Groundwater Potential of Basement Aquifers in Part of Southwestern Nigeria

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Abstract

In this study, water table elevations were monitored weekly in 81 hand-dug wells within Ondo metropolis over a period of four months that cuts across the dry and wet seasons. Some physicochemical parameters of water in the wells were measured weekly. Fifty-two Vertical Electrical Soundings were carried out at selected locations. Spatial and temporal distributions of saturated thickness of the available aquifers were determined. Recharge conditions were found to dominate central parts of the study area. Generally, three geo-electric layers, which are the Top Soil, Weathered Layer and Fresh Bedrock, are present. The fourth and fifth layers, the Boulder Zone and Fracture Zone, occur in few places. Overburden thickness range from zero at outcrop points to 29.3m in deeply-weathered areas while the saturated thickness of the aquifers varied from 1.49 to 22.76m. Groundwater development is most promising in areas where thick overburden is complemented with presence of fractures.

Keywords: groundwater, fracture, aquifer, weathering, basement.

1. Introduction

Communities located on Basement Complex terrains commonly have problems of potable groundwater supply due to the crystalline nature of the underlying rocks which lack primary porosity. Groundwater storage capacity in those areas is dependent on depth of weathering and intensity of fracturing of the underlying rocks. For Basement Complex rocks to become good aquifers, they must be highly fractured and/or deeply weathered. Thickness of the weathered overburden and fracture zone determines the nature and intensity of hydrodynamic activities within the usually-discrete bodies of aquifers in the terrain. The discontinuous nature of the basement aquifer systems makes detailed knowledge and application of the geological, hydrogeological and geophysical investigations inevitable (Amudu *et al*., 2008).

The fractured zones usually occur at deep depths and may have large accumulation of potable water that is protected from pollution while the weathered zones which are usually at shallow depths contain smaller quantity of groundwater. This shallow depth of occurrence commonly allow for easy pollution of groundwater in the weathered overburden.

The potable water in the deep-seated fractured zone can only be reached with boreholes which are usually expensive and out of reach for most households. In the absence of reliable public water supply, most households rely on hand-dug wells which tap their water from the shallow water table within the weathered overburden. Pollution in this type of aquifers occurs both in time and space.

Thus, there is the need for continuous study of groundwater in weathered overburden to understand the hydrodynamics within the subsurface system and to determine the saturated thickness of this shallow aquifer within the overburden.

1.1 The Study Area

The study area is Ondo metropolis in Ondo State, Southwestern Nigeria. It lies between longitudes E004°48' and E004°52'; and latitudes N07°3.5' and N07°7.5' (Fig. 1). It falls within the humid tropical region with two distinct seasons, the rainy season, from March to October, and dry season, from November to March. The annual rainfall in the area is estimated to be about 2,000 mm (Ondo State Ministry of Economic Planning & Budget, 2010) with mean monthly temperature range of 25.7°C to 30.2°C and high humidity, generally above 50% (Ondo State Ministry of Lands, Housing & Environment, 2000). Ondo township falls within the Pre-Cambrian Basement Complex of Southwestern Nigeria which consists of migmatite, gneisses, schist and quartzite into which has been an emplacement of granitic and, to a lesser extent, more basic materials (Rahaman, 1981). The dominant rock types in the area are the medium to coarse grained granite, granite gneiss and quartzite (Fig. 2).

2. Methodology

Eighty-one hand-dug wells were randomly selected and geo-referenced in the study area to monitor the changes in their water levels and physicochemical parameters. The choice of a well depends on its distance from a previously chosen one in the locality, the consent of the owner to make the well available for study and the observed geology of the well (Malomo *et al.*, 1990; Asiwaju-Bello & Akande, 2001; Aiyegbusi, 2006). Prominent rock outcrops whose sizes are large enough to affect groundwater flow in the subsurface were geo-referenced. Regular monitoring of the sampled wells was done on weekly basis for fourteen continuous weeks, a period that cuts across the dry and rainy seasons in the study area. The physicochemical parameters determined in this study are temperature, pH, electrical conductivity, total dissolved solids (TDS) and depth to water table in the well. The HANNA pH/EC/TDS meter was used for the determination. The spatial distribution of the well locations within the study area is shown in Fig. 3.

Geophysical investigation of the area was carried out to know the depth to fresh Basement and to determine the saturated thicknesses of the aquifers. The Vertical Electrical Sounding (VES) using Schlumberger electrode array was carried out at fifty-two locations within the study area (Fig. 4) using maximum current electrode spacing of 65m. The ABEM SAS-1000 terrameter was employed.

3. Results

3.1 Physico-Chemical Parameters

3.1.1 Water Table

The water table map is presented in Fig. 5. The direction of movement of groundwater in the area varies from place to place and the flow potentials are shown as 1-dimensional grid vectors. Areas where flow vectors converge are the areas of discharge called "sink" while areas where flow vectors diverge are the areas of recharge called "source". Also, areas with long flow vector clustered together are the areas of high flow magnitudes while the short ones are areas with low flow magnitude.

3.1.2 pH

Spatial distribution map of pH values is presented in Fig. 6. The values range from 4.71 to 7.57. This range of values indicates water of slightly acidic nature.

3.1.3 Temperature

There is fluctuation in the temperature of groundwater in the area of study. The temperature ranges between 26.2°C and 30.7°C (Fig. 7). The values confirmed existence of hydraulic connection between the groundwater environment and the ground surface.

3.1.4 Total Dissolved Solids and Electrical Conductivity

The TDS values are presented as iso-con lines, in ppm $CaCO_3$. Increasing TDS values are associated with increase in the velocity of groundwater flow as shown in the spatial TDS distribution map (Fig. 8). The iso-con map of EC values is similar in structure and trend to that of TDS in Fig. 8.

3.2 Geophysical Survey

3.2.1 Field Curves

Typical curves for the 52 VES points are shown in Fig. 9. The summary result from the interpretations of the VES data is presented on Table 1. The curve types range from A, H, AA, HA, KH, QH to AKH. The A curve type is the most predominant as it accounts for 57.7%; the KH type accounts for 13.5%; the H, HA and AKH curves account for 7.7% each, while the AA and QH account for 3.8% and 1.9%, respectively.

3.2.2 Isopach Map of the Overburden

Depth to fresh bedrock (overburden thickness) at each sounding station was contoured and shown as isopach map of the overburden (Fig. 10). The overburden include the topsoil, weathered basement and / fractured basement. The depth to fresh basement varies from 3.7 to 29.3m. The isopach map reveals areas with relatively thin overburden (< 10m) and areas with thick overburden (>10m). Areas with thin overburden correspond to shallow depths of weathering while areas with thick overburden correspond to those with deep depths of weathering.

3.2.3 Saturated Thickness of Aquifer

Saturated thickness was obtained by subtracting water table depth from depth to bedrock. The thicknesses were contoured as saturated thickness map of the basement aquifer (Fig. 11).

3.2.4 Geo-electric Sections

Five lines of sections (A-B, C-D, E-F, G-H and I-J) were established in the area of study for the construction of geo-electric sections. The interpreted VES results on Table 1 were used to prepare 2-D geo-electric sections which show respective layer resistivity values and thicknesses (Fig. 12). Geological interpretation of the profiles was done based on the expected soil profiles in the Basement complex terrain (Mohr & Van Baren, 1954; Malomo *et al*., 1983).

3.2.4.1 Geo-electric section along profile A-B

The geo-electric section along this profile (Fig. 13) connects VES 48,47,41,43,13, 14,15,16,8,7,1,2 and 4. The subsurface layers identified in this section are the topsoil, the weathered lateritic materials, partly weathered rocks and the fresh bedrock. The topsoil has thickness ranging from 0.6m to 1.6m. The weathered lateritic materials have thickness ranging from 1m to 21.7m. The partly weathered layer is observed beneath VES 7and 8 with thickness of 7.2m to 8.2m.

3.2.4.2 Geo-electric section along profile C-D

This section connects VES 32,31,30,29,12,11,6,5,1,2,4 and 3 (Fig. 14). Five geo-electric layers were delineated from this profile which include the top soil, the weathered layer, the fractured layer and the fresh bedrock. The resistivity values of the top soil ranges from 64.6Ωm to 420Ωm with variation in thickness from 0.8m to 1m. The weathered layer thickness ranges from 1.7m to 21.7m. The fracture layer which is observed in VES 3, 4, 29 and 30 has thickness ranging from 8.3m to 13.5m. In VES 3, 29 and 30, the fractured layer is overlain by a boulder layer with thickness range of 2.4m to 3.8m.

3.2.4.3 Geo-electric section along profile E-F

This profile (Fig. 15) cuts across VES 34,33,31,35,38,39,40,41,43,42,44,45,52 and 51. The identifiable subsurface layers are the topsoil, the weathered lateritic materials, the weathered layer, the fractured layer and the fresh bedrock. The topsoil resistivity values ranges from 17.7Ωm to 160.6Ωm with thickness ranging from 0.6m to 1.4m. The weathered layer thickness ranges from 1.2m to 24.5m. The highly weathered layer overlies the fresh bedrock in VES 51 and 52 with thickness values of 3.3m to 4m. In VES 33 and 34, the fractured layer also overlies the fresh bedrock with thickness of 4.8m to 6m.

3.2.4.4 Geo-electric section along profile G-H

This profile connects VES 46, 44, 25, 24, 17, 18 and 19 (Fig. 16). Four geo-electric layers observed from this profile are the top soil, the weathered layer, the partly weathered layer and the fresh bedrock. The resistivity values of the top soil ranges from 42.1Ωm to 269.4Ωm with variation in thickness from 0.6m to 1m. The weathered layer thickness ranges from 4.3m to 17.4m. The partly weathered layer which is observed in VES 19 overlies the fresh bedrock and has a thickness of 10.3m.

3.2.4.5 Geo-electric section along profile I-J

The geo-electric section along this profile (Fig. 17) connects VES 52,51,50,26,22,21 and 20. Four subsurface layers which are the topsoil, the weathered lateritic materials, highly weathered rocks and the fresh bedrock were identified in this section. The topsoil has layer resistivity values ranging from 28.2Ωm to 158.3Ωm with thickness ranging from 0.7m to 1m. The weathered lateritic materials have thickness ranging from 1.2m to 10.2m. The highly weathered layer is observed beneath VES 52, 51and 50 with thickness range of 3.3m to 7.2m.

4. Discussion

A general increase was observed in the water table heads in all the wells monitored as monitoring progressed, especially in the month of July when rainfall was at peak. The increase in the water table head was as a result of high rainfall, high infiltration and high recharge rate into the aquifer. The water table level also influences the velocity of groundwater flow in the area. Groundwater flows from areas of higher water table elevation to areas of lower elevation. Rock outcrops, where present, influenced movement of groundwater within their localities. The outcrop locations constitute areas of no flow as the velocity vectors move around the outcrops, indicating discrete movements of groundwater within the area of study.

pH values of groundwater in the area of study shows the water to be slightly acidic to neutral. The pH disfavored high dissolution of toxic elements in the groundwater. Most substances that dissolve in water dissociate into ions that can conduct electric current. Consequently, EC is a valuable indicator of the amount of material dissolved in water. The TDS and EC values obtained from monitored well water in the area of study generally suggest low dissolved ion concentration in the groundwater.

From the water table distribution maps, areas of recharge into the aquifer are seen mostly in the Northwestern, Eastern and Central parts of the study area while the areas of discharge from the aquifer occur mostly in the Northern, Southern and Southwestern parts of the area. The discharge areas are created mainly by anthropogenic activities.

The results obtained from the interpreted VES reveal that three to five geo-electric layers, which are the Top Soil, the Weathered Layer, the Boulder Horizon, the Fractured Layer and the Fresh Bedrock, are present. Occurrence of the Boulder Zone is restricted to very few areas.

Isopach map of the overburden shows that depth to fresh basement within the area ranges from 0 at outcrop points, through 3.7m in areas of averagely-shallow depth of weathering, to 29.3m in deeply-weathered areas. The Highly-weathered Zone and the Fracture Zone define the aquifers in the area of study. The observed variation in the resistivity and thickness of the aquifer layers is due to the different rates at which different rocks respond to weathering from one location to another.

The Highly-Weathered Layer and the Fracture Zone are the two aquifer types identified in the area of study. The highly weathered layer has resistivity values which range from 57.7Ωm to 170.9Ωm and thickness from 3.3m to 7.2m while the fractured zone has resistivity values ranging from 19.4Ωm to 708.9Ωm and thickness ranging from 4.8m to 13.4m. The cumulative saturated thickness of these basement aquifers in the area of study ranges from 1.49m to 22.76m. Areas with large thicknesses are expected to support boreholes with high yields (Olorunfemi, 1990).

5. Conclusion

Correlation of spatial distribution of water table heads and the physicochemical parameters confirmed that dominating discharge conditions are determined by anthropogenic factors. Results also revealed an established regional direction of movement of groundwater but with local variations that differ from place to place.

Generally, five geo-electric layers, which are the Top Soil, the Weathered Layer, Boulder zone, the Fracture Zone and the Fresh Bedrock, are present in the study area. However, the Boulder zone and the Fracture zone occur in very few areas. Both the Weathered and the Fracture Zones constitute the aquifers in the area with the latter usually occurring beneath the former. The isopach map of the overburden shows that depths to fresh basement range from zero at outcrop points, through 3.7m in averagely-shallow depth of weathering, to 29.3m in deeply-weathered areas.

This is relevant in groundwater development because the amount of available recharge and accumulation depends on the thickness of the overburden. Groundwater development is promising mainly in the areas with large saturated thickness, especially in those areas where the thick overburden is complemented by presence of fracture zone. Further studies are recommended to obtain more regional groundwater movement and characteristics.

6. References

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Table 1: Summary of Results from the Interpretation of all the VES Data

VES No.	NO. OF LAYERS	CURVE TYPE	RESISTIVITY OF LAYERS (Ω-m)					THICKNESS OF LAYERS (m)				DEPTH TO BEDROCK (m)
			ρ_1	ρ_2	ρ_3	ρ_4	ρ_5	T_1	T_2	T_3	T_4	
1	3	A	140.9	222.1	8524.4			1.0	21.7			22.7
2	3	A	105.8	302.1	4600.1			0.8	17.4			18.2
3	5	AKH	126.6	167.9	851.5	122.1	1676.2	1.0	1.7	2.4	8.3	13.4
4	4	KH	130.6	205.6	86.1	3650.2		0.9	6.6	8.5		16.0
5	3	A	32.8	120.6	1319.9			1.0	9.8			10.8
6	3	A	90.5	220.5	1200.4			1.1	7.3			8.4
7	4	HA	87.6	67.5	136.6	1898.1		1.0	1.0	8.2		10.2
8	4	HA	90.2	82.5	280.4	2400		1	5.8	7.2		14.0
9	3	A	130	450.9	2072			0.8	10.7			11.5
10	3	A	95	190	1800			1.0	12.0			13.0
11	3	A	150.6	270.8	860.8			0.9	6.6			7.5
12	3	A	129.1	164	564.6			0.9	3.3			4.2
13	3	A	51.1	57.3	2671.7			1.0	5.1			6.1
14	3	A	45.3	52.5	1150.5			1.1	7.8			8.9
15	3	A	50	75	750			0.7	10.5			11.2
16	3	A	48.7	100.8	1350			1.0	8.1			9.1
17	3	A	42.1	85	850			0.8	9.7			10.5
18	3	H	90.2	72.5	780.4			1.0	8.4			9.4
19	4	HA	85.1	58.4	190.4	2200.2		1.0	4.4	10.3		15.7
20	4	HA	113	88.5	320.8	1760		1.0	5.1	8.7		14.8
21	4	AA	158.3	520	850.5	3800.3		1.0	10.2	5.6		16.8
22	4	AA	117.4	135.3	508.2	13756.9		1.0	4.0	12.4		17.4
23	3	A	20.4	119.5	1040			1.0	7.5			8.5
24	3	A	170	108.3	1740			0.8	7.9			8.7
25	3	A	82.7	380	4550.6			1.1	17.4			18.5
26	3	H	28.2	28	1804.7			1.0	4.7			5.7
27	3	A	20.9	95.8	1300			0.9	5.4			6.3
28	5	AKH	400.2	505.5	1950	650.6	2850.1	0.9	11.9	3.7	4.4	20..9
29	5	AKH	350.2	460.2	2280.5	708.9	3780.2	1.0	9.7	4.5	11.1	26.3
30	5	AKH	420	525	1837.5	584	2362.5	1.0	11.0	3.8	13.5	29.3
31	3	A	156.3	215.4	2070.1			1.0	13.3			14.3
32	3	A	64.6	200.1	3569.1			1.0	5.7			6.7
33	4	QH	160.8	81.9	19.4	26.4		1.4	1.5	4.8		>7.4
34	4	KH	130.6	265.7	150.5	966.7		1.1	2.2	6.0		9.3
35	3	A	95.6	230.8	2450.7			1.0	22.8			23.8
36	4	KH	141.8	608.9	190.5	6000		0.9	9.7	7.9		18.5
37	4	KH	96.8	697.9	168.8	10415.6		0.6	1.9	14.6		17.1
38	3	A	160.6	299.1	3164.6			0.8	24.5			25.3
39	3	A	81.5	240.7	11831.3			1.1	11.2			12.3
40	3	A	70.5	160.9	980.4			1.0	11.8			12.8
41	3	A	17.7	115.3	507.7			0.9	12.9			13.8
42	3	A	82.1	174.1	3000.5			0.7	19.8			20.5
43	3	A	31.8	137.8	5619			0.6	20.4			21.1
44	3	H	76.9	14.9	2651.1			0.6	6.8			7.4
45	3	A	103.5	235.6	1800			0.8	6.4			7.2
46	3	A	269.4	402.5	1962			0.8	4.3			5.1
47	3	A	20.4	65.8	1605			1.2	8.5			9.7
48	3	A	22	48.9	2967.3			1.6	2.1			3.7
49	3	H	300.5	165.5	1869.7			1.0	7.2			8.2
50	4	KH	83.2	350.3	170.9	2100		1.0	6.3	7.9		15.2
51	4	KH	115.8	315.7	112.8	1350		1.0	1.5	4.0		6.5
52	4	KH	63.5	250	57.7	2557.5		0.7	1.2	3.3		5.2

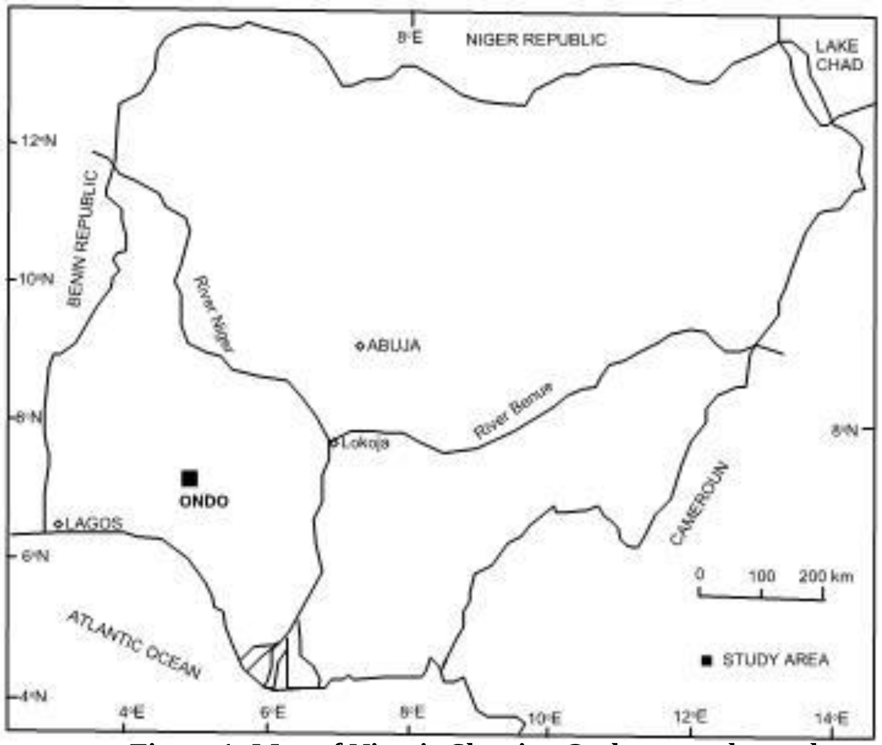

Figure 1: Map of Nigeria Showing Ondo town, the study area.

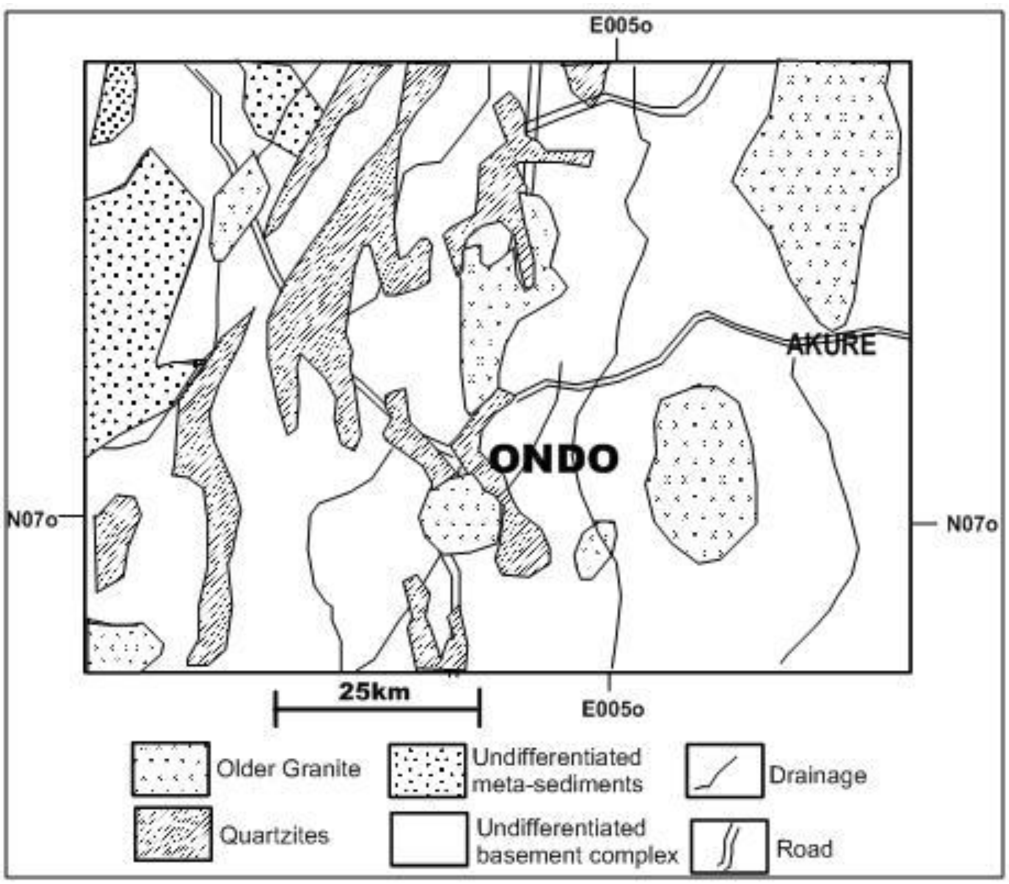

Figure 2: Geological map of the study area (after GSN, 1984).

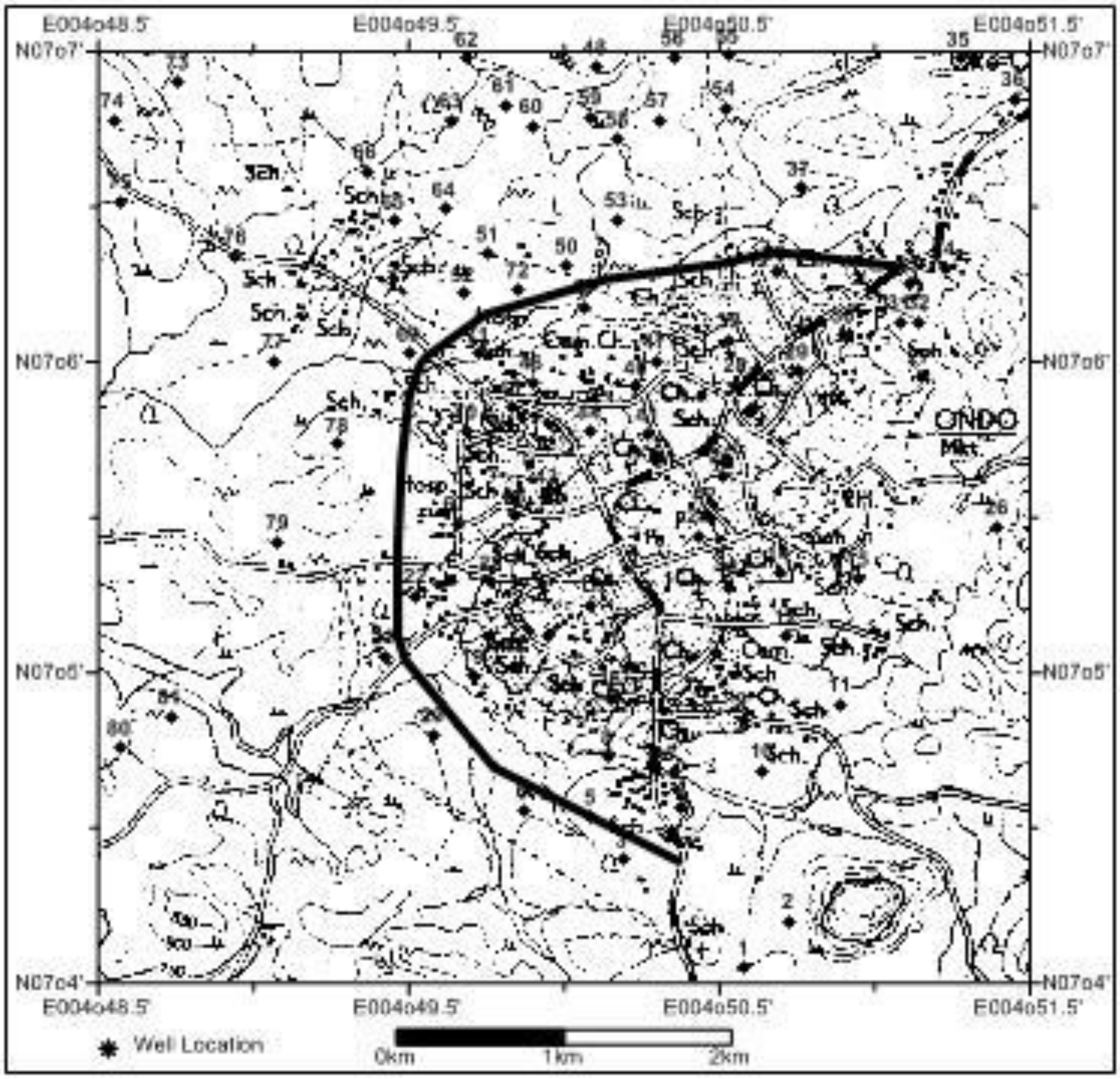

Figure 3: Topographical Map Showing Location of Well Points within the Study Area.

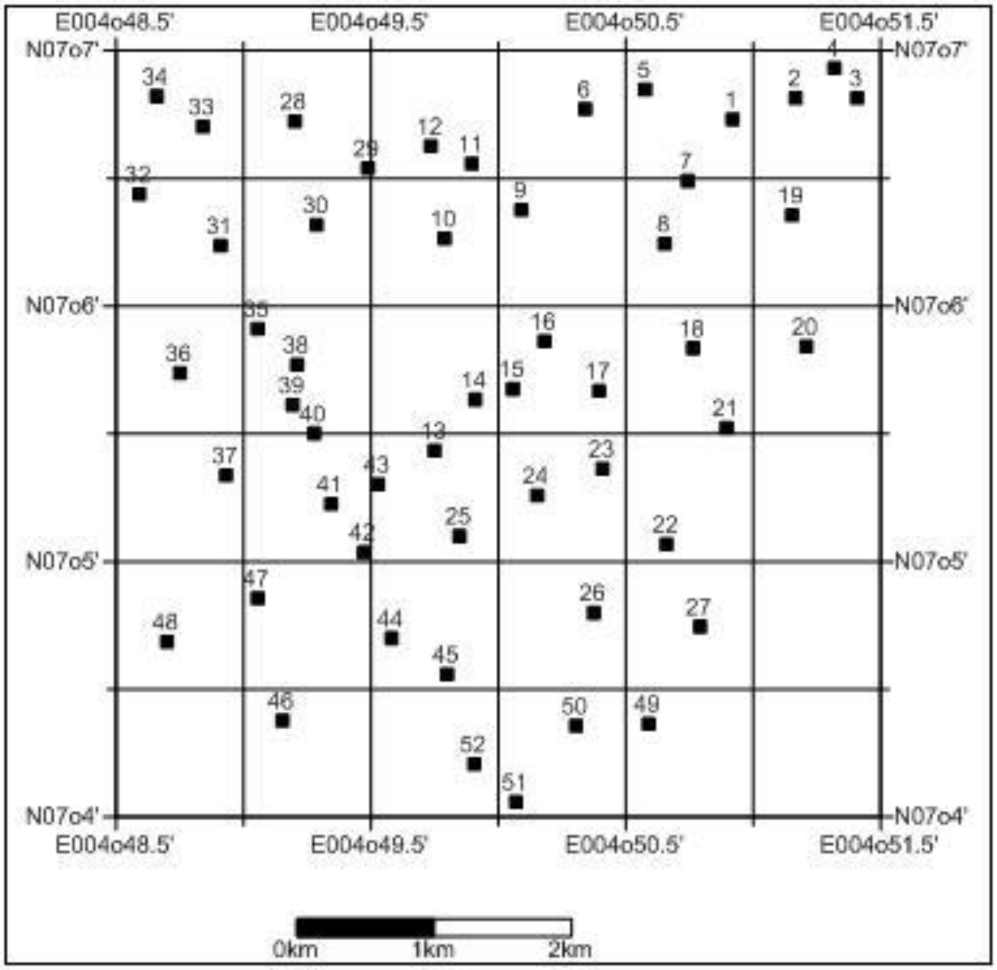

Figure 4: Location of VES points in the study area.

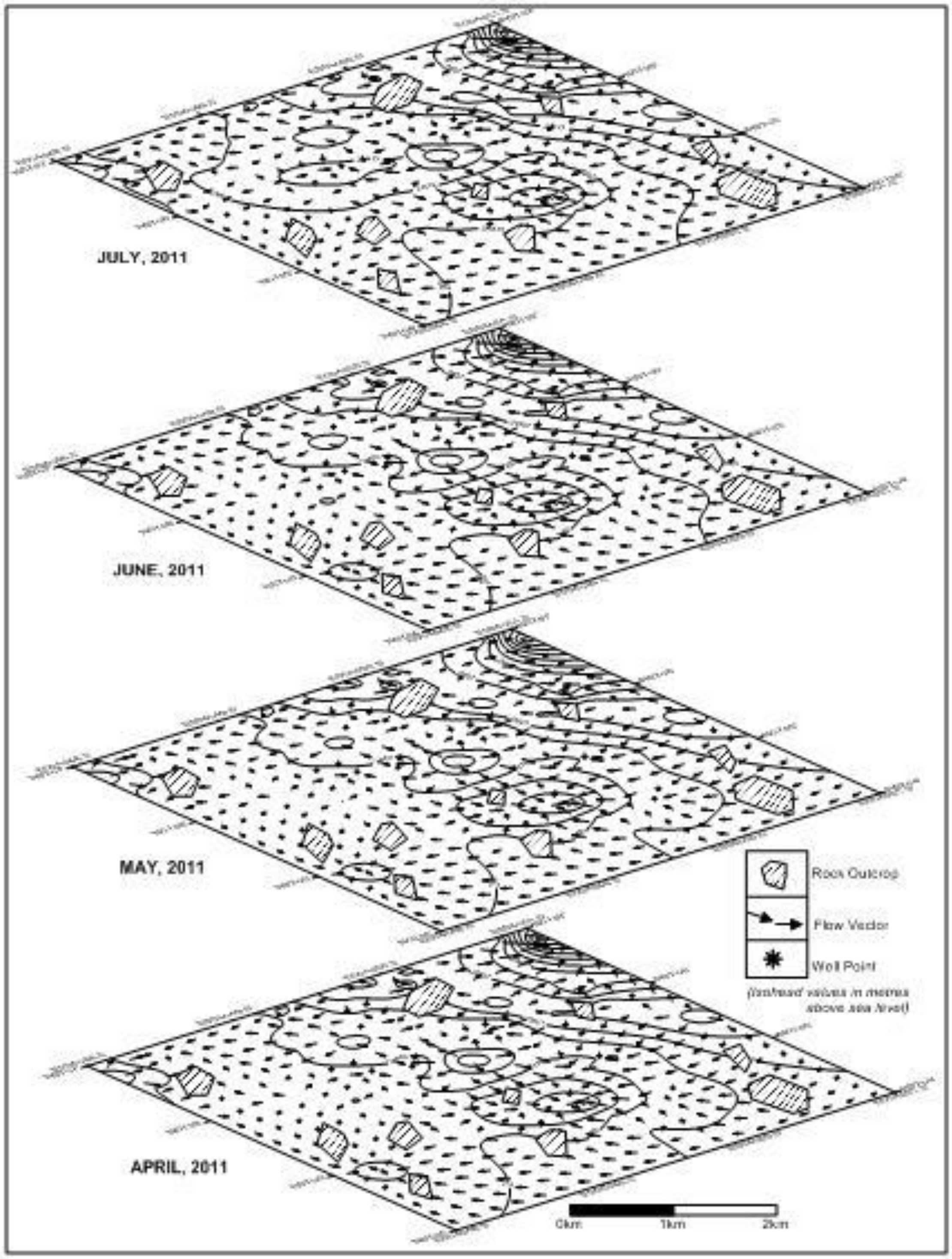

Figure 5: Spatial Distribution of Groundwater Heads and Flow Vectors.

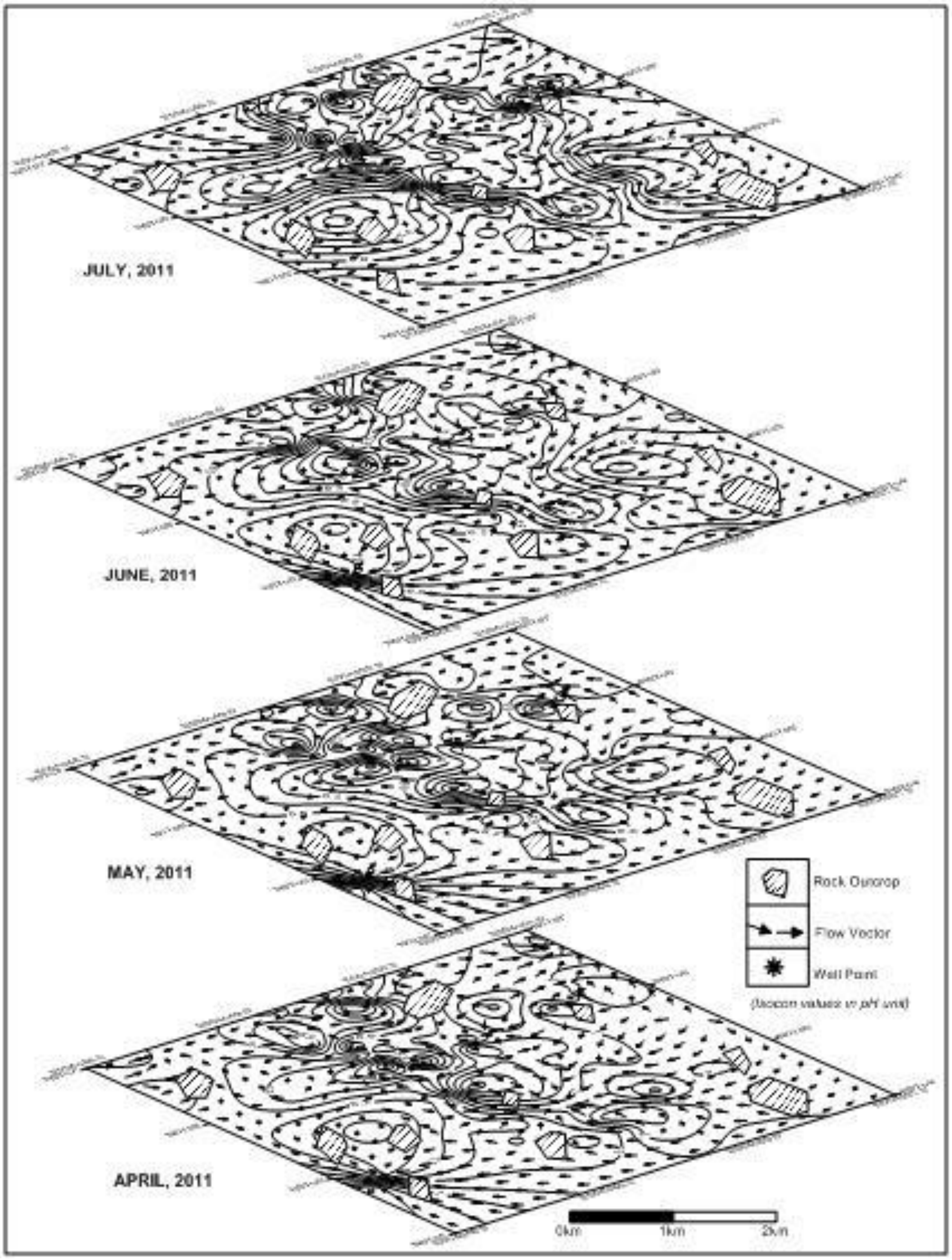

Figure 6: Spatial Distribution of pH.

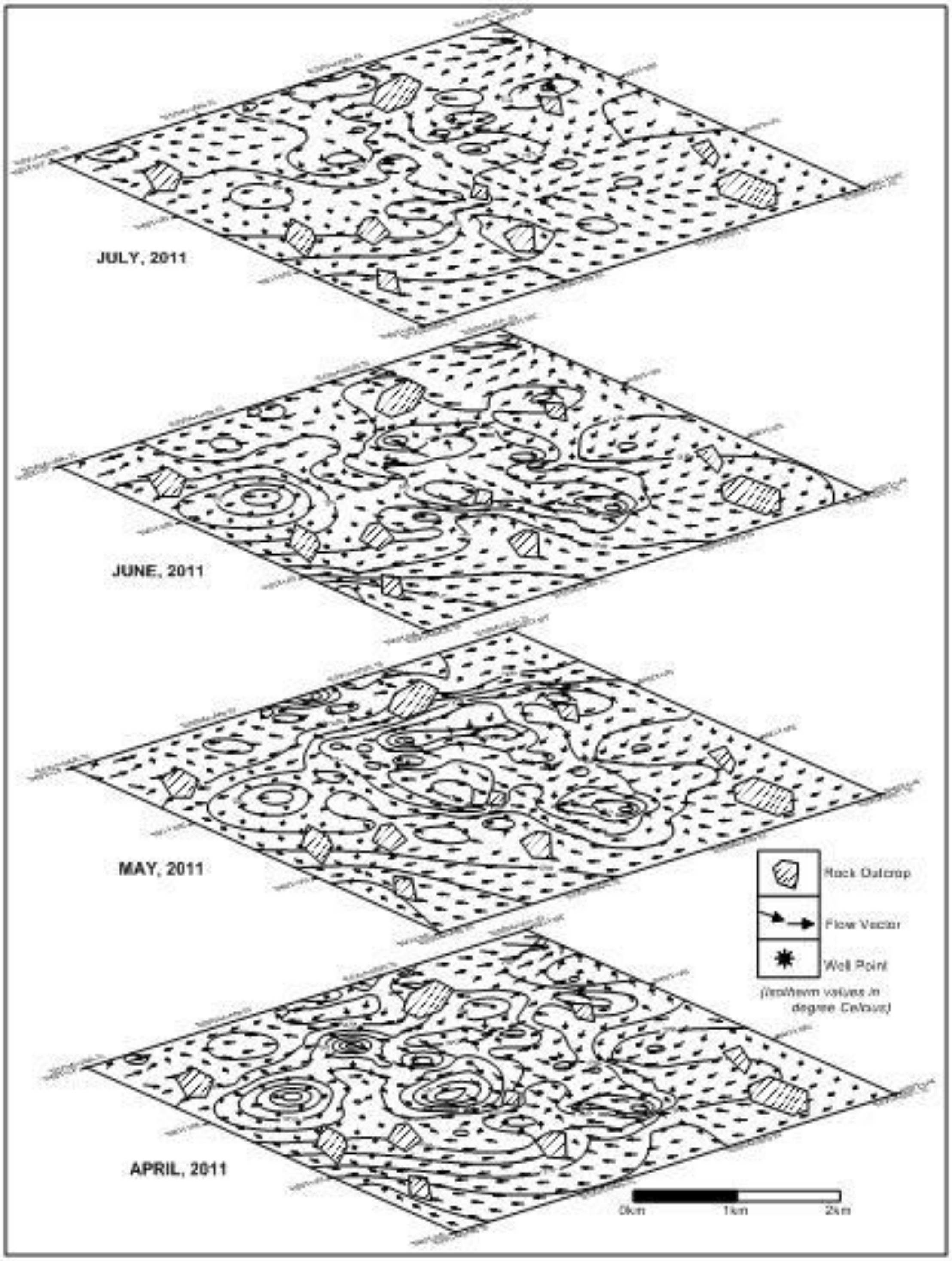

Figure 7: Spatial Distribution of Temperature

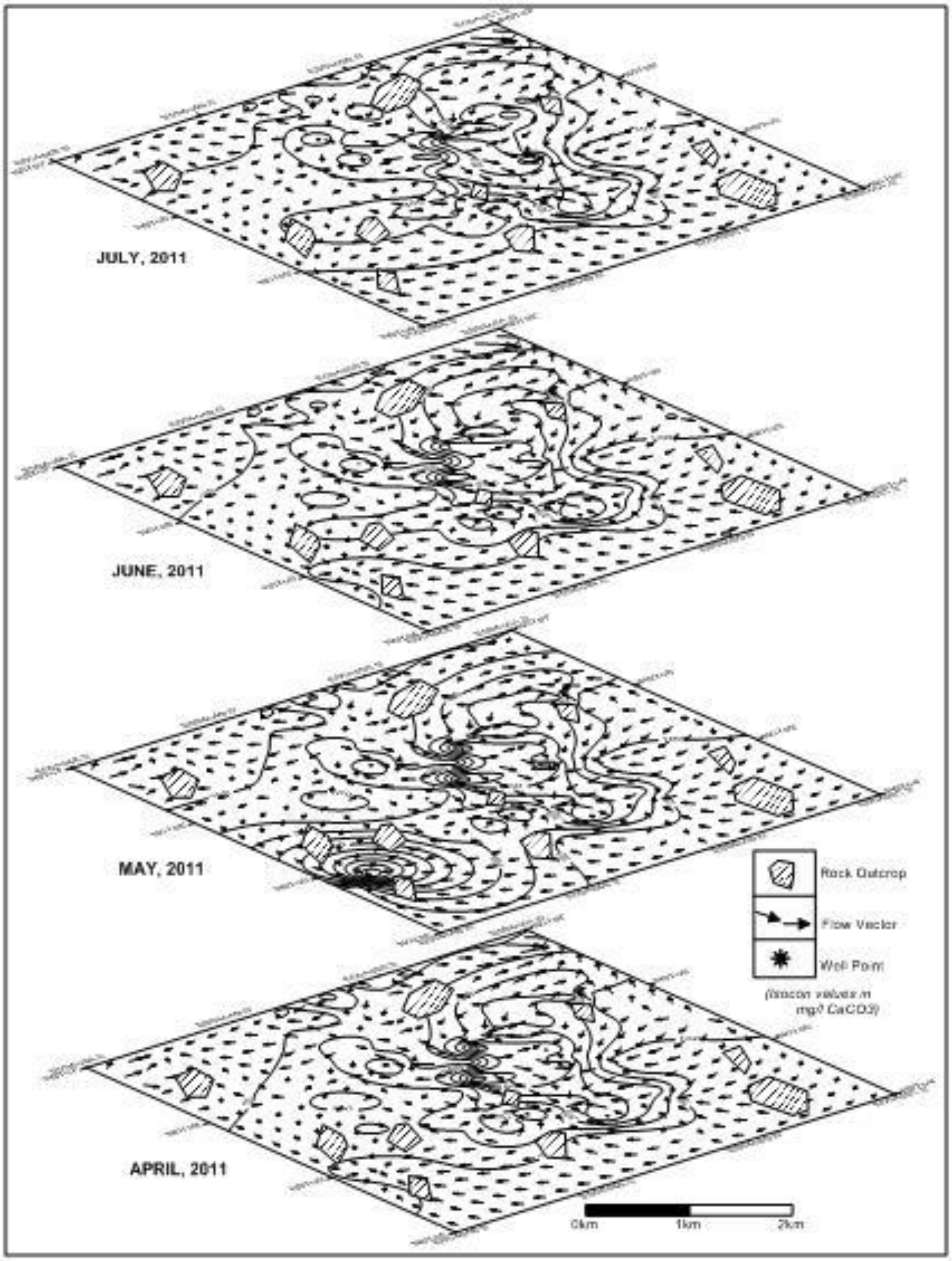

Figure 8: Spatial Distribution of TDS

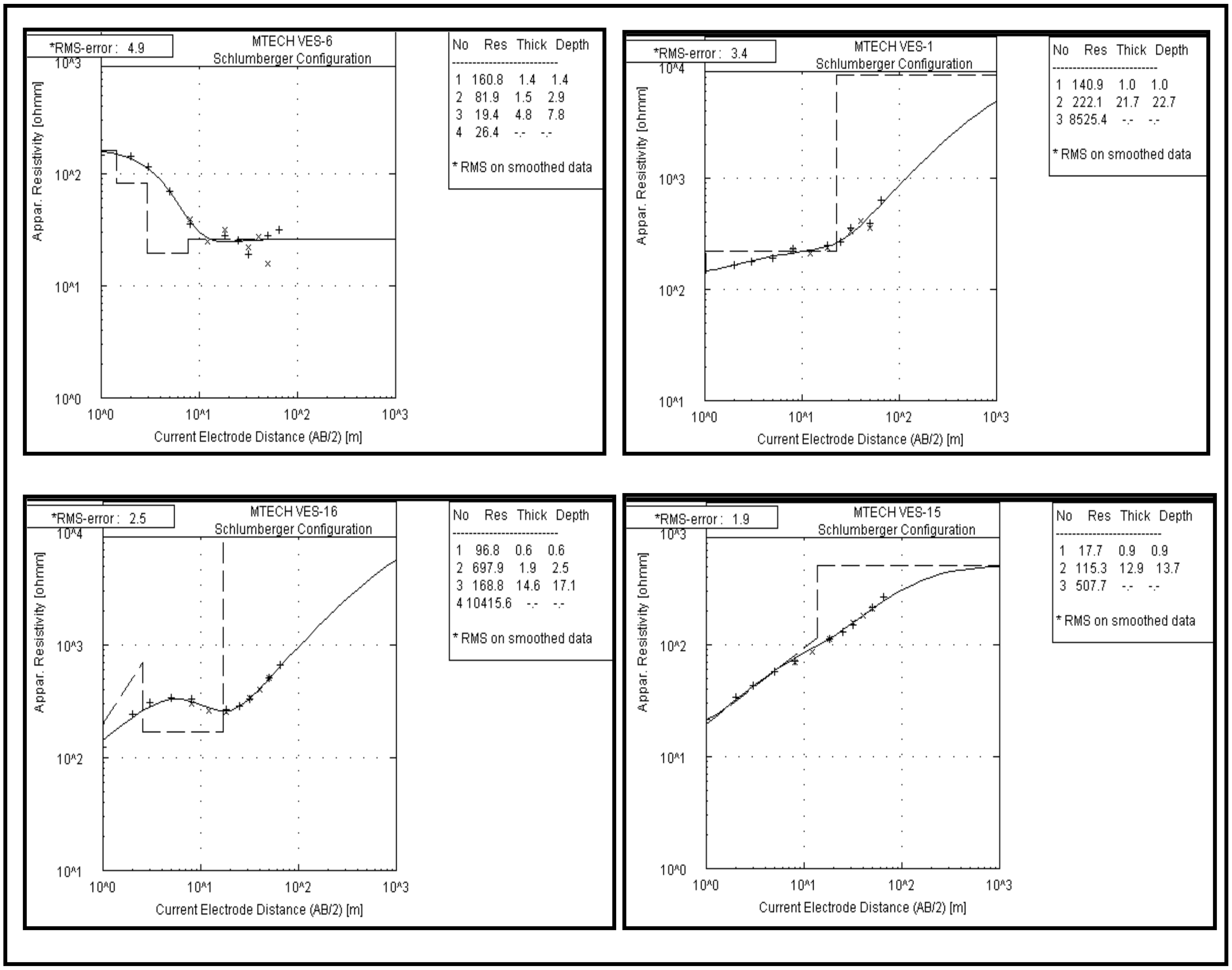

Figure 9: Typical VES Curves

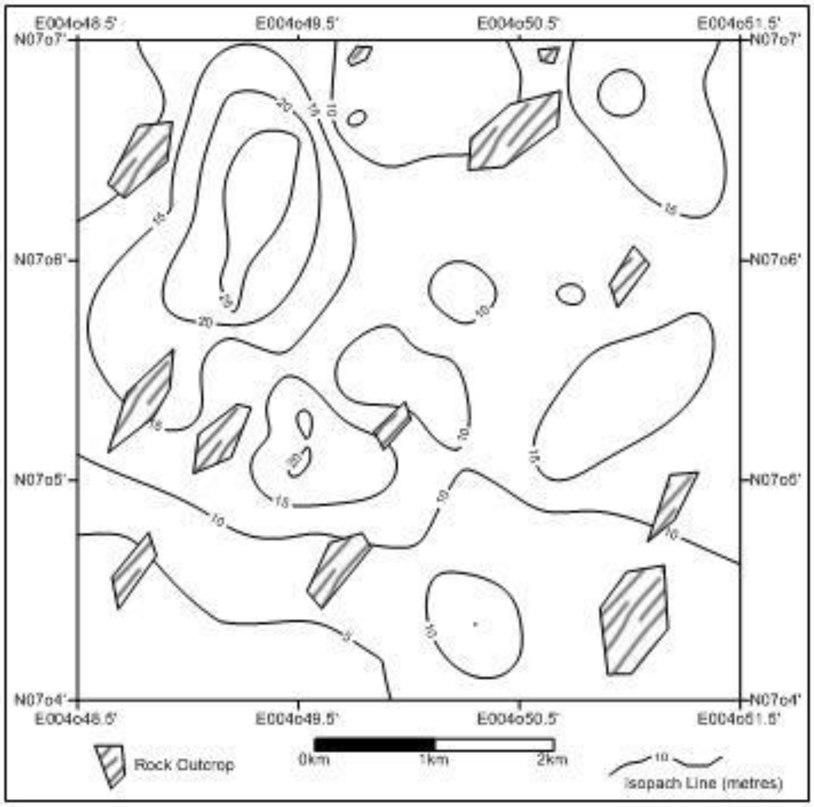

Figure 10: Isopach Map of the Overburden

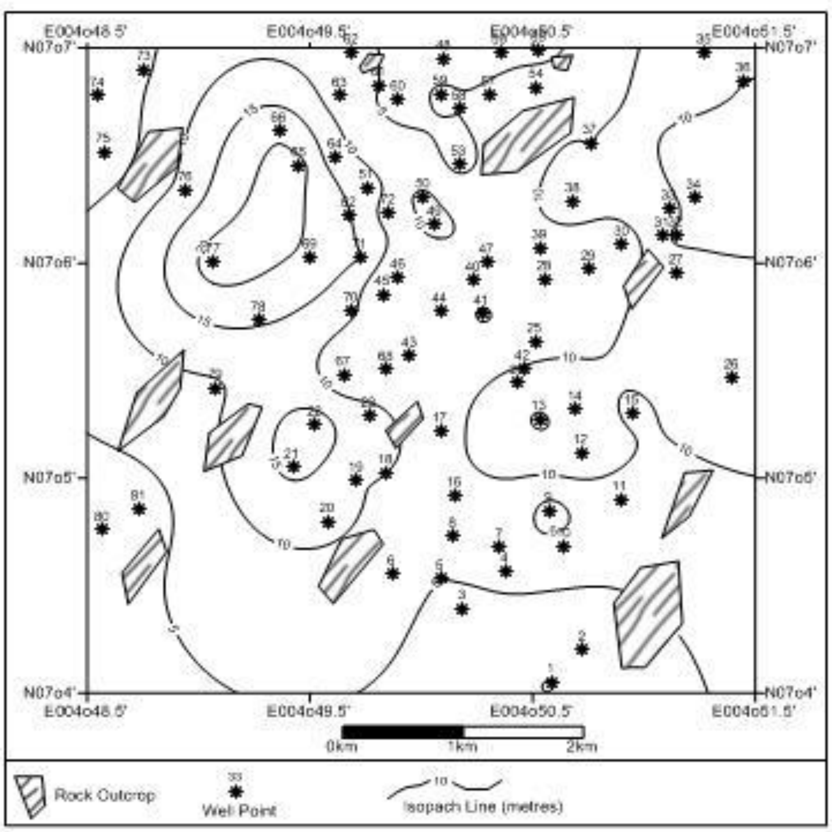

Figure 11: Saturated Thickness Map

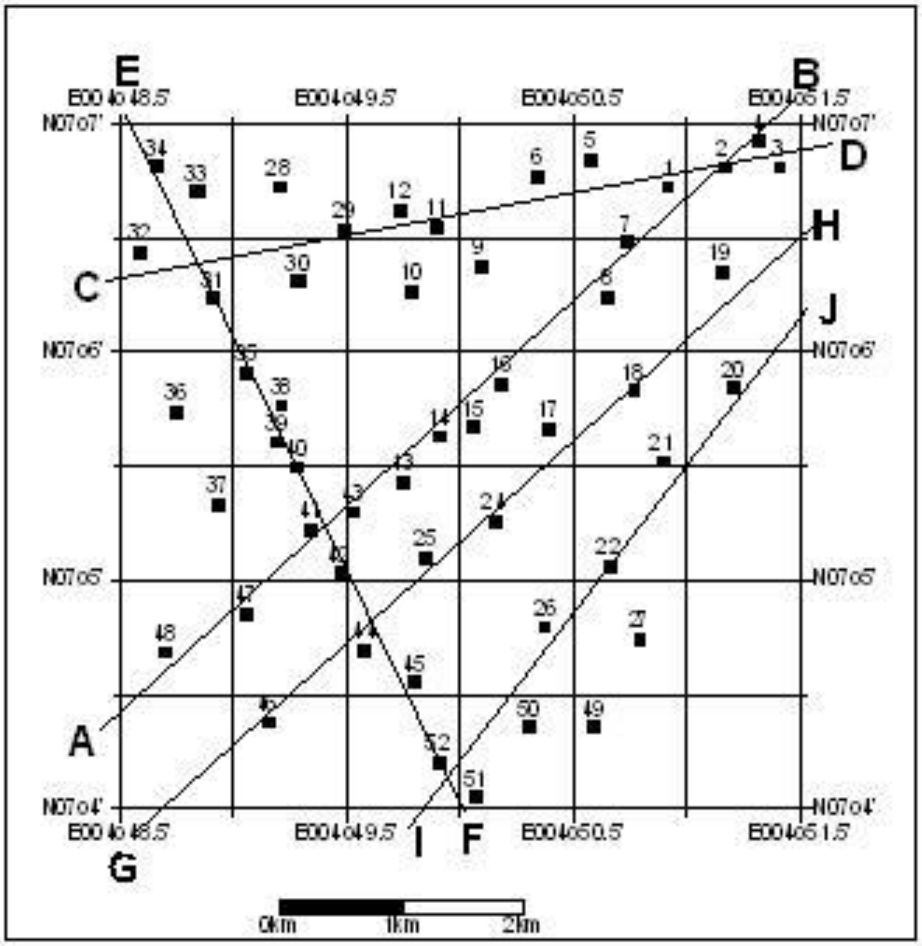

Figure 12: Lines of Profiles used for the Study

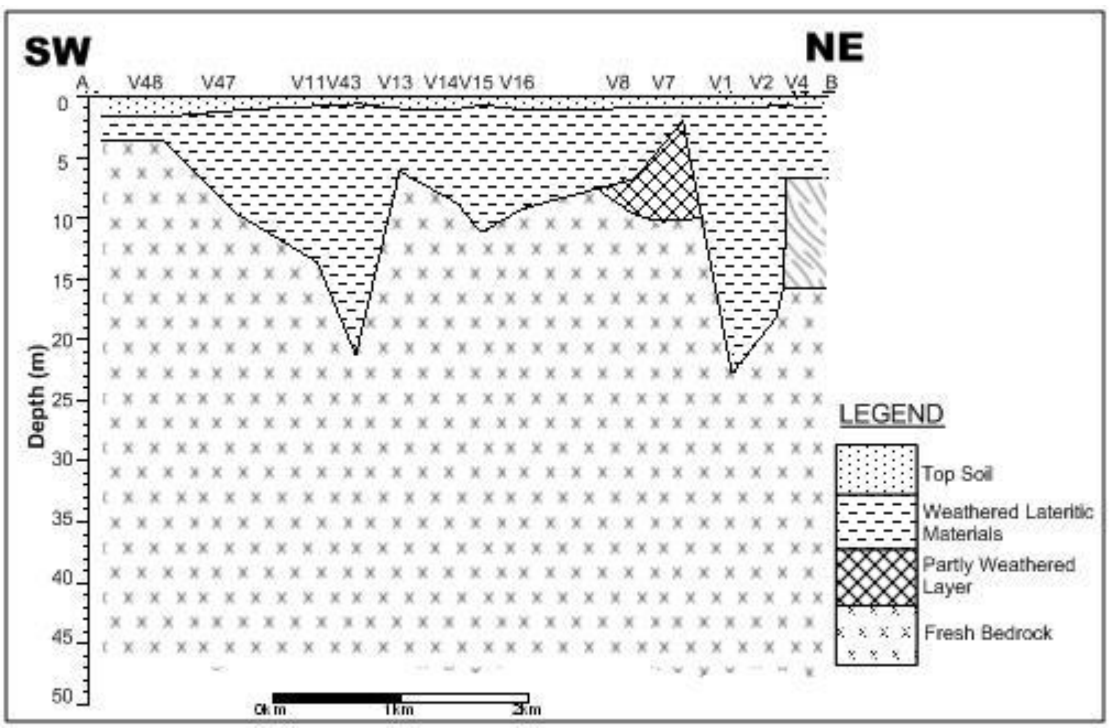

Figure 13: Geo-electric section along Profile AB.

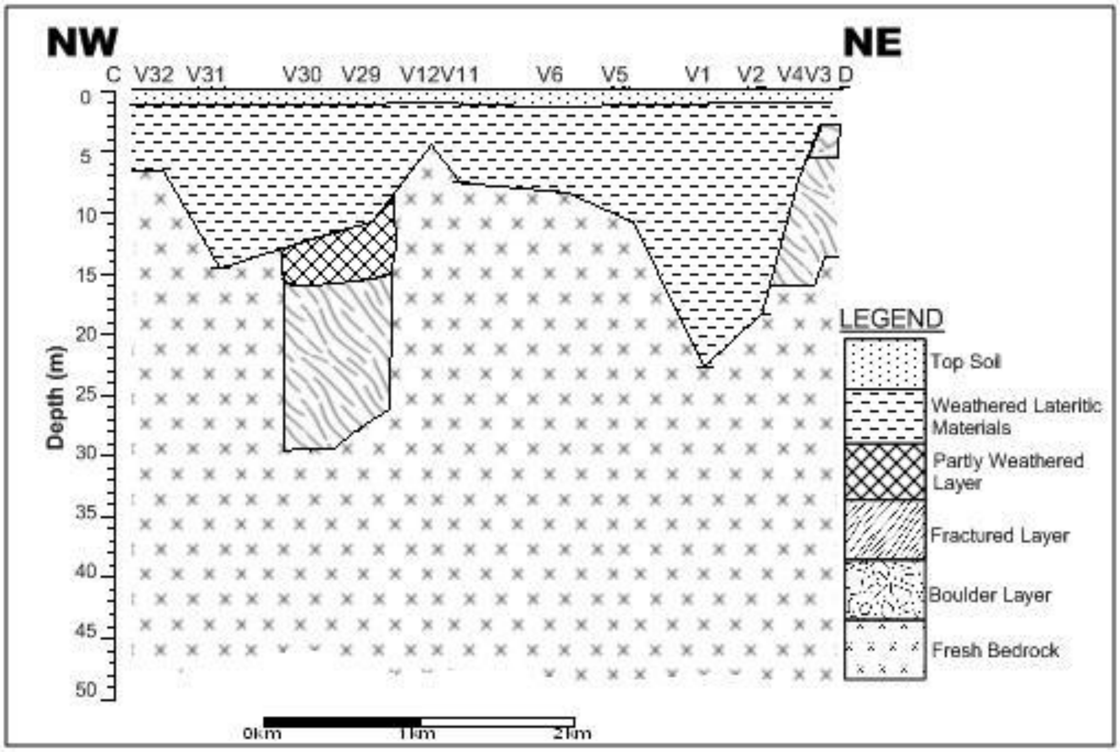

Figure 14: Geo-electric section along Profile C-D

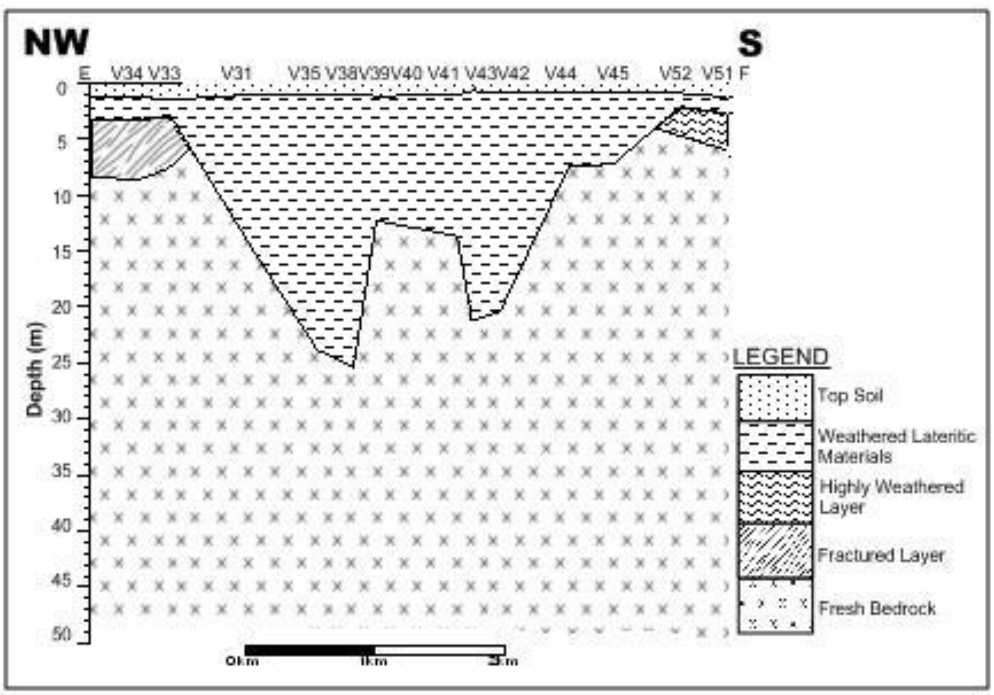

Figure 15: Geo-electric section along Profile E-F

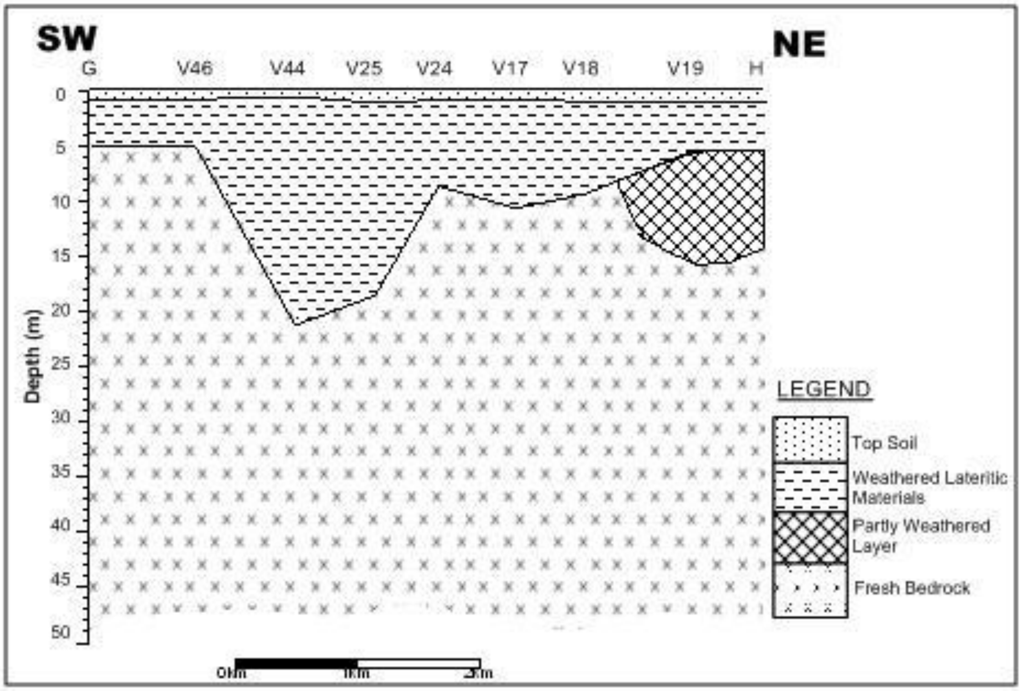

Figure 16: Geo-electric section along Profile G-H

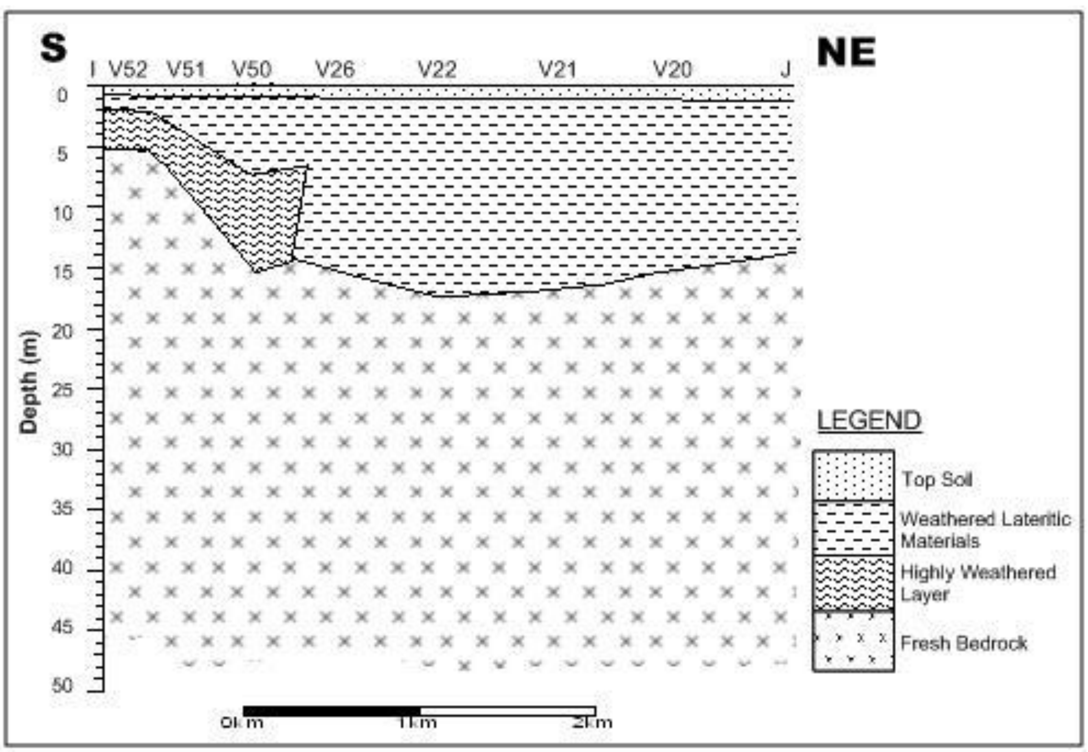

Figure 17: Geo-electric section along Profile I-J