Hydrogeophysical Characterization of a Typical Basement Complex: A Case Study of Modomo/Eleweran Area Southwestern Nigeria.

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ABSTRACT

An Integrated geophysical survey involving Very Low Frequency Electromagnetic (VLF-EM) and Electrical Resistivity Surveys was conducted at Modomo/Eleweran, along Ede-road, SW Nigeria, with a view to assessing the groundwater potential of the study area. The area was underlain by the Precambrian Basement Complex rocks.

Six (6) Very Low Frequency Electromagnetic (VLF-EM) traverses were established with a station interval of 10 m for the acquisition of the VLF field data. The VLF field data were acquired using GEONICS EM-16. The Karous-Hjelt software was used to invert the real component data into 2-D pseudo-sections. Linear features presumed to be minor fractures inferred from the filtered real pseudo-sections helped in choosing twenty-nine (29) VES point that were further probed using ABEM SAS 300 C Resistivity Meter.

The convectional Schlumberger electrode configuration with half-current electrode separation (AB/2) varying from 1 m to 100 m was used for the sounding. The quantitative interpretation of the VES data was done by partial curve matching technique. The VES data were presented as depth sounding curves and were appropriately iterated software using RESIST version (1.0). The interpreted results (geoelectric parameters) were used to generate the geoelectric sections and contour maps for the study area.

The VLF filtered real profile displayed peak values of less than 18% indicating poor fracture index. Based on the geoelectric sections generated, four subsurface geologic layers were delineated. These included the topsoil, weathered layer (comprises of clay/sandy clay and laterite), partly weathered/fractured basement and fresh bedrock. The delineated weathered and fractured basement columns constituted the aquifer units. The depth to the bedrock across the study area varies between 1.1 m and 16.3 m. The VES curve types were diagnostic of three different aquifer types. The weathered layer aquifers were characterized by H, A, KH, AA, and AAA curve types. The weathered/fractured (unconfined) aquifers are characterized by HA and KHA curve types. The weathered/fractured (confined) aquifers are characterized by HKH type curve. The electrical anisotropy coefficient map displayed values ranging from 1.0 m to 2.3 m. The values were higher at the northeastern and southern part of the study area.

The study concluded that based on the thin overburden thickness, clayey weathered layer and low fractured frequency, the groundwater potential of the study area is generally low.

(Keywords: hydrogeophysical, aquifer, groundwater potential, zonation, electrical resistivity, reservoirs, electromagnetic)

INTRODUCTION

The rates of borehole failures in the country have been on the increase in recent times (Eduvie, 2006). This is to the large extent due to improper pre-drilling geophysical investigation. However, groundwater development can be achieved by having a full understanding of the hydrogeophysical setting of the area. The rapid rate of development in Modomo/Eleweran, the study area; due to its proximity to the Obafemi Awolowo University (OAU) Campus has resulted in an increased demand for groundwater. Many boreholes sunk in Modomo/Eleweran area have failed. Hence, delineation of aquifer for groundwater development in the area becomes inevitable. Integrated geophysical prospecting methods have been used successfully in premises of the Conference centre, Obafemi Awolowo University (OAU) for groundwater development (Afolayan et. al, 2004).

This study involves the application of Very low Frequency Electromagnetic Method (VLF-EM) and geoelectric survey using vertical electrical sounding for groundwater development of the study area. The major objective is to evaluate the groundwater potential of the area.

The electromagnetic (VLF) method has found useful application in groundwater investigation in basement complex terrain, most especially as a reconnaissance tool (Olorunfemi et. al, 1995). In other words, results have shown that VLF - EM is a fast tool/technique in determination of subsurface features/fissures/faults and fracture zones in a complex basement terrain. The electrical resistivity method on the other hand measures the physical properties of rocks and soil which is largely determine by the presence of fluid therein.

Location Description

The study area is Modomo/Eleweran, area in Ile-Ife. The area has an areal extent of 0.52 km^2 and is located between Latitudes 7^{o} $30^{'}$ $30^{"}$ N and 7^{o} $30^{'}$ 5” N and Longitudes 4^{o} $29^{'}$ $10^{"}$ E and 4^{o} $29^{'}$ $35^{"}$ E. The study area is accessible through a dirt road emanating from a left flank of Ife-Ede road (Figure 1).

Geomorphology and Geology of the Study Area

The study area is underlain by the Precambrian Basement Complex rocks of southwestern Nigeria (Rahaman, 1976 and Nuhu, 2009). The main geological unit in the area is the dark, greenish grey granite-gneiss and pegmatite veins. The granite-gneiss rock belongs to the Migmatite-gneiss complex which constitutes one of the major rock units of the Precambrian Basement of the southwestern Nigeria (Nuhu, 2009) (Figure 2).

The topography of the study area consists of a gentle plain with a topographic elevation of less than 300m above sea level.

In a typical basement complex terrain, groundwater is confined within weathered layer and or fractured/jointed or sheared basement columns (Afolayan et. al, 2004). Groundwater development in such a geological area is a function of the weathered layer thickness, its clay content and the magnitude of fractures.

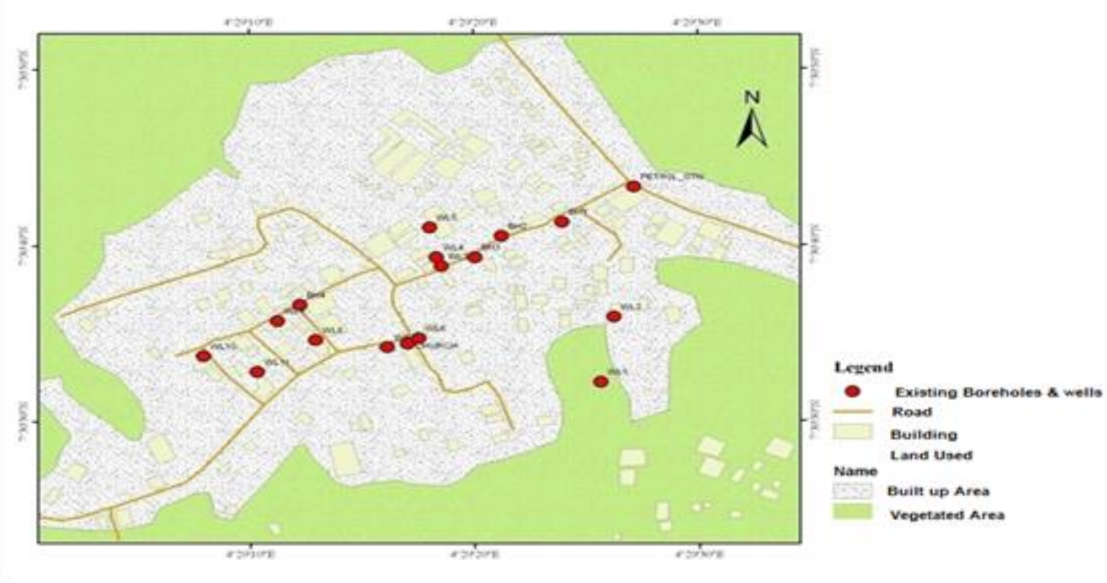


Figure 1: Base Map of Study Area.

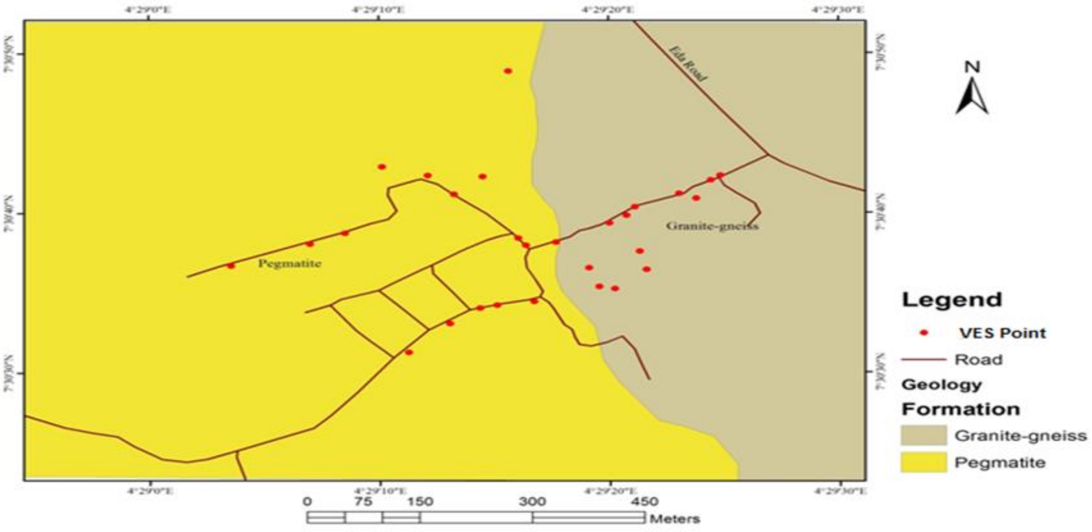


Figure 2: Geological Map of the Study Area.

MATERIALS AND METHODS

Six traverses (with profile lengths ranging from 130 m to 360 m) in the NE-SW, NW-SE, SE- NW, NE-SW, NE-SW, and NW-SE directions were established evenly throughout the study area to cover the whole study area, the length of which was dependent on accessibility (Figure 3). VLF measurements were taken at an interval of ten meters (10 m) using the GEONICS EM-16 equipment to effectively monitor the subsurface. Traverses were located perpendicular to strike direction so that the anomalous zones can be compared to background levels. The VLF-EM data (filtered real and raw real) are presented as pseudosections and interpreted qualitatively. The results of the VLF-EM field measurements helped in the choice of locations of vertical electrical soundings in the study area.

Twenty-nine (29) Vertical Electrical Sounding (VES) points were probed on the area using conventional schlumberger configuration with electrode spacings (AB/2) varying from 1.0 m to 100 m along the traverses. Field measurements were acquired with ABEM Signal Averaging System (SAS) 300 C Terrameter. The VES curves obtained were interpreted using partial curve matching technique. The geoelectrical parameters obtained were refined using the software algorithm RESIST version 1.0 (Velpen, 1988). The iterated geoelectrical parameters obtained (Table 1) were used to generate geoelectric sections and contour maps for the area.

RESULTS AND DISCUSSION

The plot of raw real measured along the traverses and the filtered real are presented as profiles (Figures 4a - 9a) while their corresponding pseudo-sections were shown in (Figures 4b - 9b) respectively.

The VLF filtered real profiles displayed peak values of less than 18% indicating poor fracture index. The positive peak zones are probable fissured basement while negative trough zones are probable aeration areas. The positive peaks thus identified were further investigated by Vertical Electrical Sounding. The results of the electrical resistivity data were presented as sounding curves (Figures 10a – 10d).

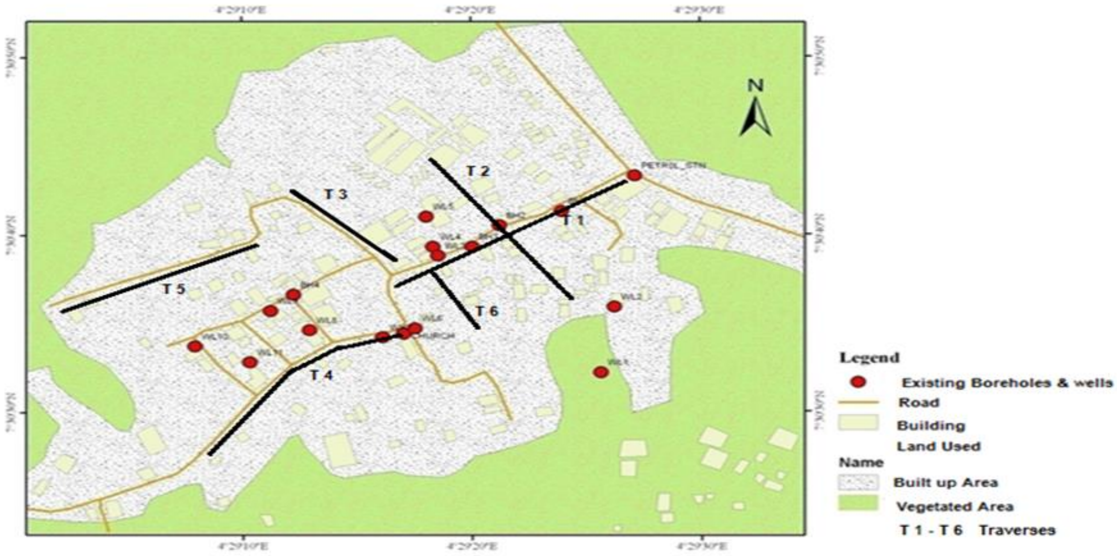


Figure 3: Map Showing the Spatial Distribution of the VLF-EM Traverses.

Eight (8) VES type curves were identified in the study area. The VES curve types revealed four geo-electric layers which consist of the topsoil, weathered layer (clay/sandy clay/laterite), partly weathered/fractured basement and fresh basement as can be seen in the geo-electric sections (Figures 11a – 11f). The study area is also characterized by topsoil resistivity values which range between 53 ohm-m and 697 ohm-m. The weathered layer resistivities range between 29 ohm-m and 243 ohm-m while the resistivity values of the fresh basement range between 225 ohm-m and 16527 ohm-m.

The characteristic geo-electric parameters at each sounding station were used to produce the isopach and isoresistivity map of the weathered layer, isopach map of the overburden, bedrock relief map and coefficient of anisotropy map.

The isopach and isoresistivity maps of the weathered layer (Figures 12 and 13) respectively revealed that the thickness and apparent resistivity values range from 0.4 m to 16.3 m and 29 ohm-m to 243 ohm-m respectively. The isopach map of the overburden (Figure 14) depicted marked resemblance to that of the weathered layer with respect to thickest and thinnest portions.

The thickest and thinnest portions of the weathered layer and the overburden correspond to the depression (D_1 – D_3) and the ridges (R_1 – R_3) respectively on the bedrock relief map which also depicted the direction of groundwater flow (Figure 15). The coefficient of anisotropy map shows the Northeastern and Southern portion to be highly fractured (Figure 16).

Three groups of resistivity type curves were delineated in the study area. The curves are diagnostic of three different aquifer types (Table 2). The weathered layer aquifer are characterized by H, A, KH, AA, AAA curve types. The weathered/fractured (confined) aquifers are characterized by HKH curve type. The partly weathered/fractured (unconfined) aquifers are characterized by HA and KHA curve types.

Since, the overburden thickness of the study area is thin; localities with moderately high overburden thicknesses are probable groundwater potential zones provided the aquifer units are not clayey.

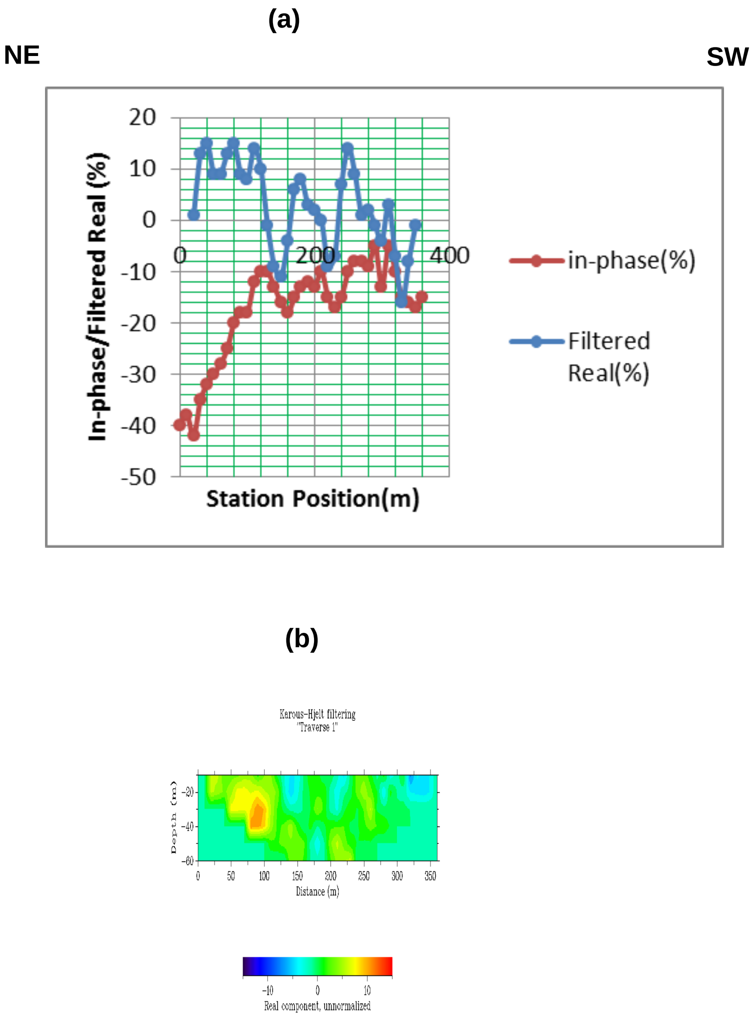


Figure 4: VLF Profiles (a) Real and Filtered Real Components (b) Karous-Hjelt Section along Traverse 1

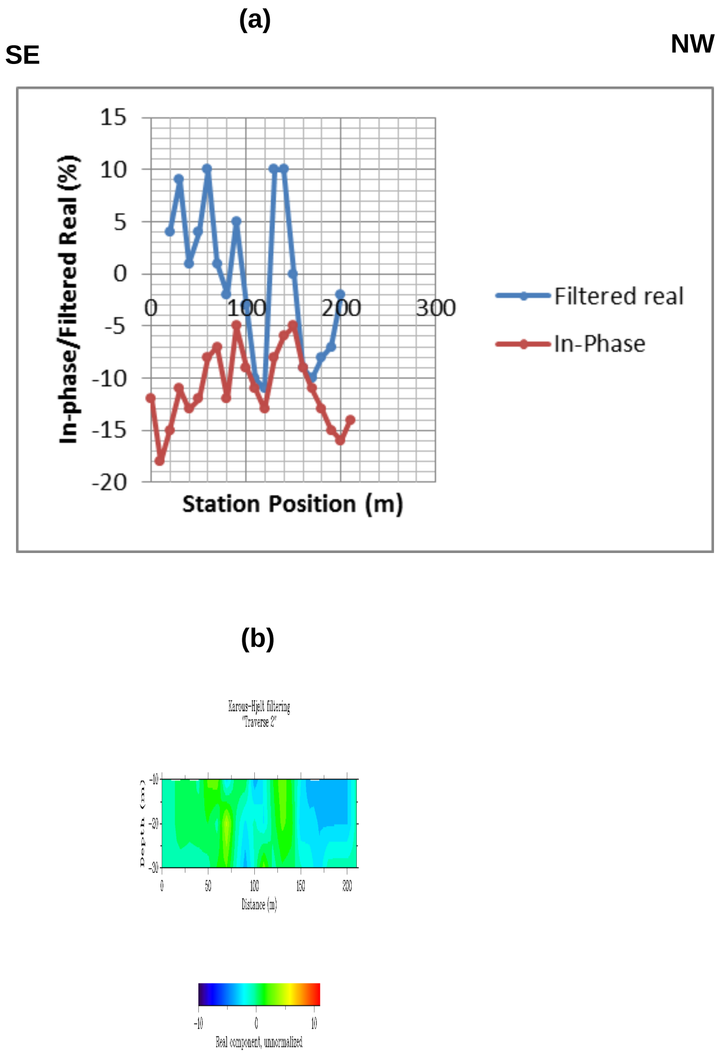


Figure 5: VLF Profiles (a) Real and Filtered Real Components (b) Karous-Hjelt Section along Traverse 2

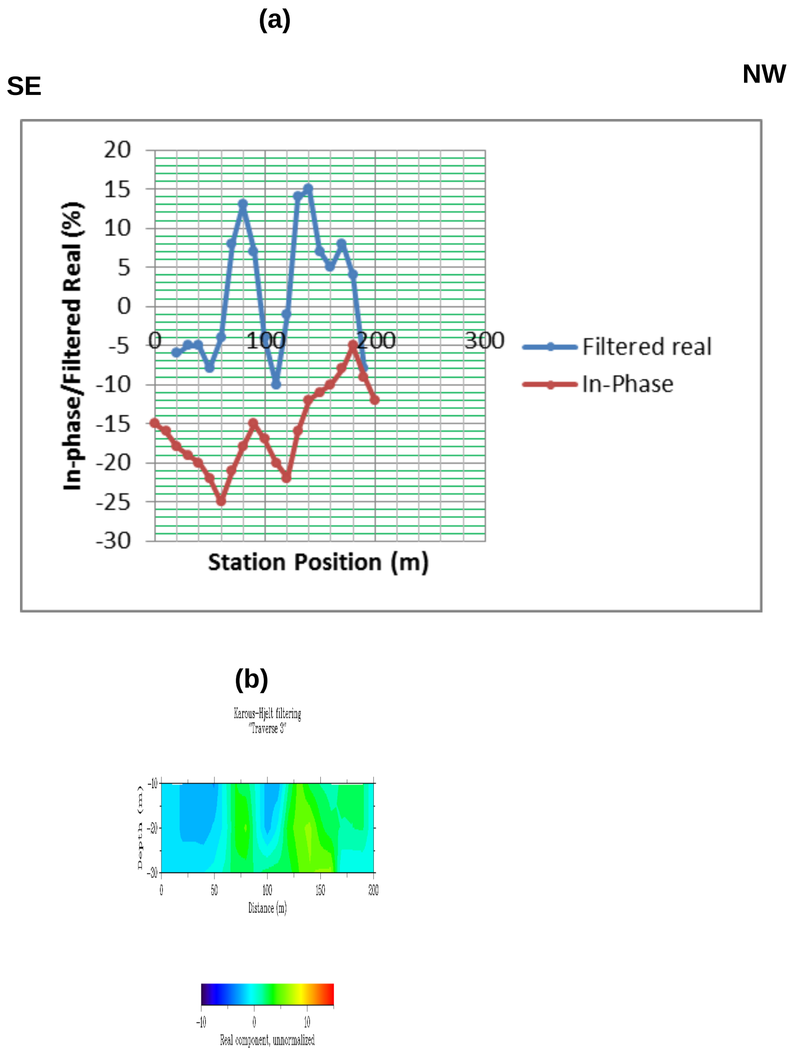


Figure 6: VLF Profiles (a) Real and Filtered Real Components (b) Karous-Hjelt Section along Traverse 3

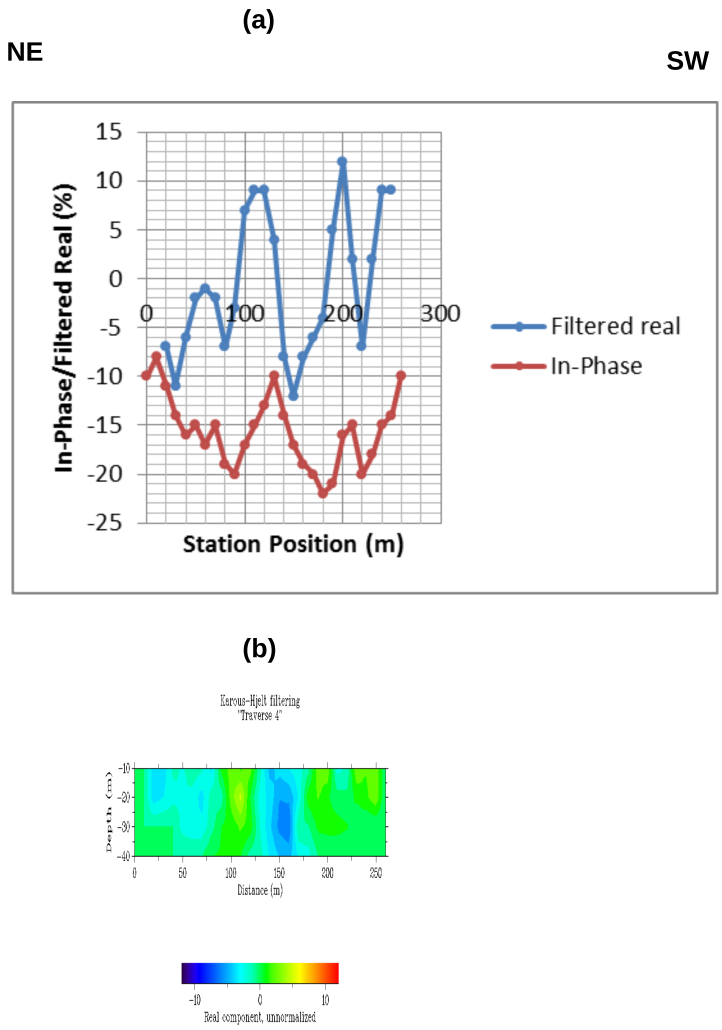


Figure 7: VLF Profiles (a) Real and Filtered Real Components (b) Karous-Hjelt Section along Traverse 4

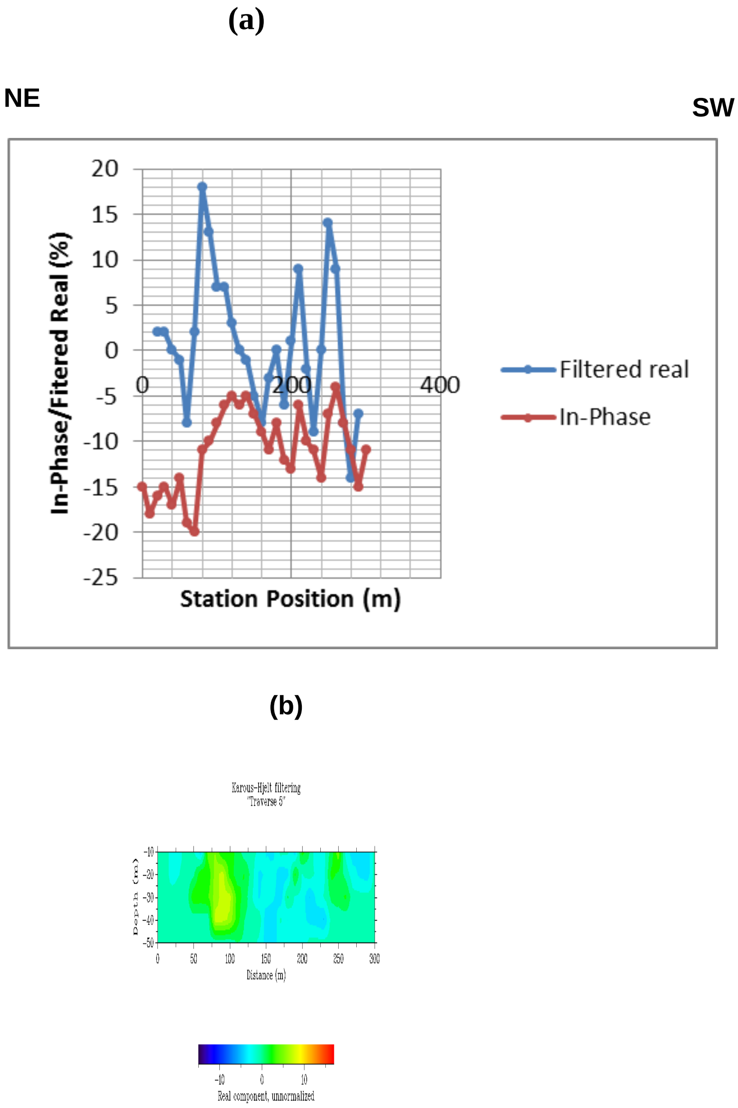


Figure 8: VLF Profiles (a) Real and Filtered Real Components (b) Karous-Hjelt Section along Traverse 5

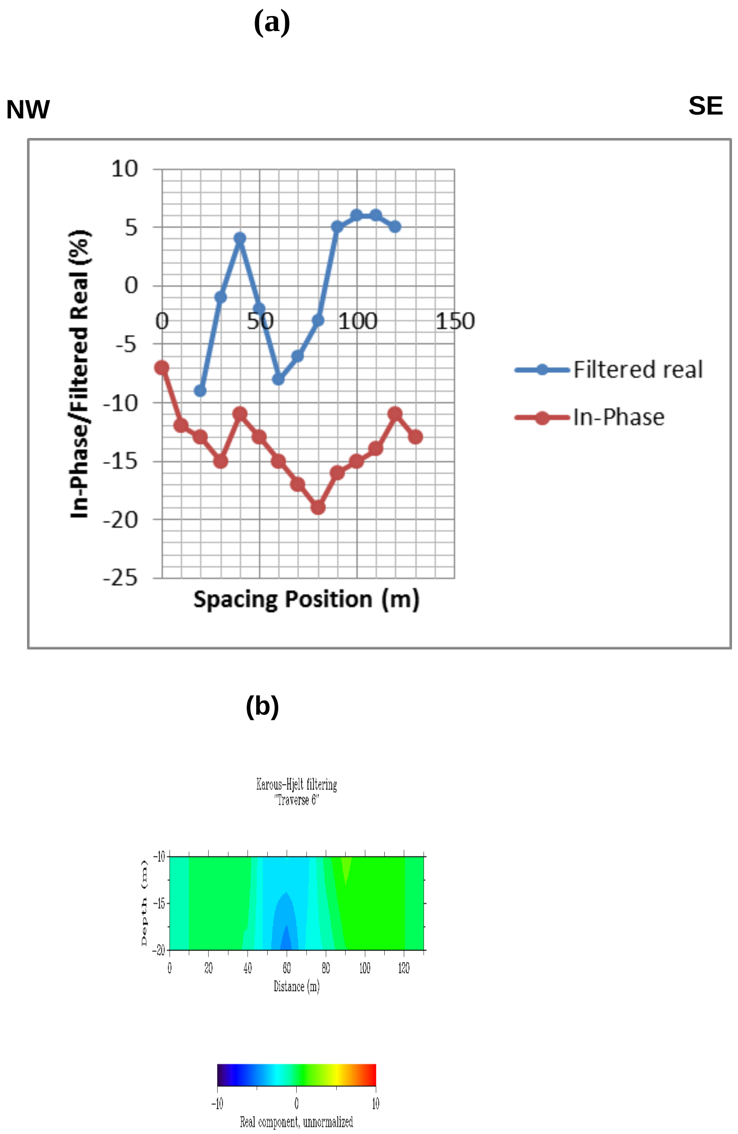
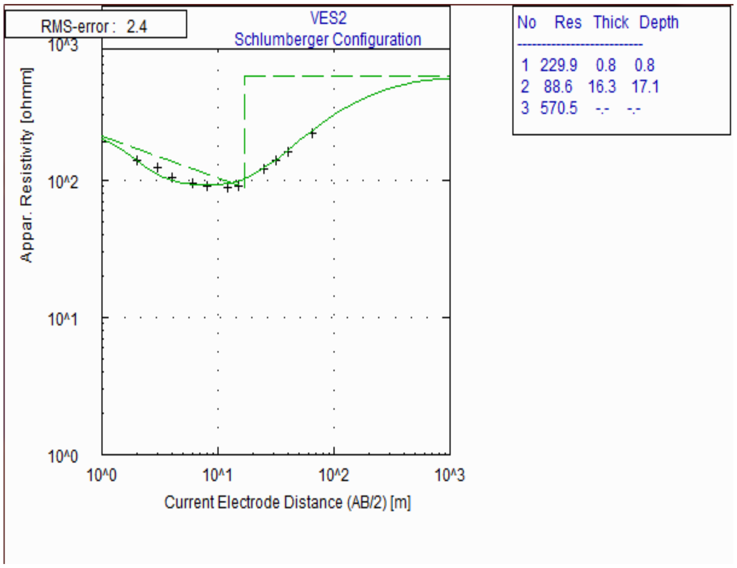
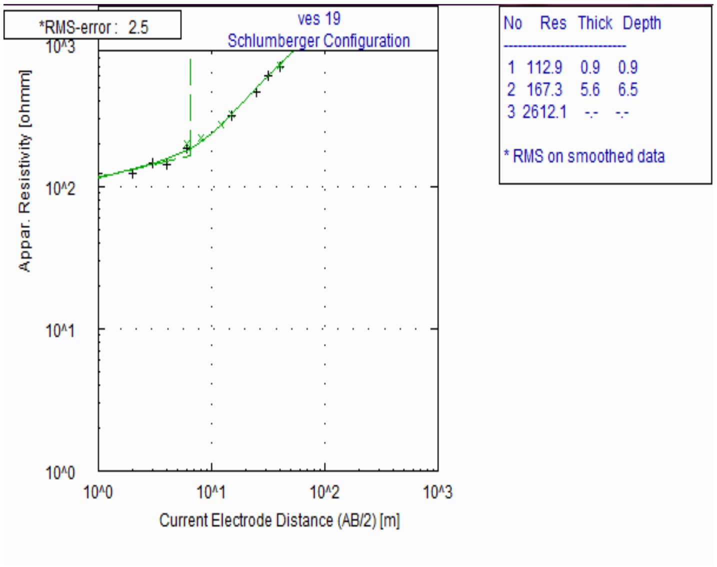


Figure 9: VLF Profiles (a) Real and Filtered Real Components (b) Karous-Hjelt Section along Traverse 6



No	Res	Thick	Depth
1	229.9	0.8	0.8
2	88.6	16.3	17.1
3	570.5	-.-	-.-

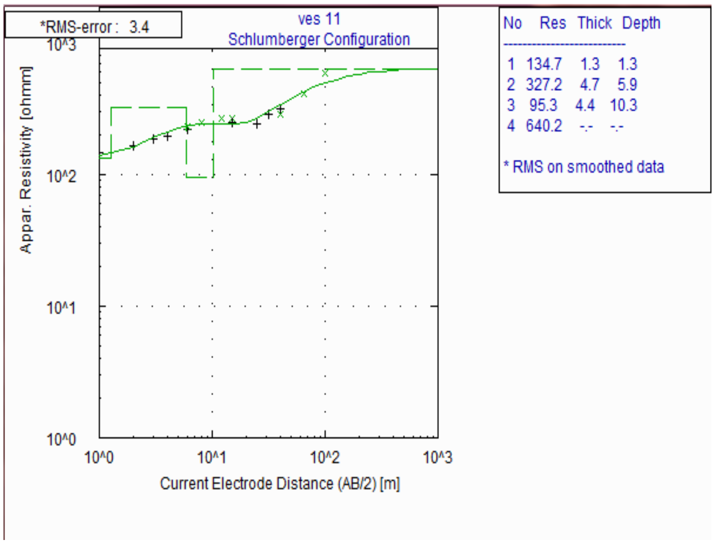
Figure 10 a: Typical Observed H-Type (3-Layered) Curve



No	Res	Thick	Depth
1	112.9	0.9	0.9
2	167.3	5.6	6.5
3	2612.1	-.-	-.-

* RMS on smoothed data

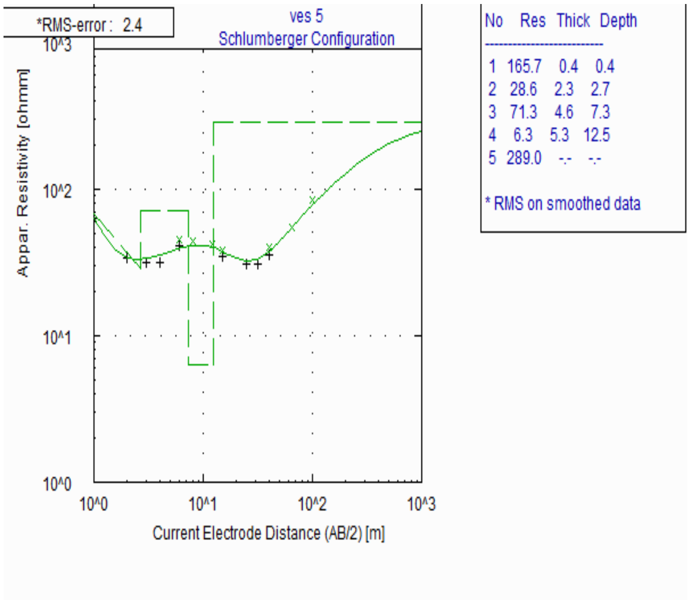
Figure 10 b: Typical Observed A-Type (3-Layered) Curve



No	Res	Thick	Depth
1	134.7	1.3	1.3
2	327.2	4.7	5.9
3	95.3	4.4	10.3
4	640.2	-.-	-.-

* RMS on smoothed data

Figure 10 c: Typical Observed KH-Type (4-Layered) Curve



No	Res	Thick	Depth
1	165.7	0.4	0.4
2	28.6	2.3	2.7
3	71.3	4.6	7.3
4	6.3	5.3	12.5
5	289.0	-.-	-.-

* RMS on smoothed data

Figure 10 d: Typical Observed HKH-Type (5-Layered) Curve

Table 1: Summary of VES Interpreted Results of the Study Area.

VES Stations	Layers	Resistivity (Ohm-m)	Thickness (m)	Overburden Thickness (m)	Curve Types	Inferred Litho-strata
1	1	200	0.5			Topsoil (Sandy clay)
	2	57	0.9	1.4		Weathered layer (Clay)
	3	161	4.2			Partly weathered basement
	4	68	6.7			Fractured Basement
	5	6305	∞		HKH	Fresh Basement
2	1	230	0.8			Topsoil (Sandy clay)
	2	89	16.3	17.1		Weathered layer (Clay)
	3	571	∞		H	Basement Bedrock
3	1	313	0.5			Topsoil (Clayed sand)
	2	146	6.6	7.1		Weathered layer (Sandy clay)
	3	246	∞		H	Basement Bedrock
4	1	130	0.5			Topsoil (Sandy clay)
	2	70	9.5	10		Weathered layer (Clay)
	3	225	∞		H	Basement Bedrock
5	1	166	0.4			Topsoil (Sandy clay)
	2	29	2.3	2.7		Weathered layer (Clay)
	3	71	4.6			Partly Weathered Basement
	4	6	5.3			Fractured Basement
	5	289	∞		HKH	Basement Bedrock
6	1	69	0.8			Topsoil (Clay)
	2	137	1.0			Lateritic clay
	3	63	8.1	9.9		Weathered Basement
	4	13594	∞		KH	Fresh Basement
7	1	78	0.7			Topsoil (Clay)
	2	176	1.8	2.5		Weathered layer (Sandy clay)
	3	285	10.4			Partly weathered basement
	4	16527	∞		AA	Fresh Basement
8	1	66	1.4	1.4		Topsoil (Clay)
	2	243	11.3			Partly Weathered layer
	3	3681	∞		A	Fresh Basement
9	1	58	0.9			Topsoil (Clay)
	2	83	0.4	1.3		Weathered layer (Clay)
	3	343	7.1			Partly Weathered basement
	4	597	7.5			Partly Weathered basement
	5	1438	∞		AAA	Fresh Basement
10	1	312	0.4			Topsoil (Clayey sand)
	2	130	10.4	10.8		Weathered layer (Sandy clay)
	3	1665	∞		H	Fresh Basement
11	1	135	1.3			Topsoil (Sandy clay)
	2	327	4.7			Weathered layer (Laterite)
	3	95	4.4	10.4		Weathered Basement
	4	640	∞		KH	Basement Bedrock
12	1	410	0.7			Topsoil (Laterite)
	2	110	6.2	6.9		Weathered layer (Sandy clay)
	3	2762	∞		H	Fresh Basement
13	1	85	0.9			Topsoil (Clay)
	2	245	4.3			Weathered layer (Laterite)
	3	82	6	11.2		Weathered Basement
	4	2260	∞		KH	Fresh Basement

14	1	199	0.9			Topsoil (Sandy clay)
	2	671	4.7			Weathered layer (Laterite)
	3	94	8.4	14.0		Weathered Basement
	4	6098	∞		KH	Fresh Basement
15	1	181	0.5			Topsoil (Sandy clay)
	2	72	1.2	1.7		Weathered layer (Clay)
	3	167	11.1			Partly Weathered Basement
	4	1465	∞		HA	Fresh Basement
16	1	697	0.4			Topsoil (Laterite)
	2	239	2.1	2.5		Weathered layer (Sandy clay)
	3	737	9.5			Partly Weathered Basement
	4	5269	∞		HA	Fresh Basement
17	1	100	1.1	1.1		Topsoil (Clay)
	2	1006	5.3			Partly Weathered/ Fresh Basement
	3	2631	∞		A	Fresh Basement
18	1	206	0.6			Topsoil (Sandy clay)
	2	169	4.3	4.9		Weathered layer (Sandy clay)
	3	1247	∞		H	Fresh Basement
19	1	113	0.9			Topsoil (Sandy clay)
	2	167	5.6	6.5		Weathered layer (Sandy clay)
	3	2612	∞		A	Fresh Basement
20	1	53	0.6			Topsoil (Clay)
	2	472	0.7			Weathered layer (Laterite)
	3	29	5	6.3		Weathered Basement
	4	608	6.1			Partly Weathered Basement
	5	1165	∞		KHA	Fresh Basement
21	1	76	0.7			Topsoil (Clay)
	2	74	3.7	4.4		Weathered layer (Clay)
	3	3190	∞		H	Fresh Basement
22	1	139	0.8			Topsoil (Sandy clay)
	2	157	2	2.8		Weathered layer (Sandy clay)
	3	1015	∞		A	Fresh Basement
23	1	206	0.6			Topsoil (Sandy clay)
	2	104	2.4	3.0		Weathered layer (Sandy clay)
	3	414	2.3			Partly Weathered Basement
	4	673	∞		HA	Fresh Basement
24	1	300	0.6			Topsoil (Clayey sand)
	2	84	1.4	2.0		Weathered layer (Clay)
	3	348	11.5			Partly Weathered Basement
	4	891	∞		HA	Fractured Basement
25	1	162	0.9			Topsoil (Sandy clay)
	2	66	1.1	2.0		Weathered layer (Clay)
	3	360	11.8			Partly Weathered Basement
	4	2853	∞		HA	Fresh Basement
26	1	460	0.8			Topsoil (Laterite)
	2	477	4			Weathered layer (Laterite)
	3	39	1.2	6		Weathered Basement
	4	4449	∞		KH	Fresh Basement
27	1	149	0.4			Topsoil (Sandy clay)
	2	91	2.1	2.5		Weathered layer (Clay)
	3	200	5.4			Partly Weathered Basement
	4	6759	∞		HA	Fresh Basement

28	1	131	0.9			Topsoil (Sandy clay)
	2	161	4.0	4.9		Weathered layer (Sandy clay)
	3	836	∞		A	Basement Bedrock
29	1	220	0.4			Topsoil (Sandy clay)
	2	169	4.3	4.7		Weathered layer (Sandy clay)
	3	7135	∞		A	Fresh Basement

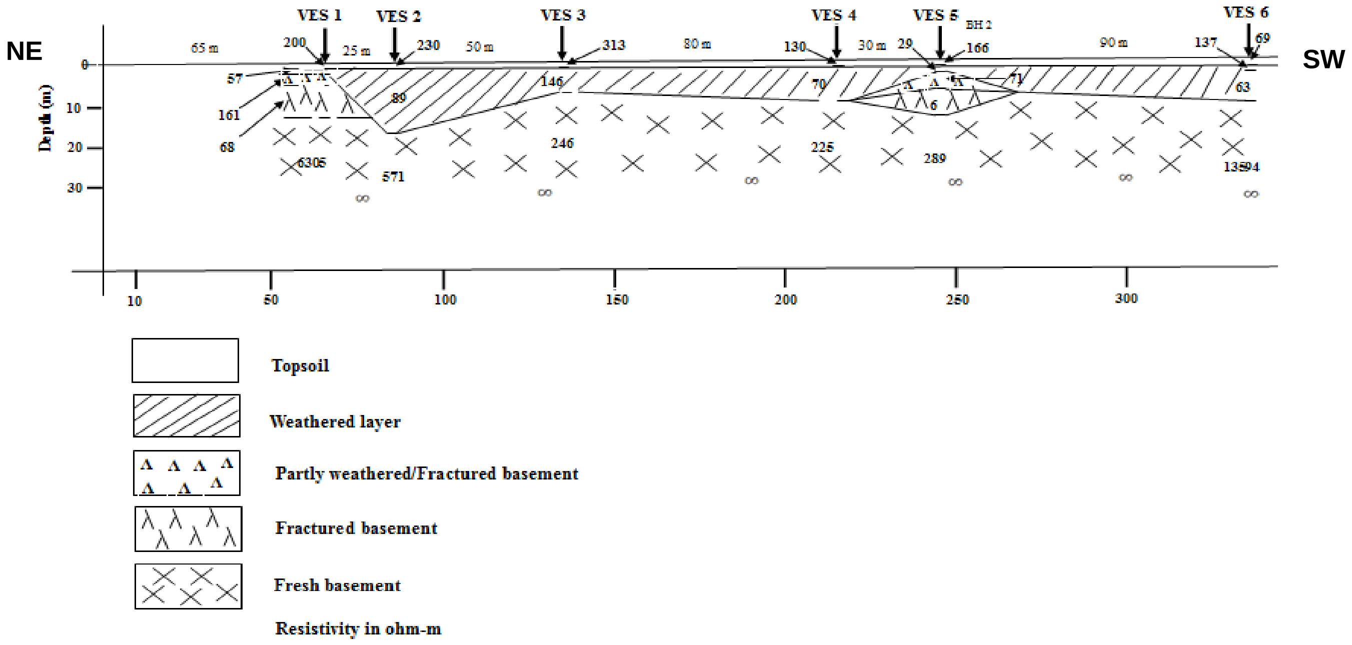


Figure 11 a: 2 - D Geoelectric Section along Traverse 1.

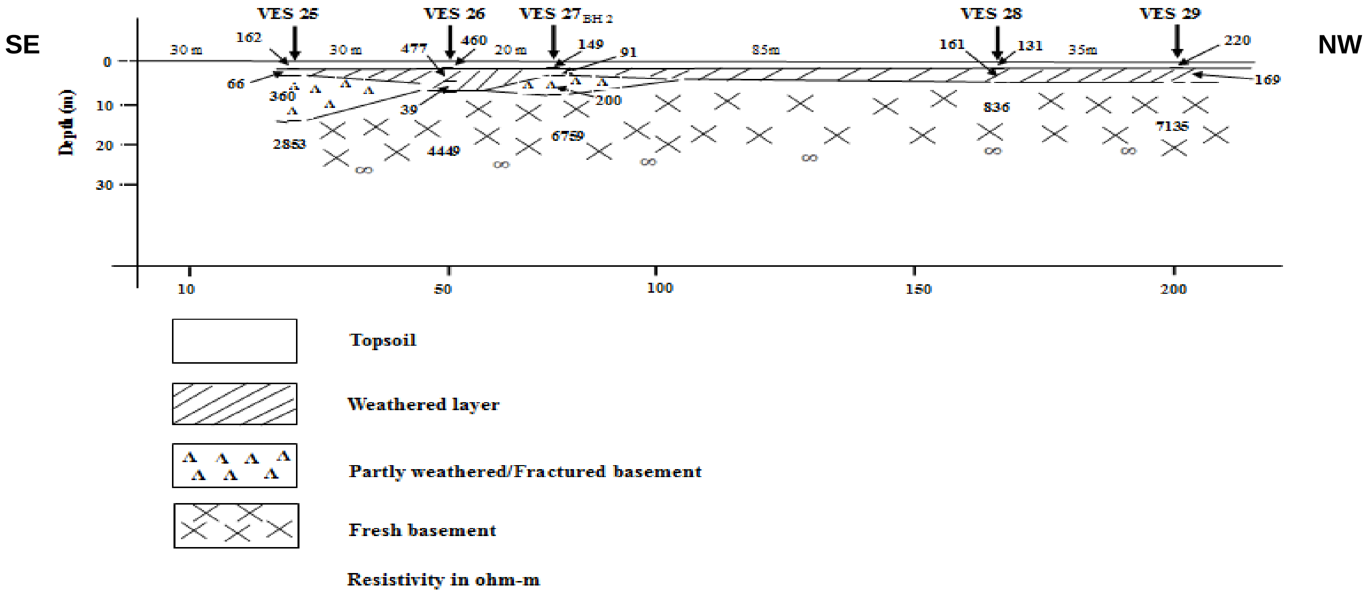


Figure 11 b: 2 - D Geoelectric Section along Traverse 2.

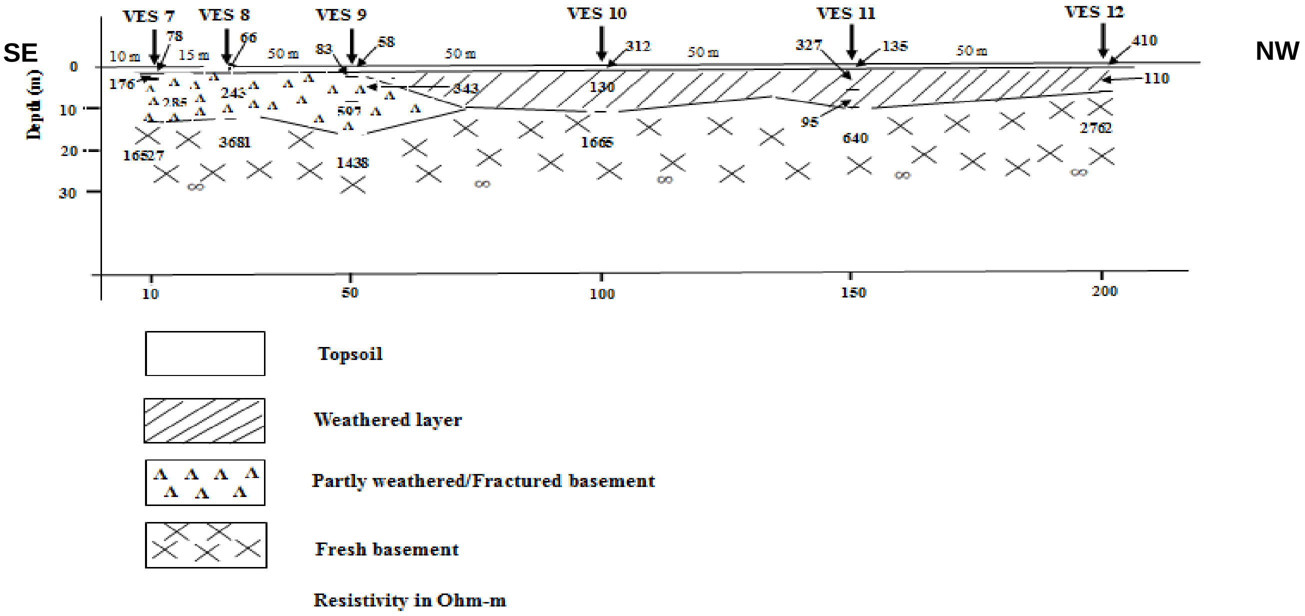


Figure 11 c: 2 - D Geoelectric Section along Traverse 3.

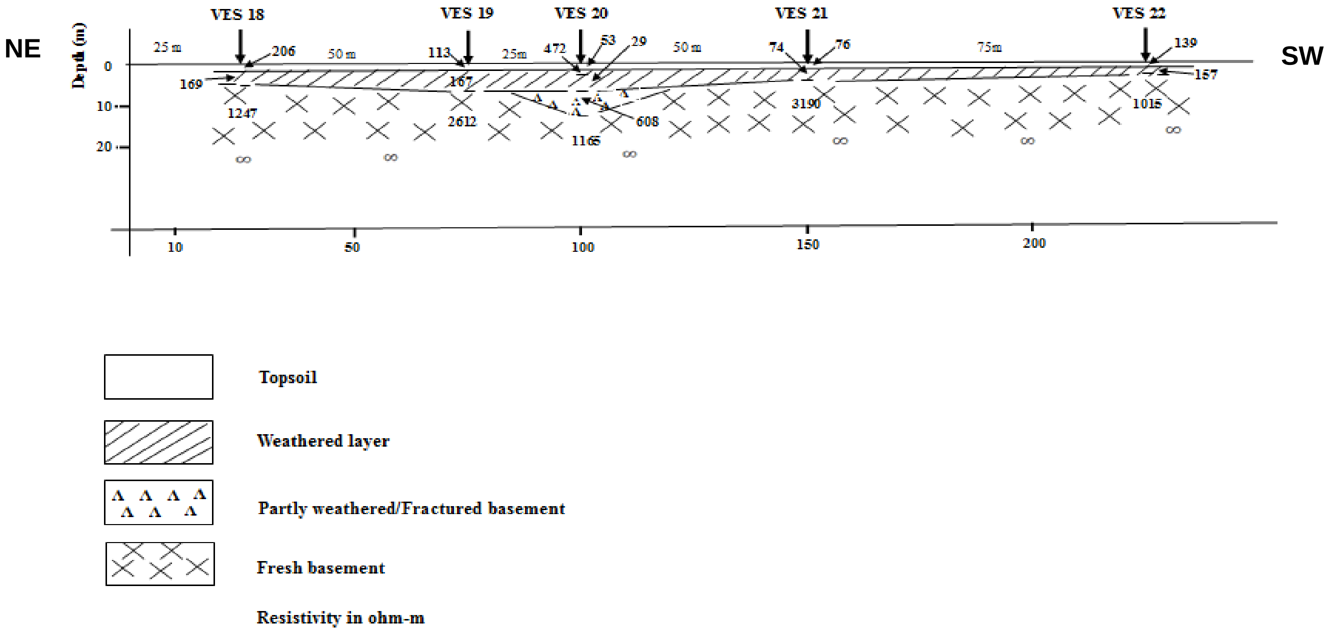


Figure 11 d: 2 - D Geoelectric Section along Traverse 4.

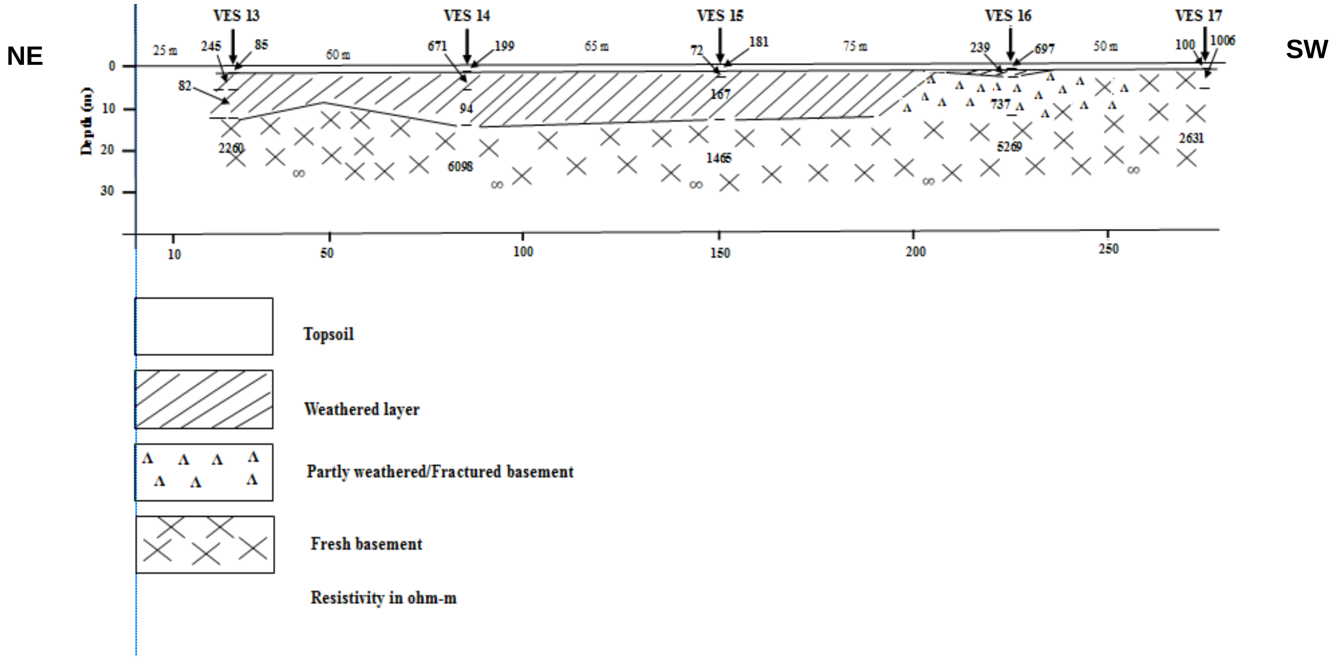


Figure 11 e: 2 - D Geoelectric Section along Traverse 5.

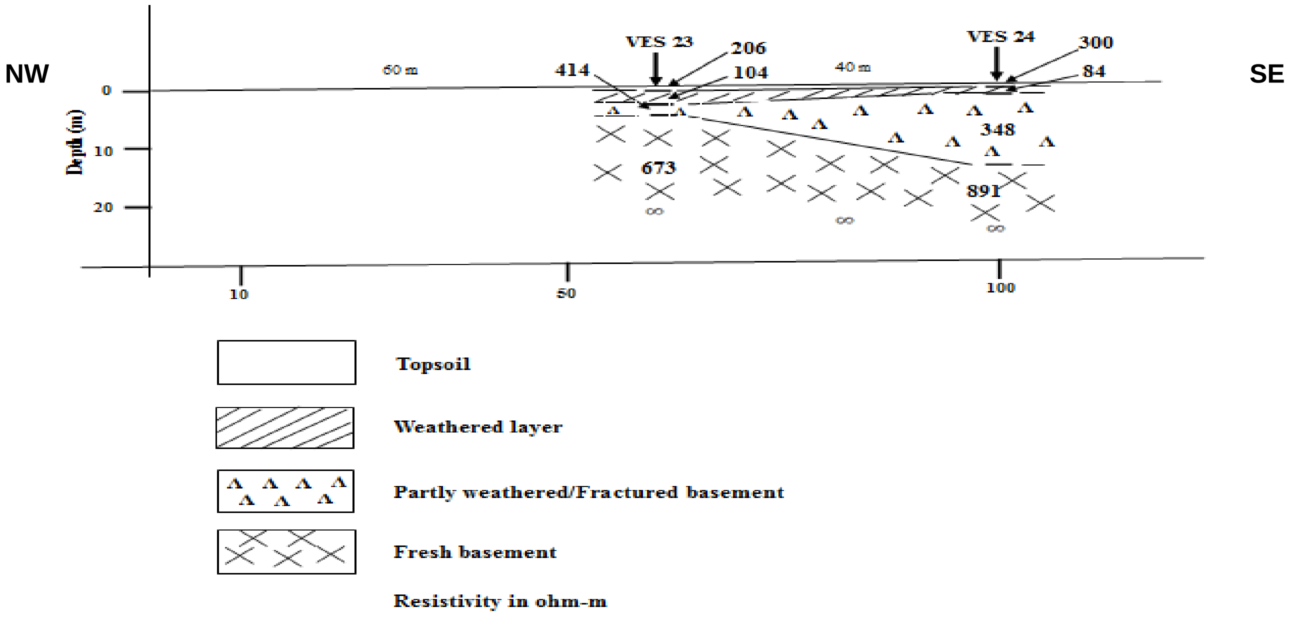


Figure 11 f: 2 - D Geoelectric Section along Traverse 6.

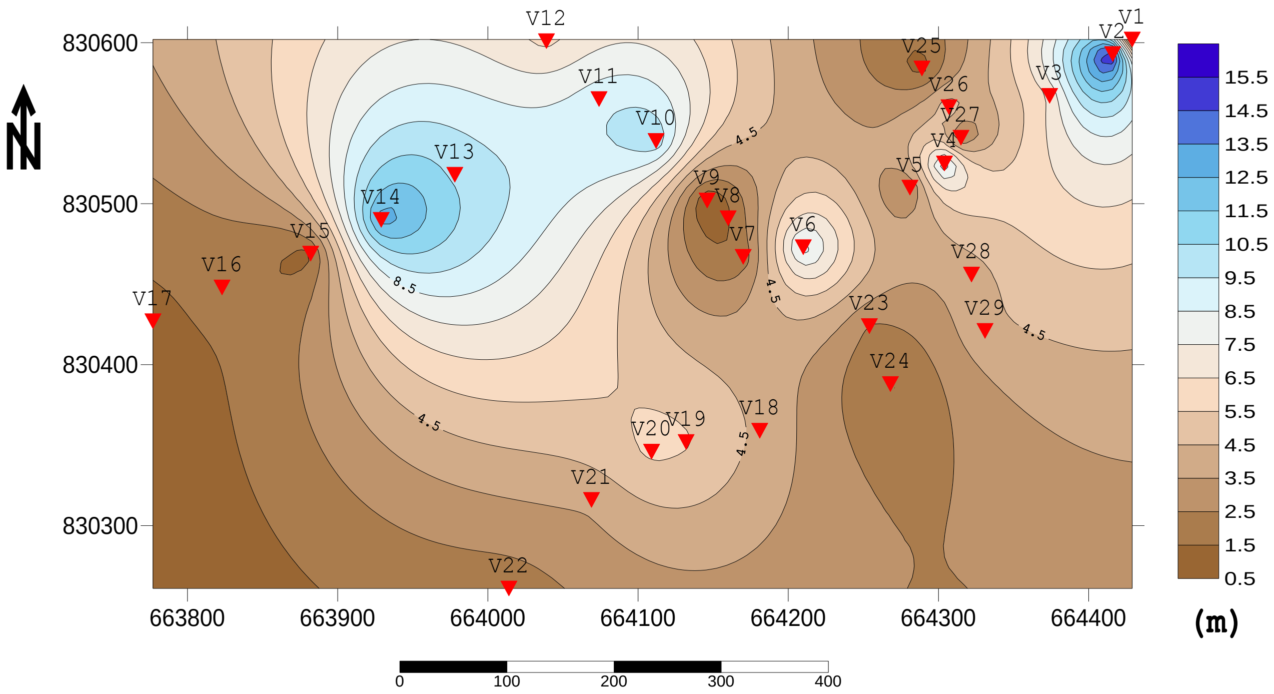


Figure 12: Isopach Map of the Weathered Layer.

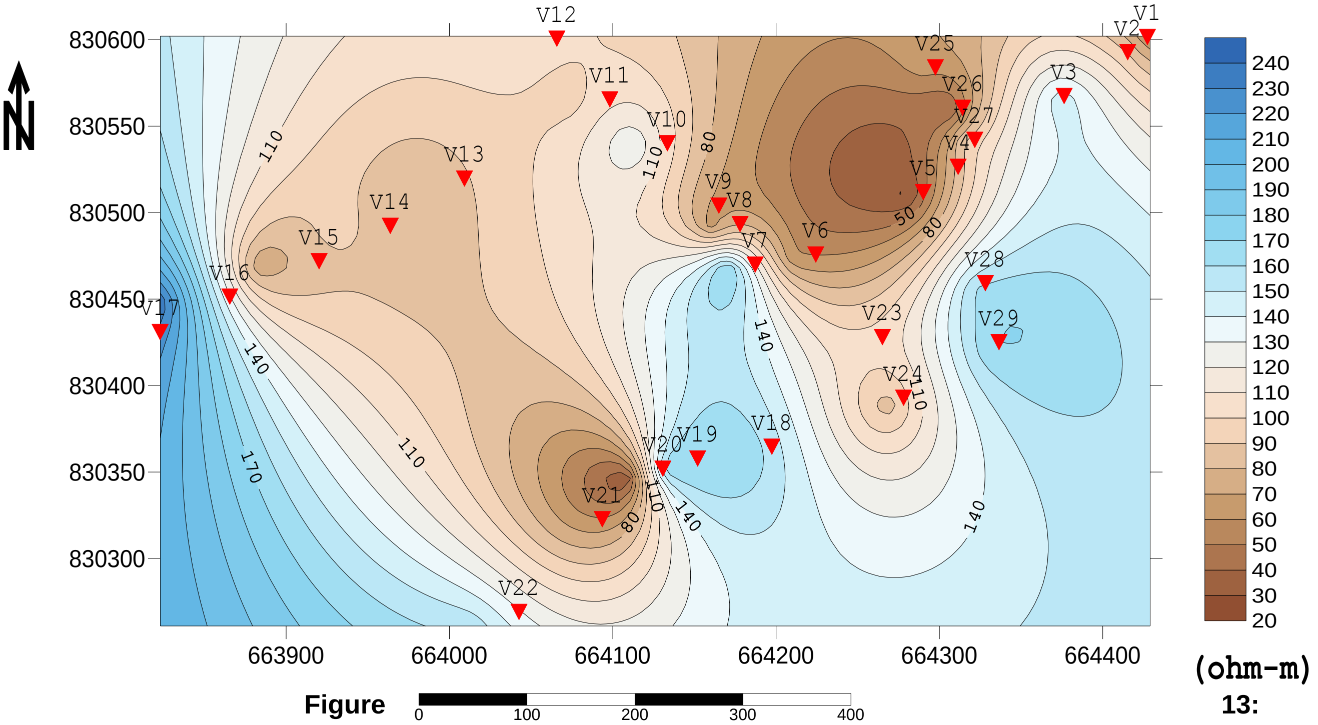


Figure 13: Isoresistivity Map of the Weathered Layer.

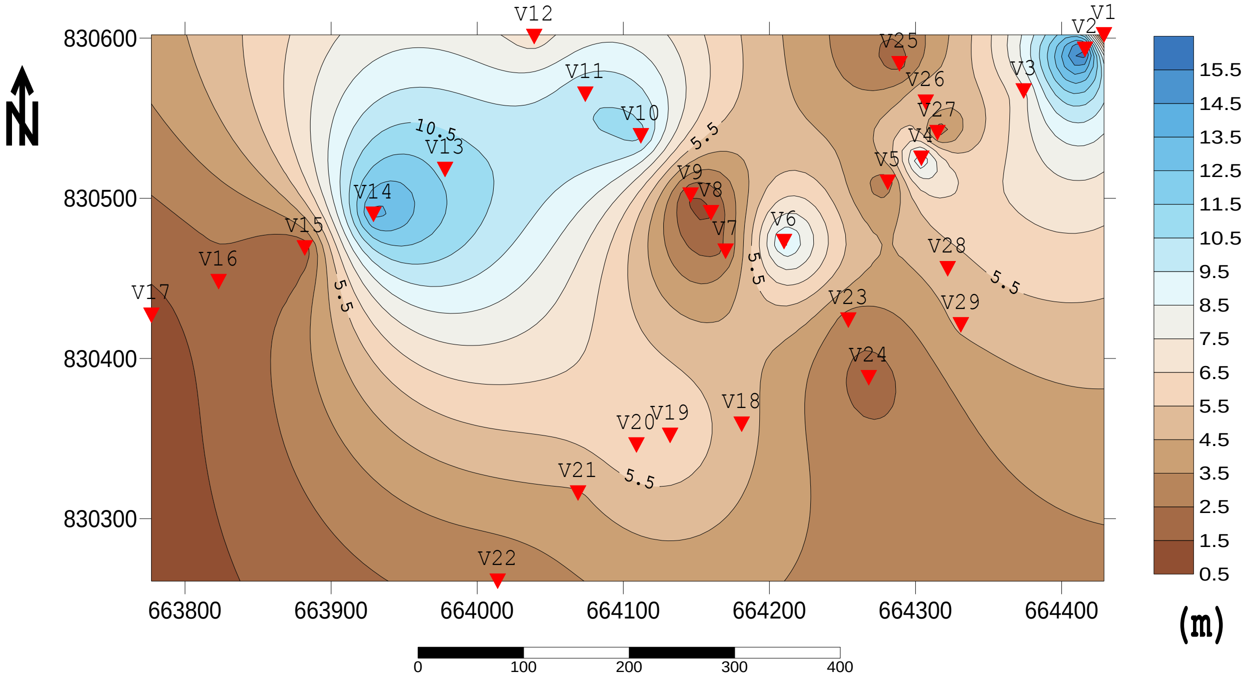


Figure 14: Isopach Map of the Overburden.

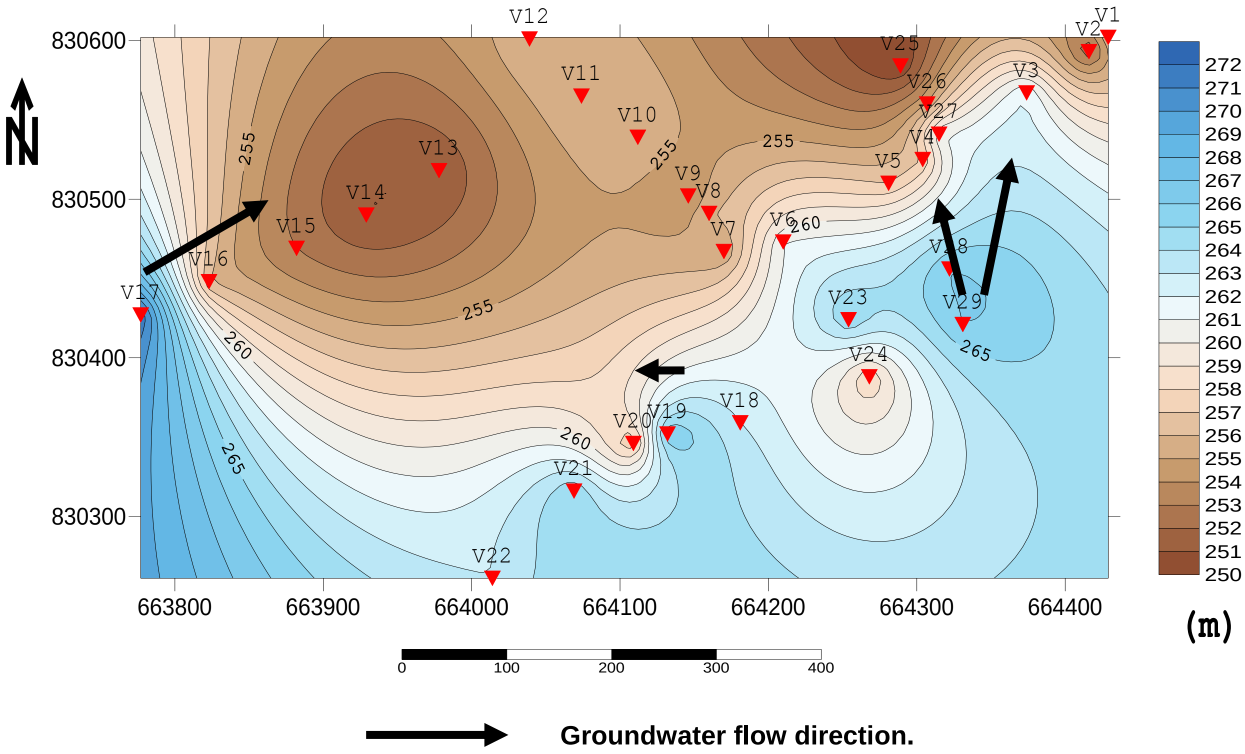


Figure 15: Map Showing Groundwater Flowing Direction in the Study Area.

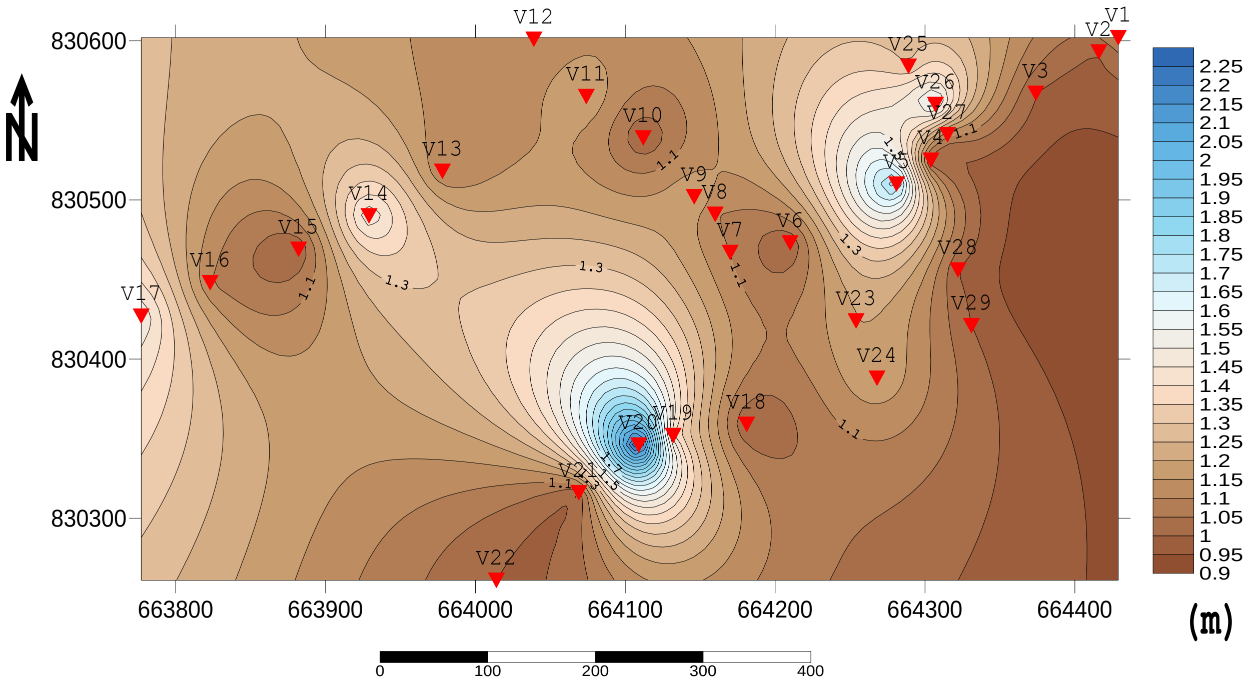


Figure 16: Map Showing the Coefficient of Anisotropy on the Study Area

Table 2: Summary of Aquifer Characteristics based on Curve Type

VES No	Aquifer Type	Curve Type	Aquifer Resistivity (ohm-m)	Aquifer Thickness (m)	Long. (m)	Latt. (m)	Geology
1	II	HKH	68	6.7	664429	830602	GGN
2	I	H	89	16.3	664416	830593	GGN
3	I	H	146	6.6	664374	830567	GGN
4	I	H	70	9.5	664304	830525	GGN
5	II	HKH	6	5.3	664429	830602	GGN
6	I	KH	63	8.1	664210	830473	PGM
7	I	AA	176	1.8	664170	830467	PGM
8	I	A	66	1.4	664160	830491	PGM
9	I	AAA	83	0.4	664146	830502	PGM
10	I	H	130	10.4	664112	830539	PGM
11	I	KH	95	4.4	664074	830565	PGM
12	I	H	110	6.2	664039	830601	PGM
13	I	KH	82	6	663978	830518	PGM
14	I	KH	94	8.4	663929	830490	PGM
15	III	HA	72	1.2	663882	830469	PGM
16	I	HA	239	2.1	663823	830448	PGM
17	I	A	100	1.1	663777	830448	PGM
18	I	H	169	4.3	664181	830359	PGM
19	I	A	167	5.6	664132	830352	PGM
20	III	KHA	29	5	664109	830346	PGM
21	I	H	74	3.7	664069	830316	PGM
22	I	A	157	2.8	664014	830261	PGM
23	III	HA	104	3	664254	830424	GGN
24	III	HA	84	2	664268	830388	GGN
25	III	HA	66	2	664289	830584	GGN
26	I	KH	39	6	664307	830558	GGN
27	III	HA	91	2.5	664315	830541	GGN
28	I	A	161	4.9	664322	830456	GGN
29	I	A	169	4.7	664331	830421	GGN

GGN: Granite-gneiss
PGM: Pegmatite

Generally, the groundwater potential of the study area is low, but some locations such as VES 1, VES 5 and VES 20 though with moderate overburden thicknesses are feasible points for groundwater prospect in lieu of fractured units beneath the locations. However location around VES 2, 10, 13, and VES 14 are marginal/fair zones for groundwater development due to their moderate overburden thicknesses with high porosity and permeability.

By all indication, the study revealed the groundwater potential of the area to be generally low.

CONCLUSION

The geophysical investigation conducted at Modomo/Eleweran area, Osun State revealed the underlying lithology to be made up of topsoil, weathered layer (consisting of clay, sandy clay and laterite), partly weathered/fractured basement and fresh basement rock. It was observed that the area is characterized by a thin overburden thickness, low fractured frequency and clayey weathered layer. However, from the geo-electric sections and the calculated anisotropy coefficient values, it can be inferred that the VES locations with moderate overburden thickness and high values of anisotropy coefficient would be favorable for borehole locations. Hence, location around VES 5 and VES 20 are favorable zones for groundwater development. However, drilling to the basement is necessary in other to tap the reserved groundwater within the fractured zones.

In all, results of this study provide an idea indicating that the groundwater potential of the area varies from poor to low.

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