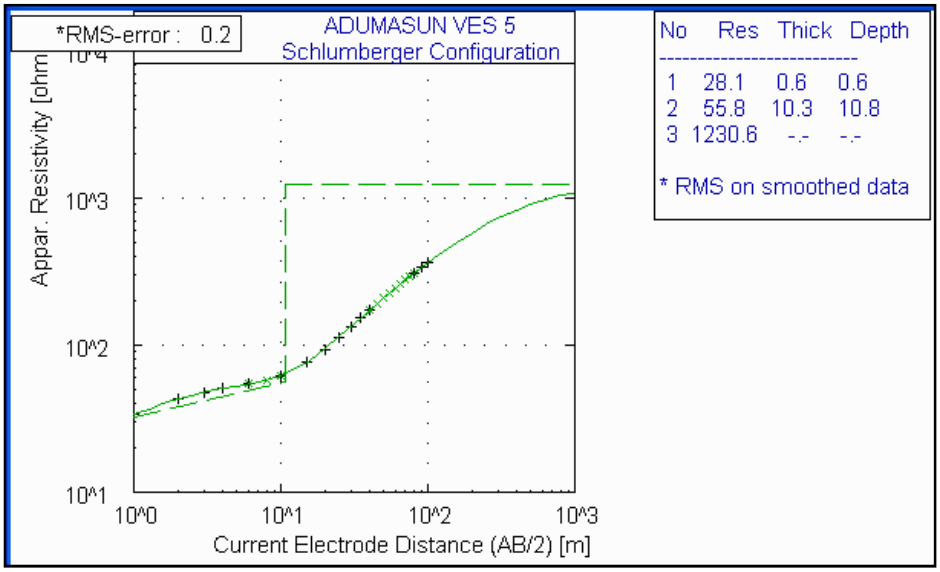

Figure 5(e): The modeled curve for VES 5.

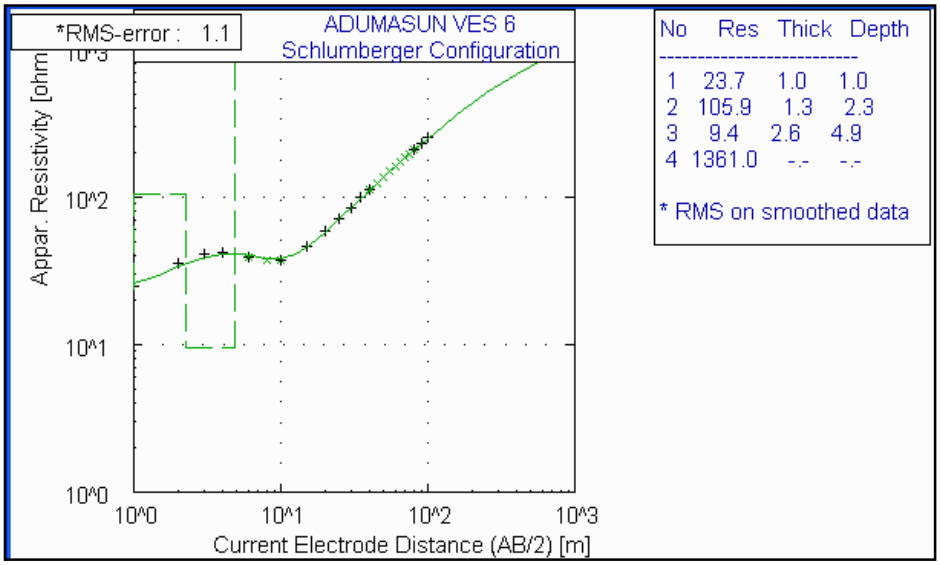

Figure 5(f): The modeled curve for VES 6.

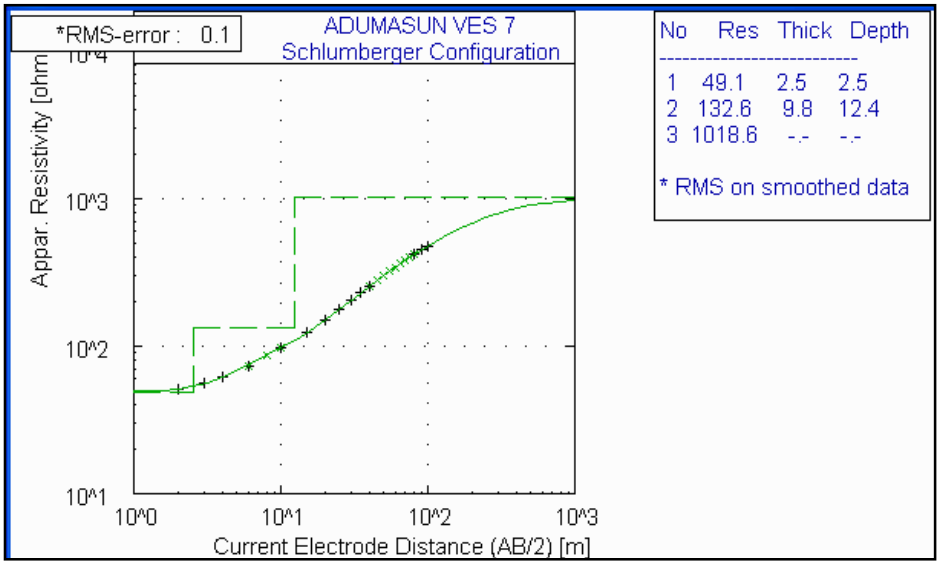

Figure 5(g): The modeled curve for VES 7.

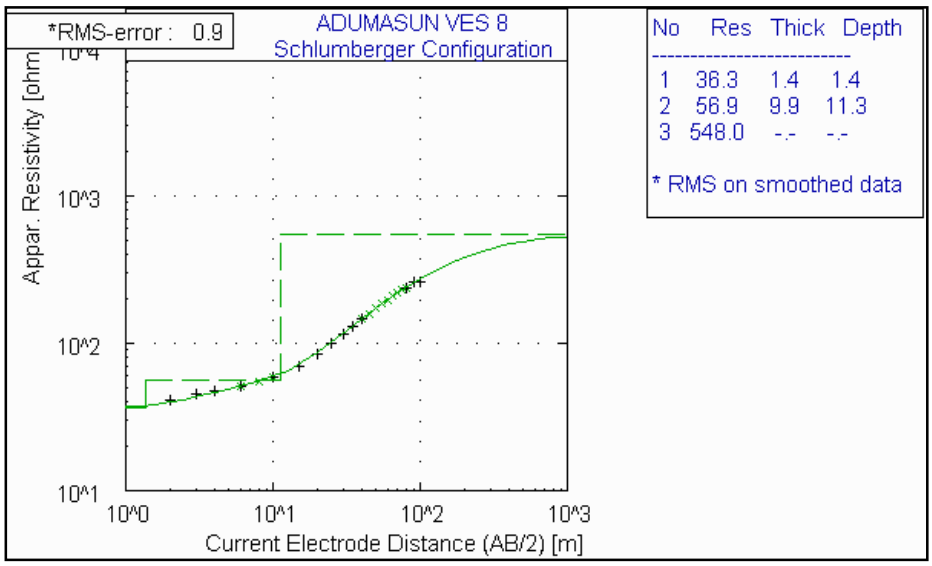

Figure 5(h): The modeled curve for VES 8.

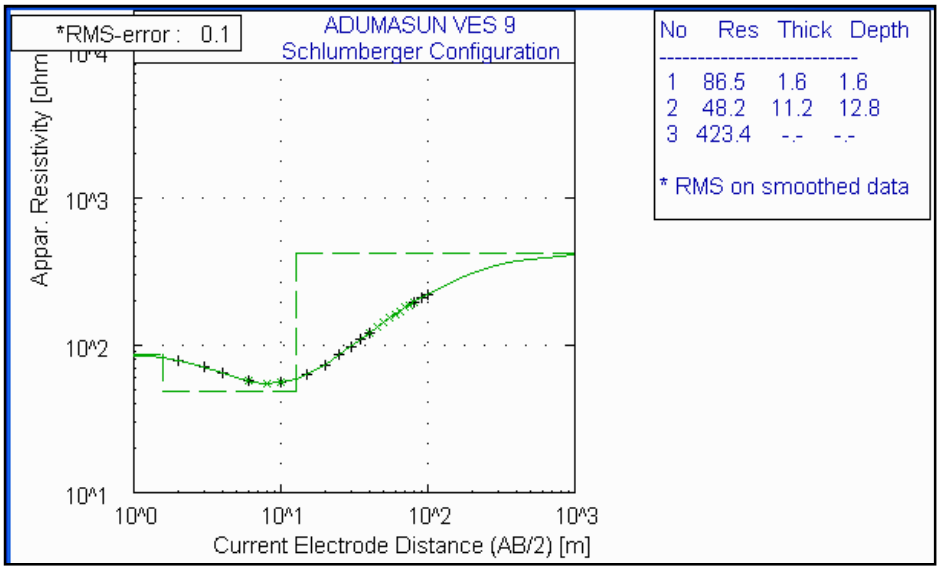

Figure 5(i): The modeled curve for VES 9.

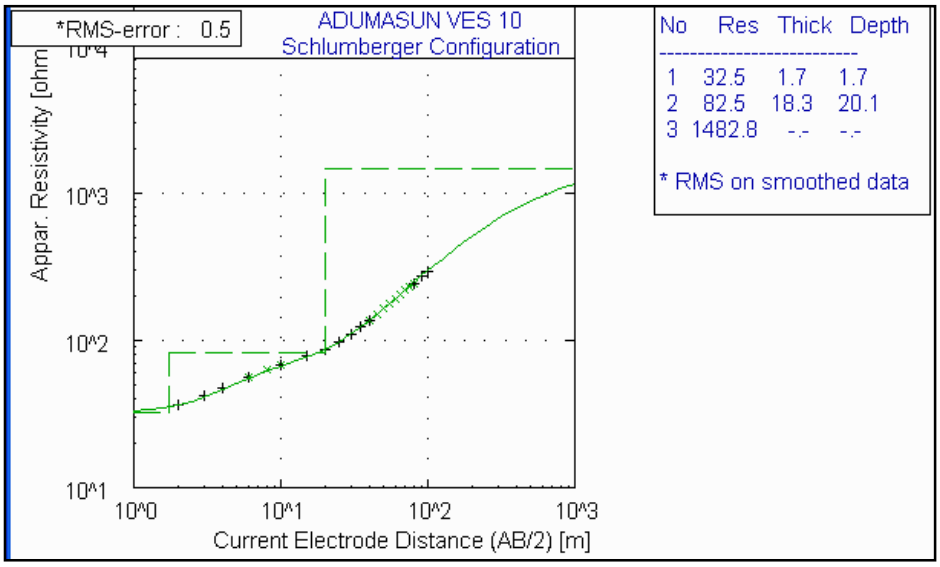

Figure 5(j): The modeled curve for VES 10.

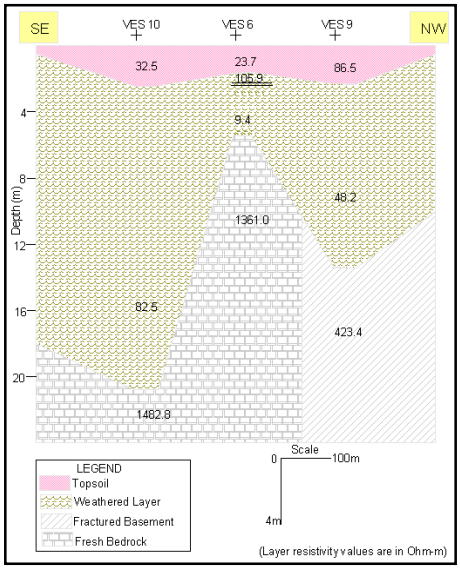

Figure 6(a): Geoelectric section along traverse A.

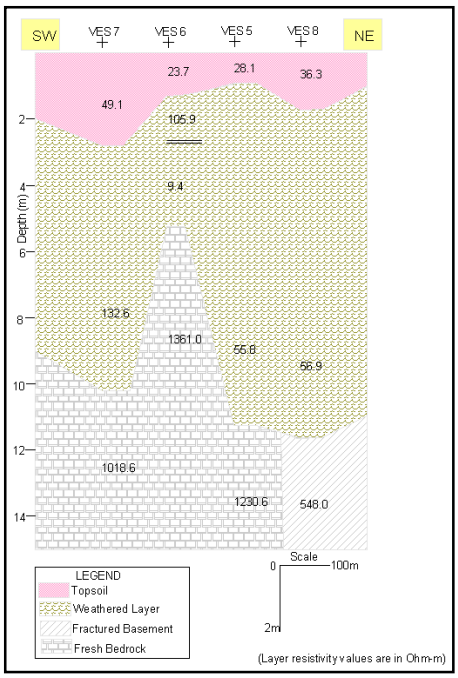

Figure 6(b): Geoelectric section along traverse B.

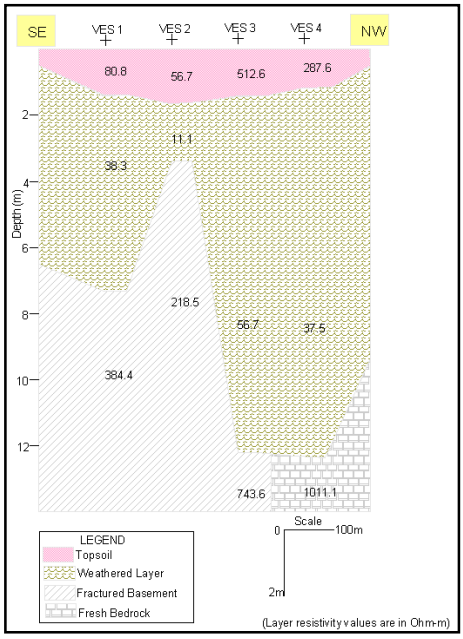

Figure 6(c): Geoelectric section along traverse C.

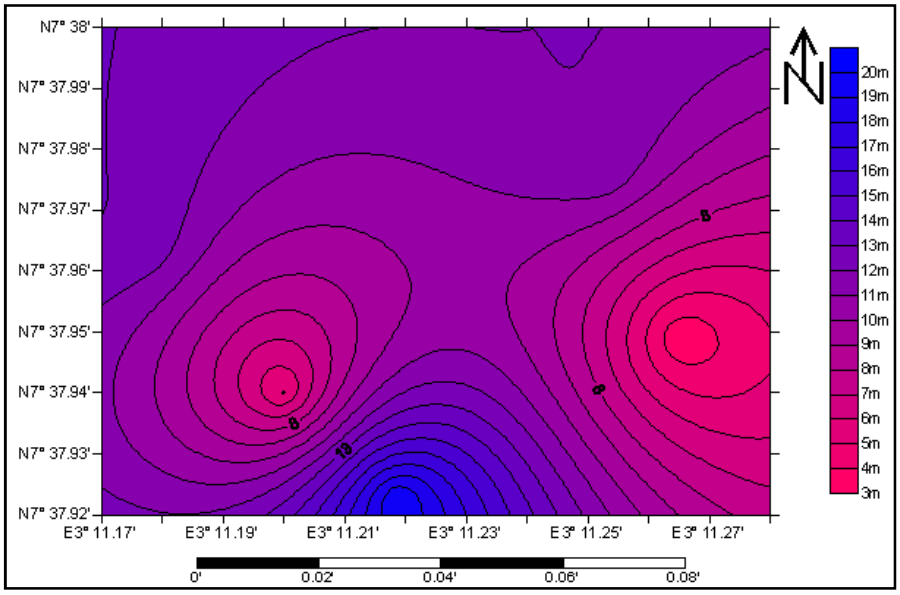

Figure 7: Contour map of thickness of unconsolidated material overlying the Basement at Adumasun.

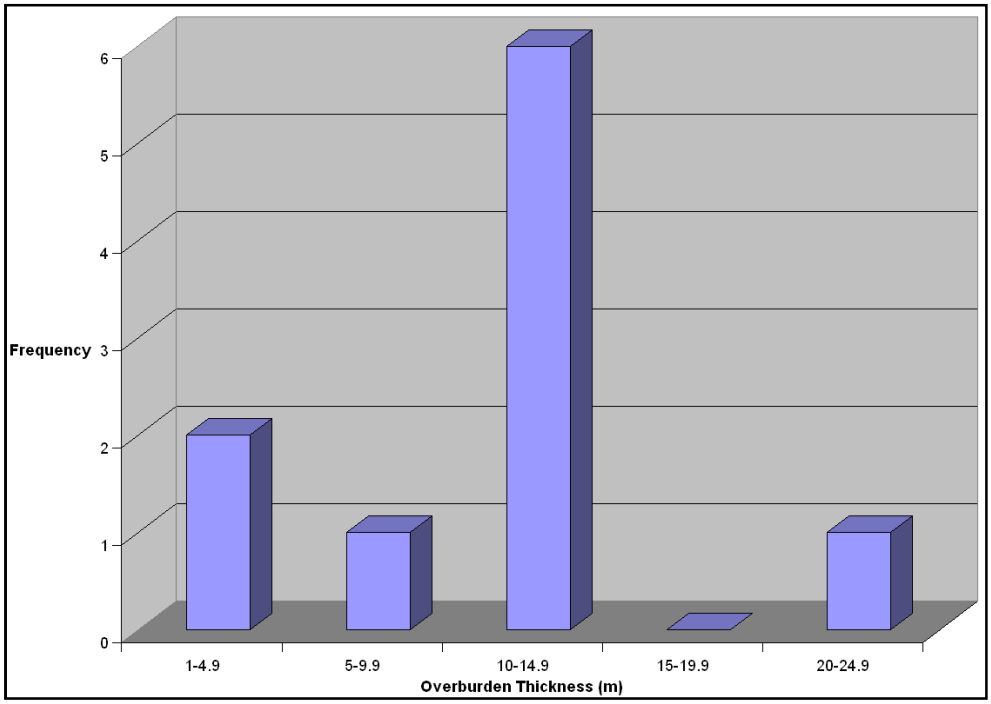

Figure 8: Distribution of thickness of unconsolidated material at Adumasun.

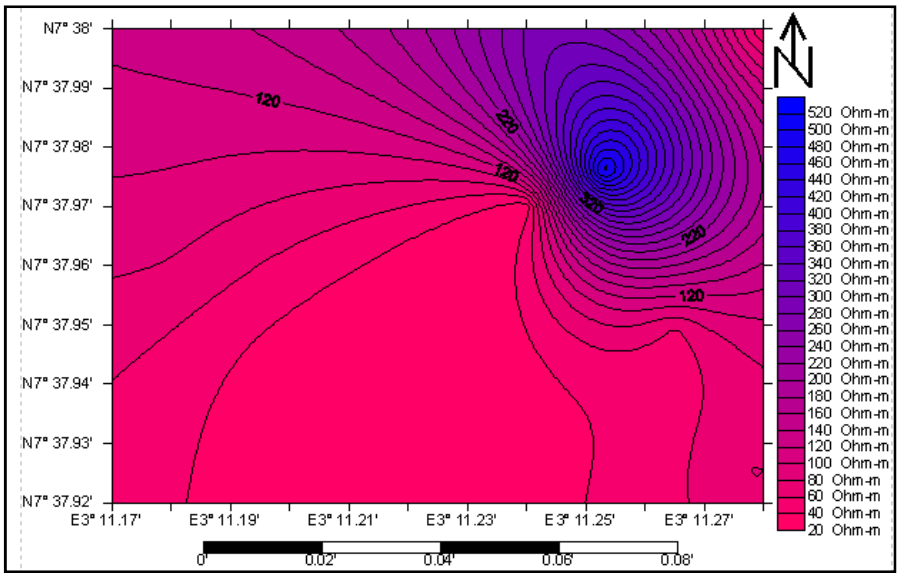

Figure 9: Contour map of resistivity distribution in the first layer at Adumasun.

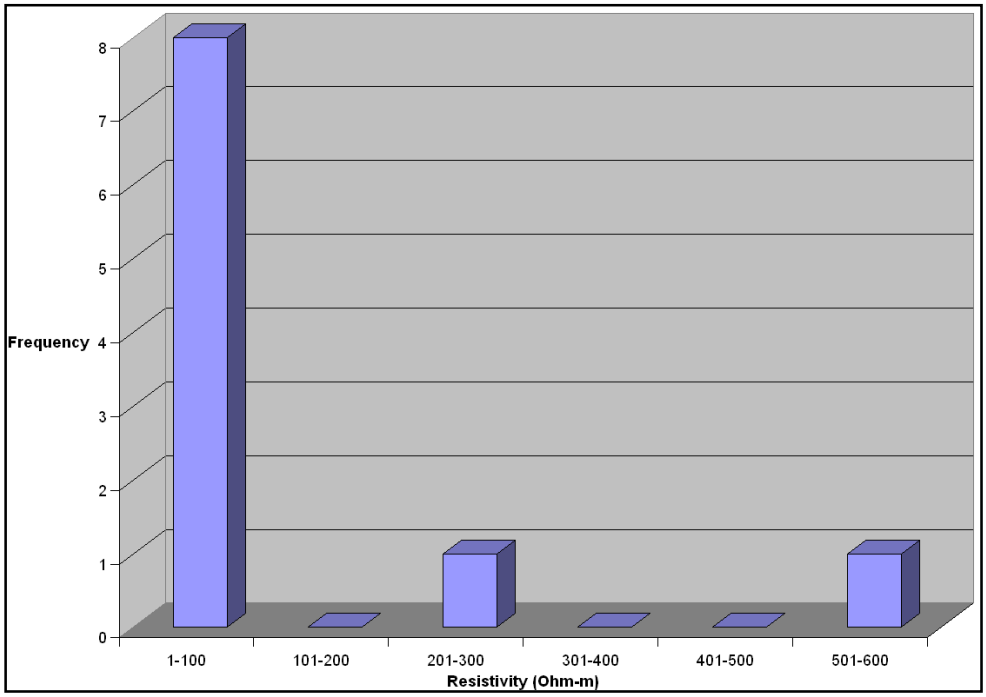

Figure 10: Distribution of resistivity in the topmost geoelectric layer at Adumasun.

Table 1: Summary of the formation of layer parameters.

Location	Layer 1		Layer 2		Layer 3		Layer 4	
	ρ_1 (Ωm)	h_1 (m)	ρ_2 (Ωm)	h_2 (m)	ρ_3 (Ωm)	h_3 (m)	ρ_4 (Ωm)	h_4 (m)
VES 1	80.8	1.1	38.3	5.9	384.4	-	-	-
VES 2	56.7	1.3	11.1	1.8	218.5	-	-	-
VES 3	512.6	1.1	56.7	10.8	743.6	-	-	-
VES 4	287.6	0.8	37.5	11.2	1011.1	-	-	-
VES 5	28.1	0.6	55.8	10.3	1230.6	-	-	-
VES 6	23.7	1.0	105.9	1.3	9.4	2.6	1361.0	-
VES 7	49.1	2.5	132.6	9.8	1018.6	-	-	-
VES 8	36.3	1.4	56.9	9.9	548.0	-	-	-
VES 9	86.5	1.6	48.2	11.2	423.4	-	-	-
VES 10	32.5	1.7	82.5	18.3	1482.8	-	-	-

Table 2: Classification of the resistivity sounding curves

Curve types	Resistivity model	Model frequency	VES Locations
A	$\rho_1 < \rho_2 < \rho_3$	4	5, 7, 8, 10
H		5	1, 2, 3, 4, 9
KH	$\rho_1 > \rho_2 < \rho_3$	1	6
Total	$\rho_1 < \rho_2 > \rho_3 < \rho_4$	10	

Table 3: Aquifer potential as a function of the weathered layer resistivity (modified after Wright, 1992).

Weathered Layer Resistivity (Ωm)		
Range	**Aquifer Characteristics**	**Weighting**
< 20	Clay with limited potential	7.5
21 - 100	Optimum weathering and good groundwater potential	10
101 - 150	Medium conditions and potential	7.5
151 - 300	Little weathering and poor potential	5
> 300	Negligible potential	2.5

CONCLUSION

The study has been able to highlight the importance of resistivity method in effective hydrogeologic assessment of aquifers and its vulnerability to near-surface contaminants that might have pave way into the aquifers. Geoelectric depth soundings around the study area revealed that the thickness of the unconsolidated materials varies from 3.1 to 20.1m, where values within 10-14.9m brackets constitute about 60%. This indicates that the unconsolidated material in the area is not significantly thick, this suggesting that the groundwater potential is averagely low.

About 80% of the resistivity values of the topmost geoelectric layer in the area fall within the range of 1-100 Ω m. Values of resistivity within these brackets suggest aquitard (silt or clay), which constitute effective, impervious geologic barriers to infiltrating near-surface contaminants. Aquifers within the unconsolidated materials at Adumasun are therefore mostly caped by impervious/semi-pervious geologic materials, suggesting that they are mostly non-vulnerable to near-surface contaminants.

Since decomposed bedrock in the crystalline basement terrain can house significant quantity of groundwater, groundwater developers in the area may explore the bedrock for bedrock aquifers, to complement the aquifers within the unconsolidated overburden. It is therefore recommended that other relevant geophysical techniques should be used at Adumasun to confirm the predictions from this study.

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