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Full Length Research Paper

An assessment of hydrogeologic characteristics of Bamikemo's hard rock terrain using geophysical techniques

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Resistivity depth soundings integrated with the very low-frequency electromagnetic (VLF-EM) profiling and some hydrogeologic measurements were conducted at Bamikemo, Nigeria. The exercise attempted to evaluate the groundwater potential of the main water supply area. The integrated approach enabled the delineation of the regolith/weathered layer containing the overburden aquifers from the hard rock housing the bedrock aquifers. The study reveals that the thickness of the overburden/weathered layer ranges from 2.4 to 24.5 m, with average value of 12.6 m. Static water level also varies from 0.2 to 14 m in the area. The potentiometric surface map constitutes groundwater occurrence guide for the area. In all the fifteen electromagnetic (EM) profiles established, prominent fractures in varying magnitudes were only in two profiles. A comparative correlation with the appropriate geoelectric sections show that resistivity parameters around the EM-delineated bedrock fractures within the granite/granite-gneiss bedrock in the area which reveals that the bedrock is not considerably decomposed or fractured to hold significant quantities of groundwater. The prominent EM anomalies at these locations are apparently attributable to fairly thick unconsolidated weathered mantle. Consequently, the weathered overburden in the area, especially the central/western segment is considered groundwater prospect specific area. Beyond the results concerning the main objectives of the survey, the study also justified the reliability in integrated application of hydrogeologic, VLF-EM and depth sounding data in locating groundwater prospect specific areas in hard rock terrains.

Key words: Electromagnetic profiling, depth sounding, overburden/weathered layer aquifers, bedrock aquifers, potentiometric surface.

INTRODUCTION

The study area, Bamikemo, is underlain by the basement complex rocks of southwestern Nigeria. In typical hard rock areas, the geological sequence normally encountered is characterized by the existence of a basement rock overlain by variably thick unconsolidated materials, often referred to as the overburden or regolith (Louis et al., 2002). The portion of the basement rock directly underlying the overburden may be degraded or weathered, owing to prolonged period of contact with moist or water-saturated overburden, and consequently referred to as the weathered layer or partially weathered bedrock. The bedrock may also be fractured or faulted to house groundwater in varying quantities. These horizons often constitute the water supply area in the basement terrain (Lenkey et al., 2005; Omosuyi, 2010). Aquifers contained in these horizons are referred to as the overburden, the weathered layer and bedrock aquifers, respectively (Jones, 1985; Louis et al., 2002; Cook et al., 2005; Sharma and Baranwal, 2005; Das et al., 2007).

Due to the heterogeneous nature of the geology of the basement complex terrain, which often vary widely in composition and structure (Jeelani, 2008; Singhal, 2008), the aquifer system in the mentioned horizons is characterized by spatial and temporal variability.

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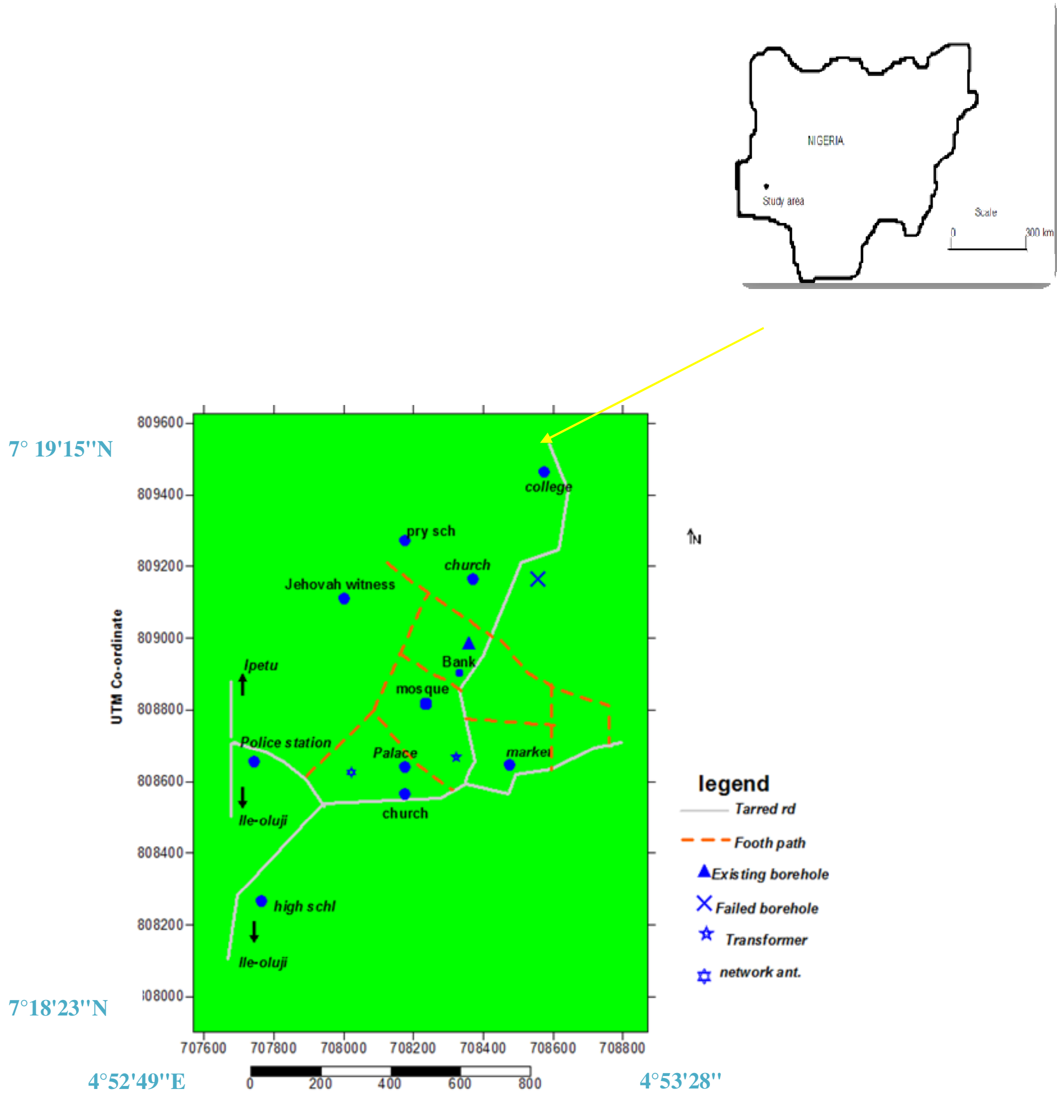

Figure 1. Location map for the area (Inset: map of Nigeria).

Consequently, it is highly desirable to put in place the appropriate geophysical and hydrogeologic approach in order to delineate and evaluate the prospect specific areas.

Recently, profound attention has been given to the application of geophysical methods to derive parameters and variables characterizing near surface groundwater systems, particularly in the hard rock terrains. Among all geophysical methods, geoelectric and electromagnetic (EM) methods, either in solitary or composite approach (van Overmeeren, 1989; McNeill, 1990, 1991; Bernard and Valla, 1991; Lenkey et al., 2005; Rubin and Hubbard (eds), 2005; Powers et al., 2006; Vereeken et al., 2006; Sundararajan et al., 2007) are undoubtedly the leading ones in the exploration and management of groundwater.

In the present work, the EM and electrical resistivity methods have been integrated with some hydrogeologic measurements from existing wells to evaluate the hydrogeologic characteristics of local aquifer for water supply.

The work can reliably constitute a base for rural groundwater development plan for the area, in addition to fulfilling an academic research programme.

Geographic setting

The study area is one of the communities in Ileoluji/Okeigbo local district areas of Ondo State, southwestern Nigeria. It is located along the Ileoluji-Ipetu Ijesa roadway, and about 10 km from Ileoluji. The area lies within longitudes 40° 52' 49" and 40° 53' 28" and latitudes 70° 18' 23" and 70° 19' 15" (Figure 1).

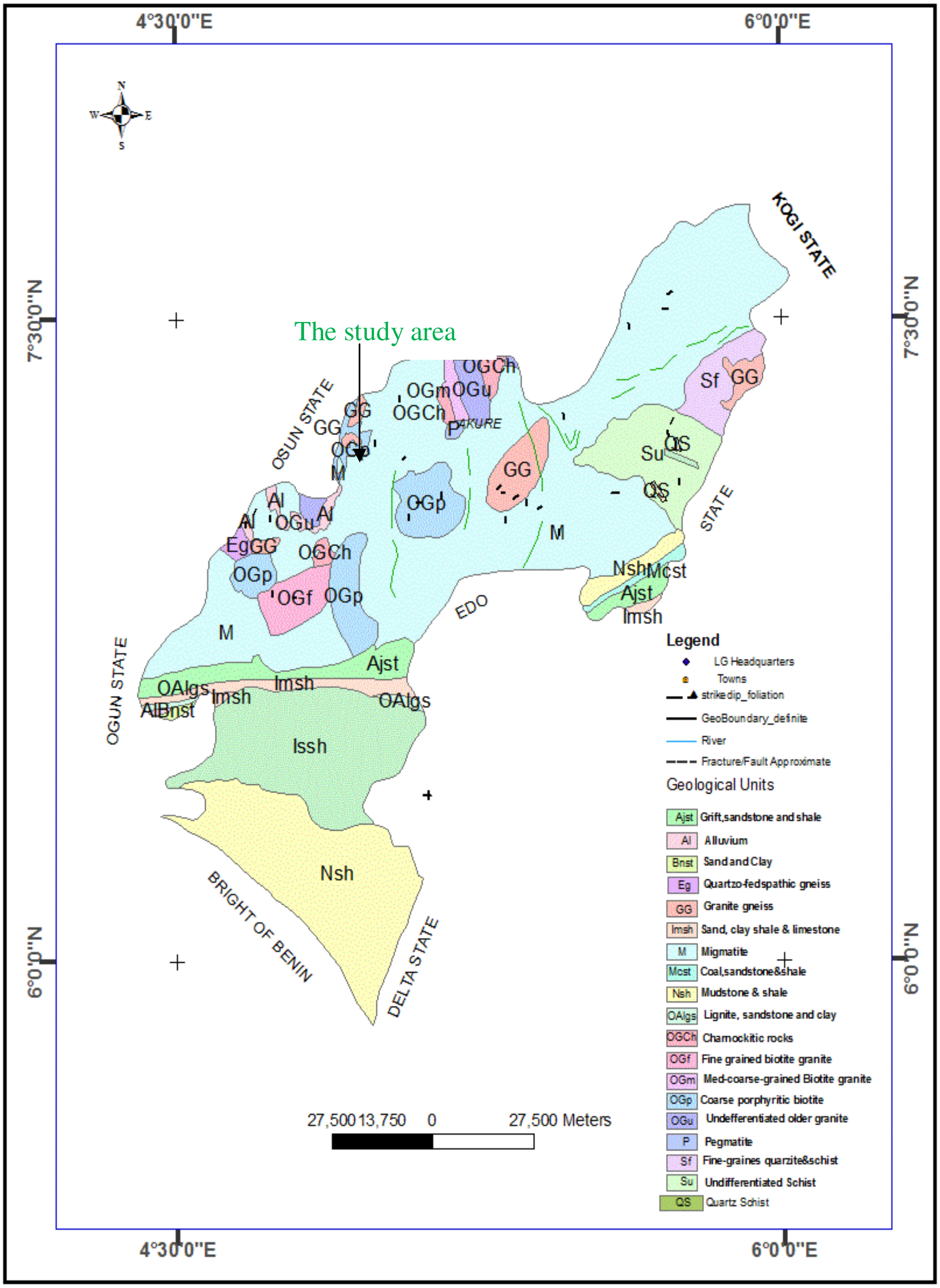

Figure 2. Geological map of Ondo State, Nigeria (Adapted from NGSA, 2006).

Geologic setting

The area is underlain by the Precambrian basement complex rocks of southwestern Nigeria (Rahaman, 1976). The local geology consists of granites, migmatite-gneiss and biotite-gneiss. The granites are the most widespread (Figure 2). They are light to dark grey, coarse-grained and usually contain euhedral phenocrysts of alkaline

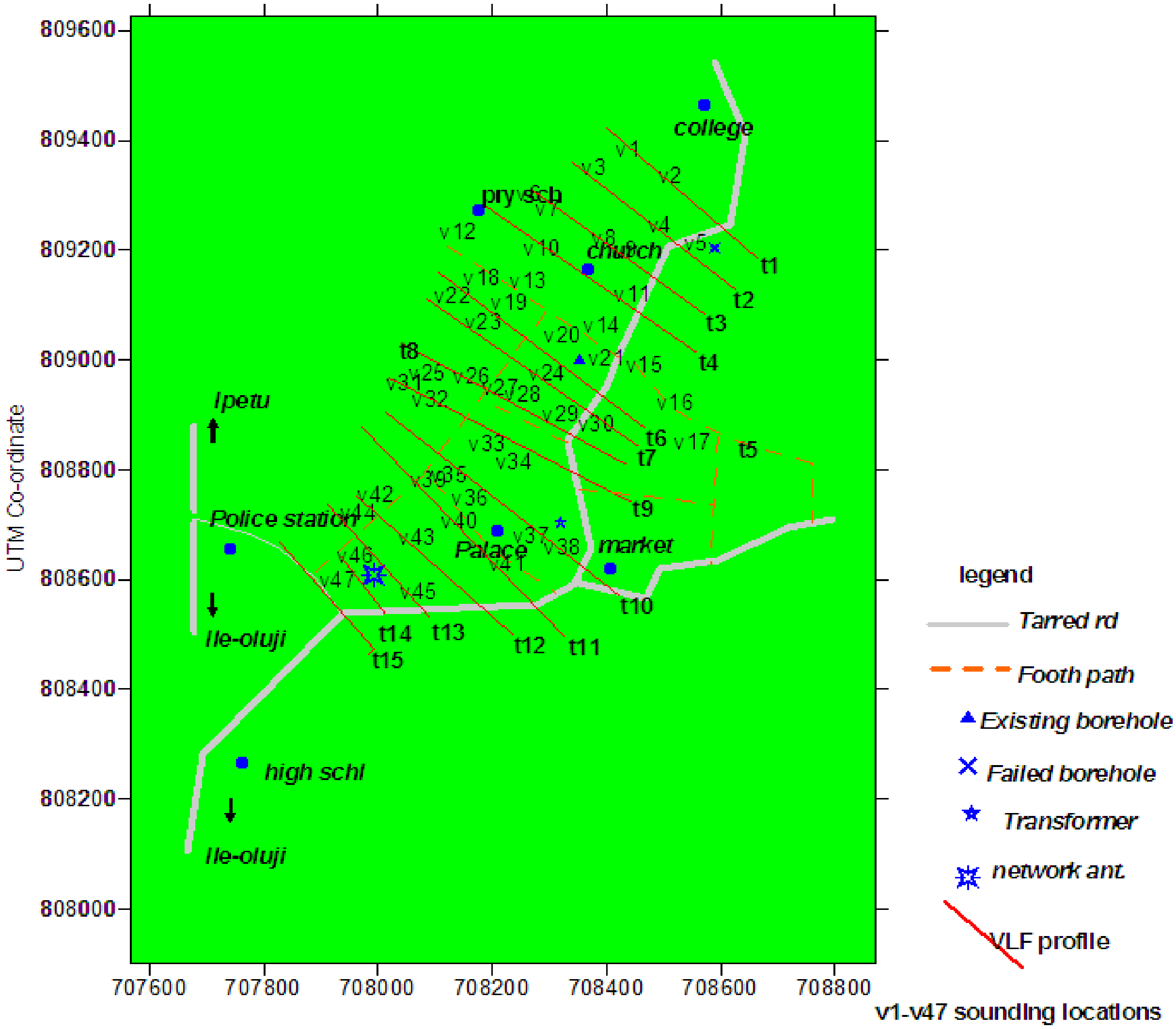

Figure 3. Map showing EM profiles and depth soundings locations in the area.

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METHODOLOGY

The ABEM Wadi instrument (Model 9133001869) was used for the very low-frequency electromagnetic (VLF-EM) data acquisition. The instrument measures the electrical properties of subsurface materials as detailed in McNeill (1980). Measurements were carried out in fifteen near-parallel profiles ranging from 150 to 350 m. Readings were taken at 20 m intervals along each profile. The measurement layout is shown in Figure 3. VLF-EM data tend to be rather noisy. Field data are therefore often filtered, engaging the methods of Fraser (1968) and Karous and Hjelt (1983).

Application of filtering was crucial to remove effects of minor anomalies due to geological noise and electrical interference. The ABEM Wadi instrument automatically displays Karous-Hjelt filtered data. Quantitative analysis of the EM profiles enabled the identification of points where positive amplitude of filtered real crossover the inflection points of the raw real. These points of anomaly were considered suitable for depth soundings as reported in Sundararajan et al. (2007).

A total of forty-eight depth soundings were conducted in the area (Figure 3). The depth sounding engaged the Ohmega Ω resistivity meter (with measurement range of 0.001 Ohm to 400 kOhm), manufactured by Allied Associates Geophysical Limited. The depth soundings adopted the Schlumberger array (Patra and Nath, 1998) with maximum AB spread of 200 m. The sounding locations were mostly points of anomaly established from the plot of reconnaissance EM profiling. The vertical electrical sounding (VES) data were presented as sounding curves (Typical curves are shown in Figure 4). The field curves were preliminarily manually interpreted, using the conventional partial curve matching (Koefoed, 1979; Patra and Nath, 1998) to determine the thickness and resistivity of the layers. The model derived from manual interpretation was interactively adjusted (Vander Velpen, 1988) to get a better fit in each case. The fit in all cases is within the error limit of 2.5%.

Depths to water level (static water levels) and the rock head were measured in sixty three existing wells across the area (Figure 5). Static water levels were measured with water level dipper, while depth to rock head was physically measured with steel tape (Moore, 2002). The elevation above sea level at each well location

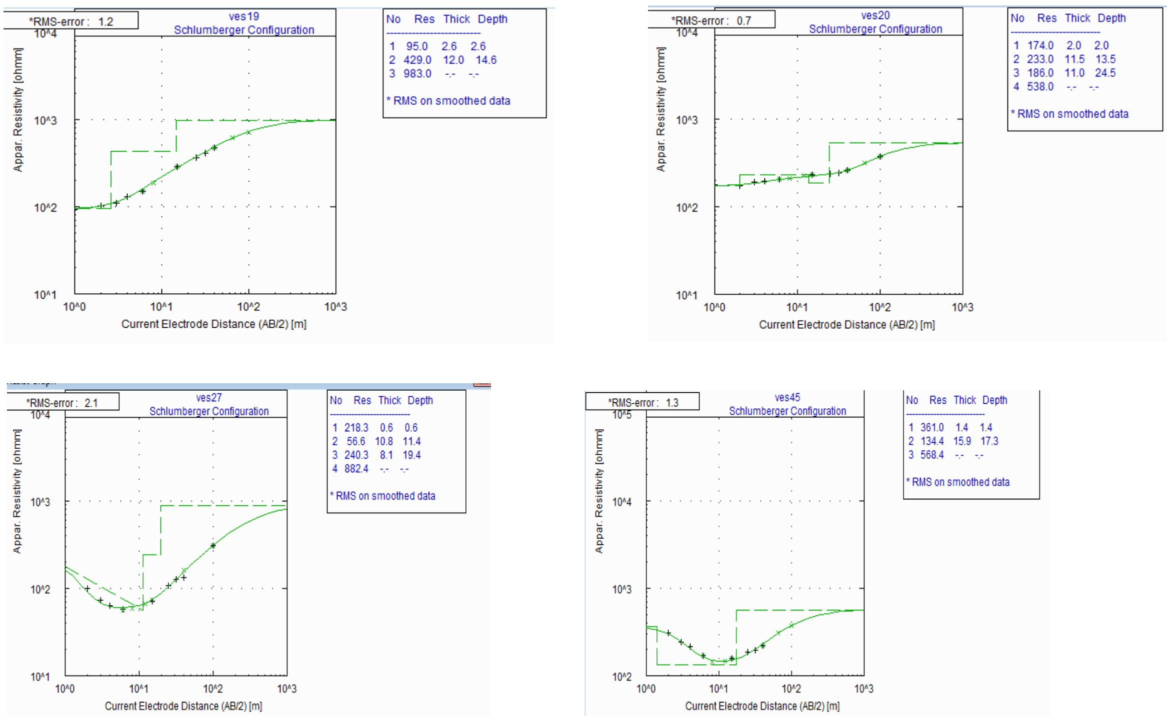

Figure 4. Typical VES curves from Bamikemo.

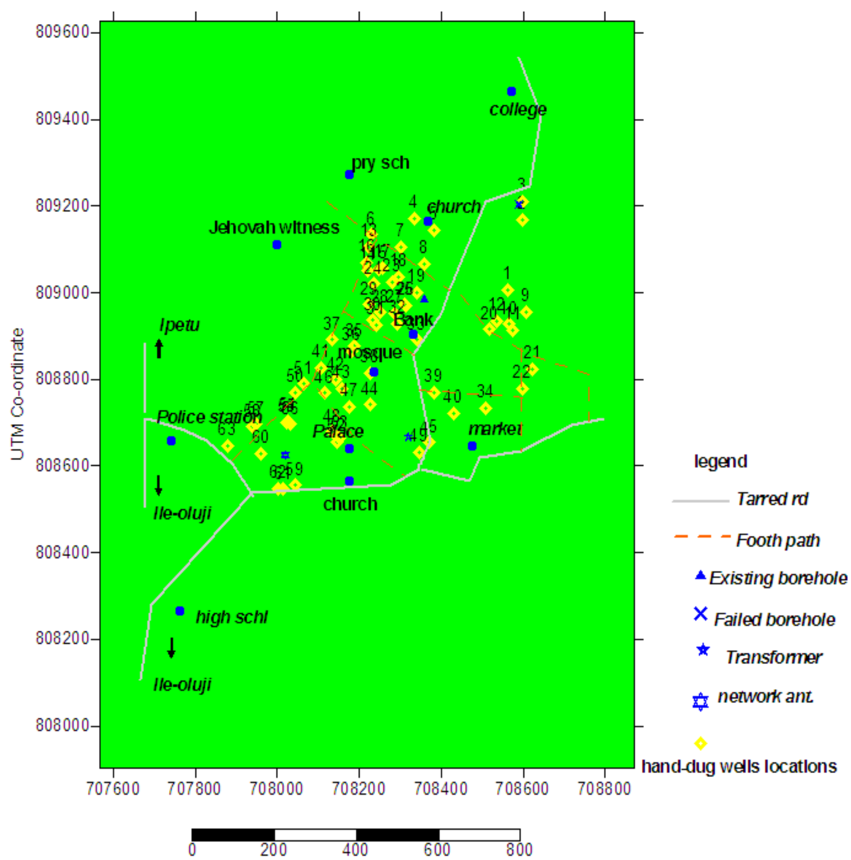

Figure 5. Map showing locations of wells studied in the area.

was also determined. These parameters were used to compute the general hydraulic head (HH) across the area, based on Buddermeier and Schloss (2000). The data also enabled the preparation of potentiometric surface map for the area, using the approach in Hiscock (2005) and Willis (2008).

RESULTS AND DISCUSSION

The VLF-EM data were presented as plots of real component (field data) and Fraser filtered data with corresponding pseudo sections of the subsurface relative current density distributions (Karous and Hjelt, 1983). The amplitudes of responses (the EM anomaly) are functions of host rocks resistivity, conductance, clay content and perhaps the geometry of the conductors (Ogilvy and Lee, 1991; Kaikkone, 1998). High Fraser anomaly is believed to be a response of a conductor or fracturing within the bedrock (Sharma and Baranwal, 2005).

Fraser filtering responses range in value from -83.2 to 84% along the profiles, with corresponding relative density from -64.1 to 38.3%. Representative sections are shown in Figure 6. Conductors (coloured red) were delineated from relative current density pseudo sections along traverse 5, 6 and 10 (Figure 6), where relative values range from 6.2 to 27%. A higher value of relative current density is regarded as conductive subsurface structures, such as fractures (Sharma and Baranwal, 2005; Santos et al., 2006), which often store groundwater in hard rock terrains.

However, the anomaly obtained from VLF-EM measurements indicates the presence of conductive domain, which may be clay (Palacky, 1987) or fractures at deep or shallow sources, which the method cannot effectively delineate, thus, emphasizing the need for an integrated approach.

Geoelectric layers, not fully representative of geologic layers, range from 3 to 4 across the study area. Resistivity values range from 90 to 670 Ohm-m, with thickness value of 0.5 to 3.0 m in the topsoil or first layer. In the unconsolidated (second) layer, resistivity values vary from 40 to 640 Ohm-m, with layer thickness of 3.2 to 23 m and average thickness of 12.6 m. The resistivity of the bedrock is mostly over 400 Ohm-m. Representative geoelectric sections showing subsurface distribution of the geoelectric parameters, and correlated with the corresponding EM profiles, are shown in Figure 6.

The correlation of the EM profile and depth sounding interpretive sections enabled some correlative analysis. Figure 6b reveals that the magnitude of the Fraser responses along profile 5 varies from 2.3 to 17%, with Karous-filterng current density value ranging from –0.7 to 7.3%. The pseudo section shows that conductors within the highest current density (coloured red and marked E) lie at depth of about 25 to 40 m between stations 280 to 320 m. The resistivity value of the bedrock (267 Ohm-m) at this location (VES15) suggests that the bedrock is just fairly fractured.

Figure 6c shows the signature and the pseudo current density cross-section along VLF profile 5. The Figure 6c also shows geoelectric section correlating four VES locations established along the profile. The pseudo current density cross-section shows conducting features near stations 150 and 160 m (marked B). However, the bedrock resistivity (533 Ohm-m) at the corresponding sounding location (VES 20) does not suggest significant fractures.

In Figure 6d, the pseudo current density cross-section along this profile clearly indicates conductive/fracture zone at 100 to 150 m (marked A) and 250 to 300 m (marked B), which correspond to bedrock resistivity values of 401 Ohm-m (VES 36) and 466 Ohm-m (VES 37), respectively. A high Fraser peak with high positive current density and low resistivity is often diagnostic of water-bearing fracture (Sundararajan et al., 2007). Since the resistivity parameter of the conductive bedrock, source of the anomaly does not appropriately correlate with the magnitude of the current density; the inferred conductive body may not in reality be a conductor. It may be attributable to surface or near surface spurious sources.

In the study area, the thickness of the weathered overburden ranges from 4.1 to 24.5 m (Table 1), with an average thickness of 12.6 m across the area. Figure 7 shows that the central/western and southern segments of the area show moderately thick weathered overburden (13 to 19 m) while the overburden materials in the southern and northwestern area are not significantly thick (4 to 11 m). Ioannis et al. (2002), Lenkey et al. (2005) and Omosuyi (2010) believed that boreholes located within thick saturated weathered materials are likely to give high yields of groundwater. The depth to the bedrock measured from the existing wells across the area (Figure 8) also significantly correlates with the trends reported in Figure 7.

Measurements from existing wells in the area show that depth to bedrock varies from 2 to 17 m while potentiometric surface ranges from 0.2 to 14 m. Depths to bedrock measured from the wells correlate fairly well with depths to bedrock (ranging from 2.4 to 24.5 m) delineated from VES data interpretation across the area (Figures 7 and 8).

Figure 9 shows potentiometric surface map of the area. In an unconfined aquifer, potentiometric surface gives a picture of water table (Hiscock, 2005). The map shows that water table occurs at shallow depths in the eastern/southwestern and western/northwestern parts of the area. Potentiometric surface map constitutes an important groundwater occurrence guide in the area, since water table cannot be reliably delineated from the EM and VES data interpretation.

The map (Figure 10) showing bedrock resistivity distribution across the area tends to suggest that the bedrock is generally not significantly or extensively

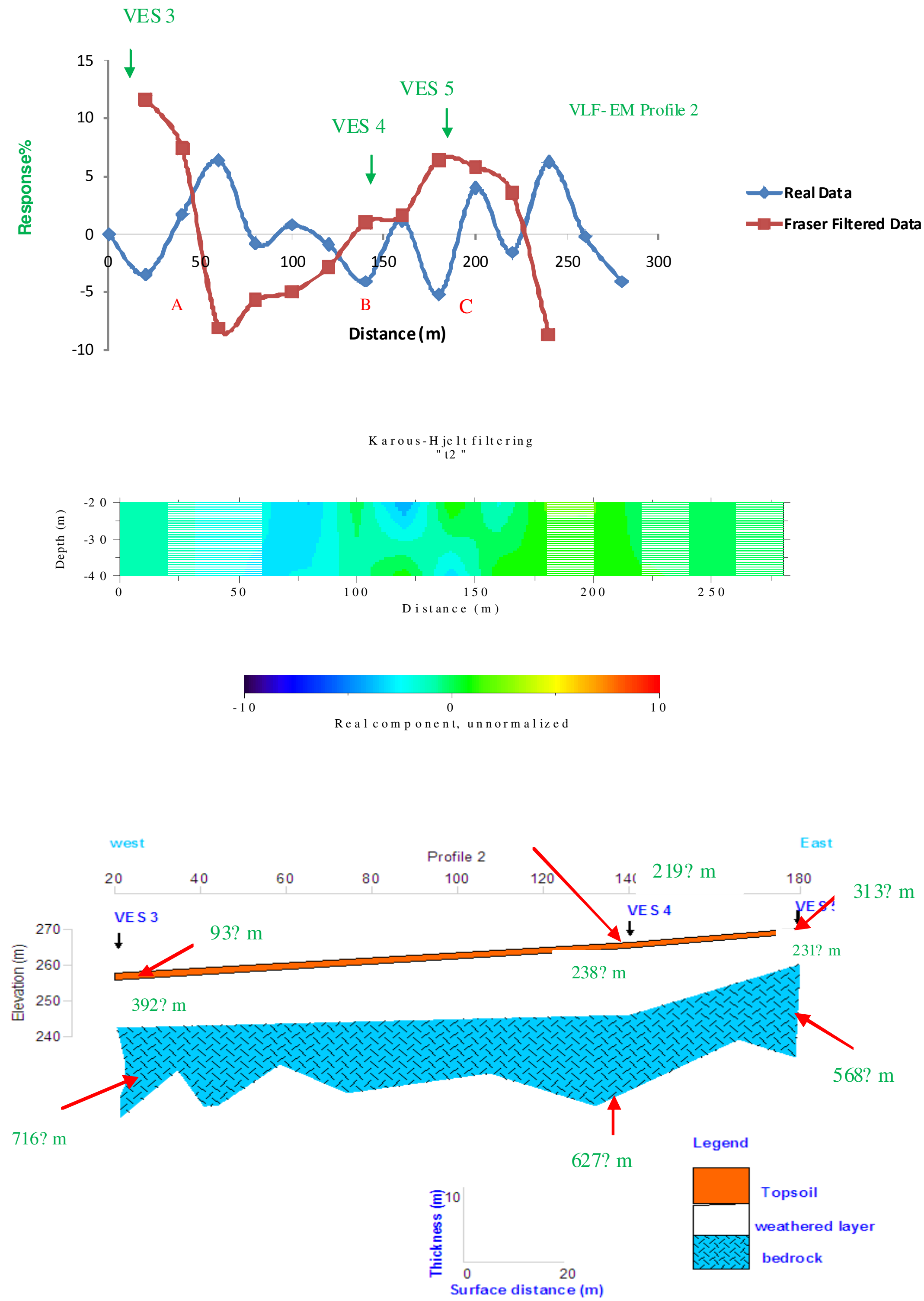

Figure 6a. EM profile with corresponding geolelectric section along traverse 2.

fractured. The prominent current density rather seemly reflects the presence of fairly thick weathered materials, possibly containing groundwater. There is good correlation between these two cross-sections since the thickest overburden/weathered material was delineated in this location (VES 20).

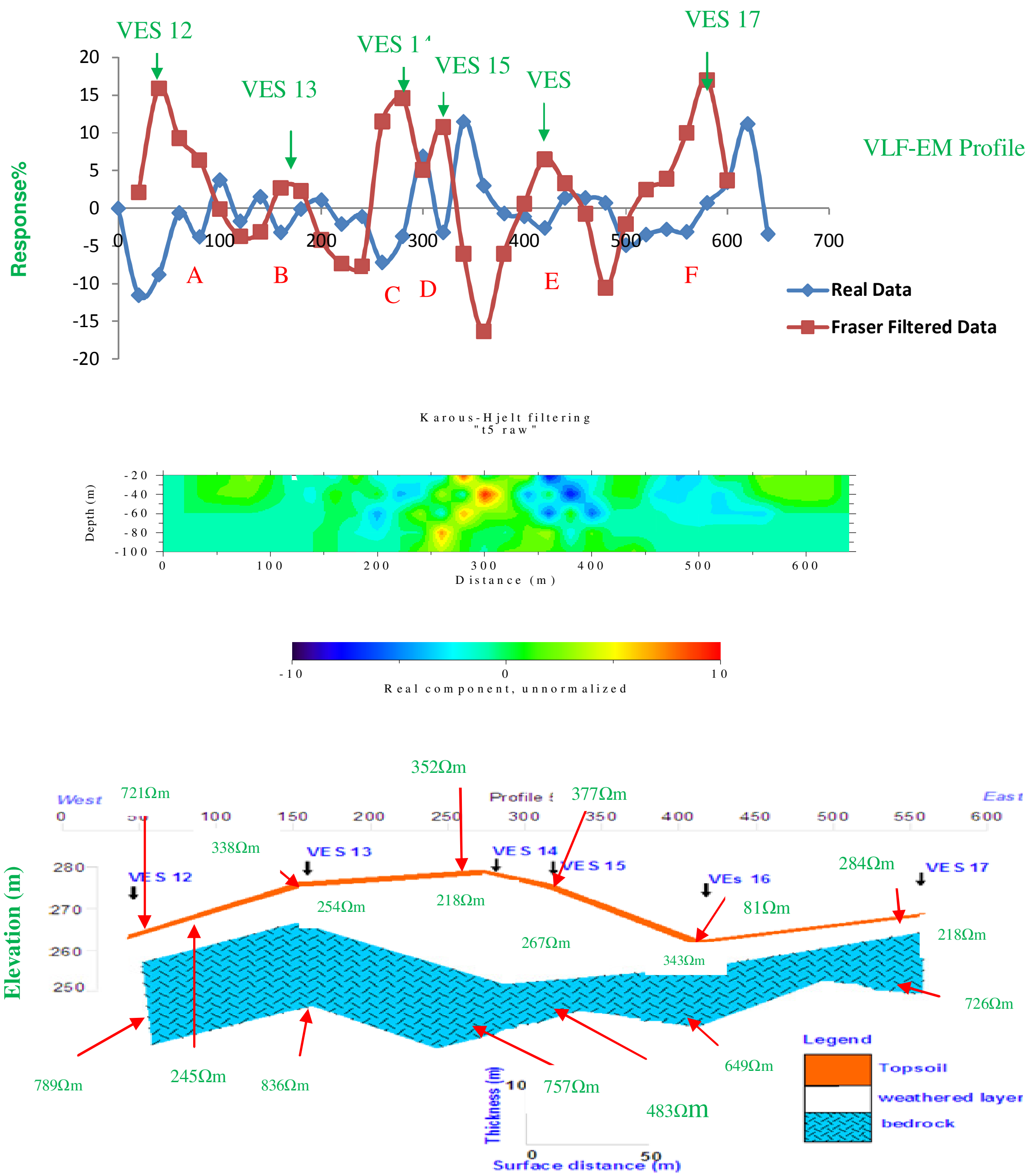

Figure 6b. EM profile with corresponding geoelectric section along traverse 5.

In profile 10 (Figure 6d), the magnitude of the anomaly is large, apparently extensive and also scattered.

Conclusion

A comparative integrated interpretation of VLF-EM and VES data enabled the delineation of water supply areas and the evaluation of the groundwater prospect of Bamikemo, a basement complex terrain of southwestern Nigeria. With the additional information obtained from existing wells across the area, the spatial distribution of the regolith/weathered layer, containing the near-surface or overburden aquifers, was reliably delineated from the bedrock housing the bedrock aquifers. The study revealed that the weathered overburden thickness ranges from 2.4 to 24.5 m, with an average value of 12.6 m across the area.

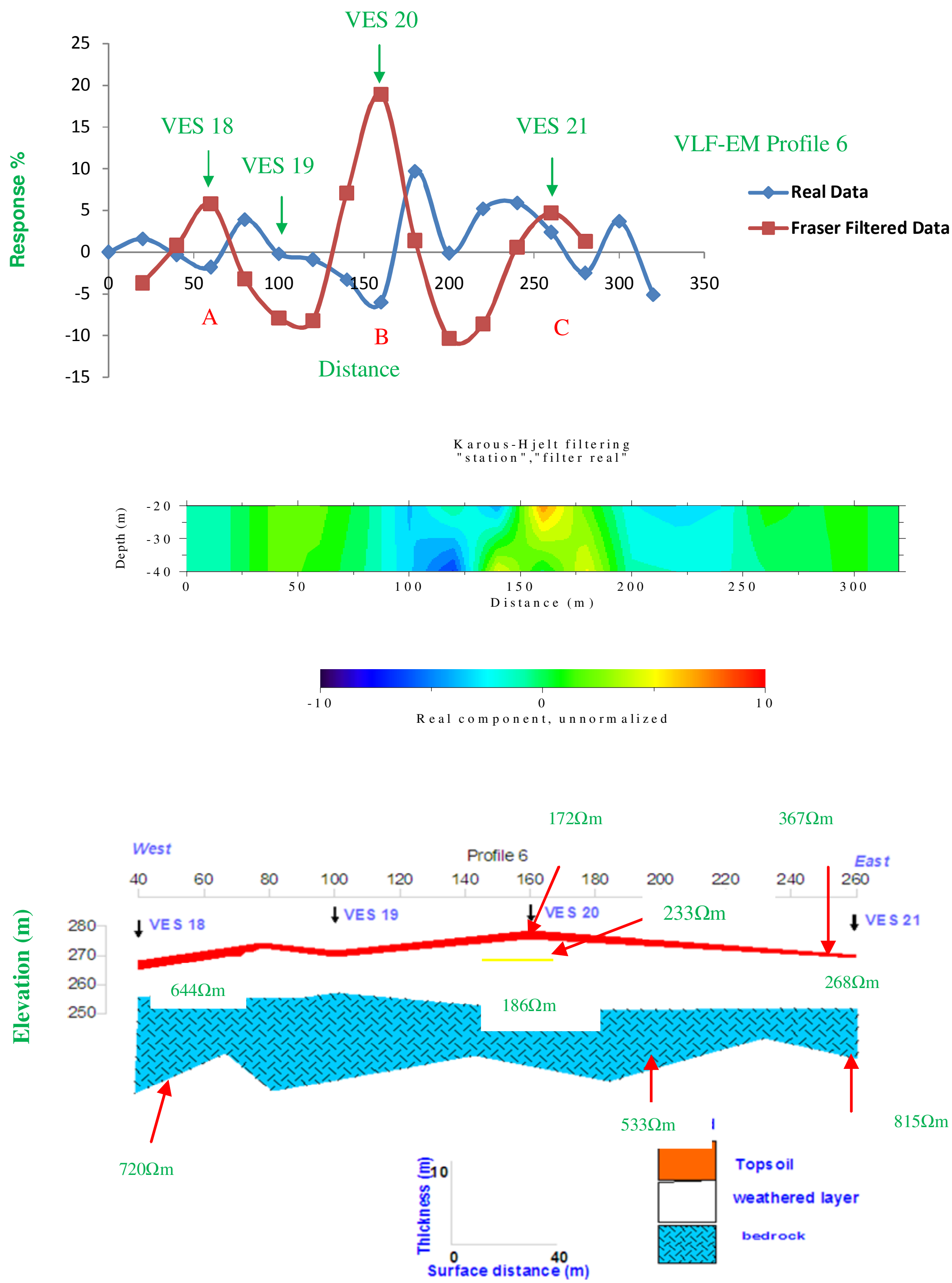

Figure 6c. EM profile with corresponding geoelectric section along traverse 6.

Potentiometric surface in the area varies from 0.2 to 14 m. Potentiometric surface map constitutes groundwater occurrence guide for the area.

Out of the fifteen VLF-EM profiles established, apparently prominent fractures were delineated in only two. A comparative correlation with the appropriate geoelectric

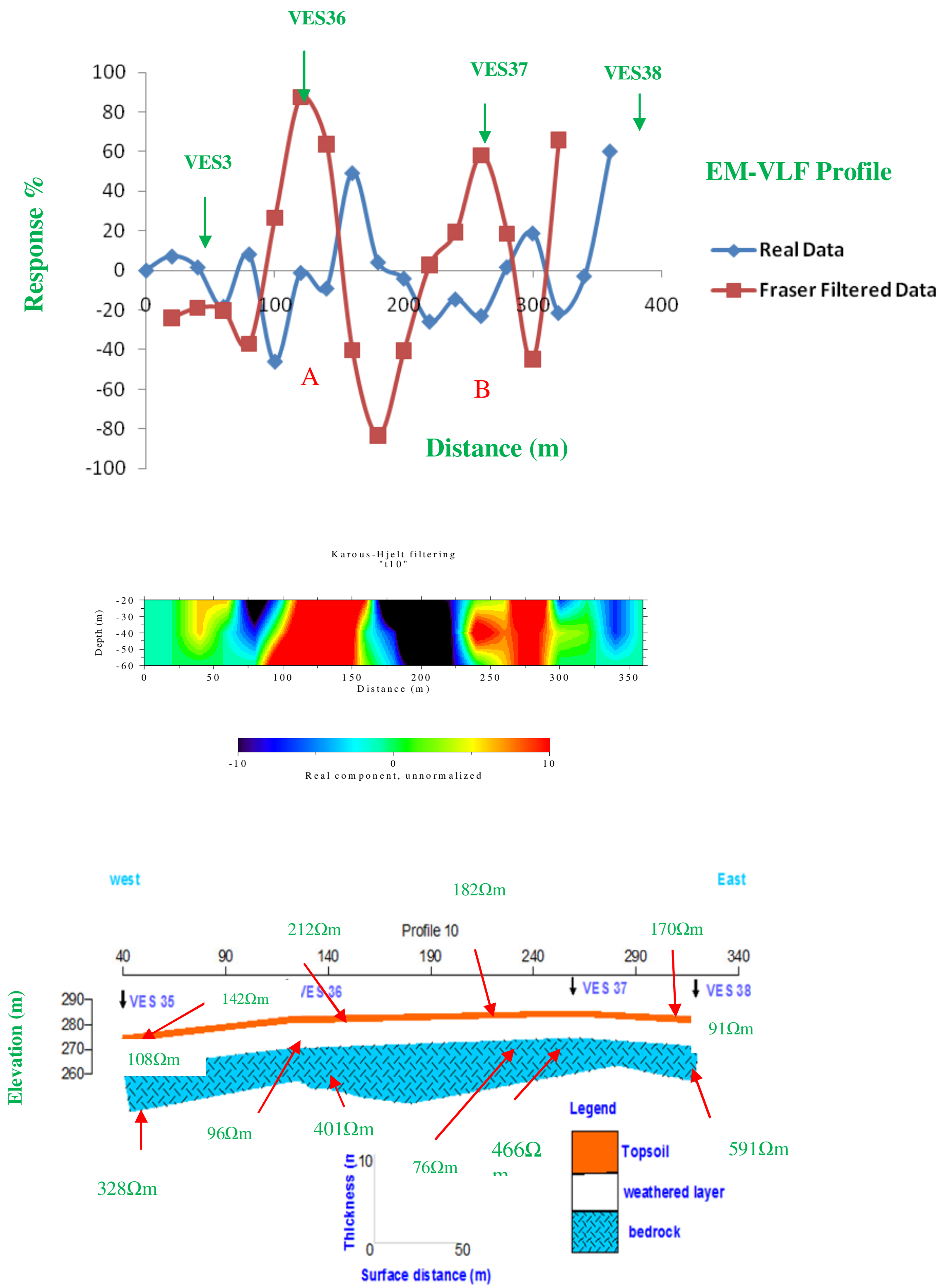

Figure 6d. EM profile with corresponding geoelectric section along traverse 10.

sections reveals that the resistivity parameters of the EM-delineated bedrock fractures suggests that the granite/granite-gneiss bedrock is after all not significantly decomposed or fractured to hold significant quantities of

Table 1. Interpreted layer thickness and resistivity across the VES locations.

No. of VES	Thickness (m)			Resistivity Ωm			
	h_1	h_2	h_3	ℓ_1	ℓ_2	ℓ_3	ℓ_4
1	0.8	8.0	9.0	245	226	546	825
2	0.5	2.5	16.3	251	109	267	556
3	2.1	13.0	-	85	352	771	-
4	0.8	15.2	-	346	237	574	-
5	1.0	8.9	-	327	246	584	-
6	2.1	9.5	-	96	232	666	-
7	0.9	12.6	-	431	323	576	-
8	0.9	3.2	-	332	220	519	-
9	1.0	3.0	11	339	204	656	843
10	1.1	8.3	-	363	168	710	-
11	3.0	5.8	-	84	197	526	-
12	0.4	5.1	-	720	251	789	
13	0.8	6.0	-	338	254	836	-
14	0.5	20.0	-	352	218	757	-
15	0.9	15	-	377	267	483	-
16	3.0	11	-	81	343	648	-
17	1.0	4.2	-	284	218	726	-
18	3.0	10.5	-	99	644	720	
19	2.6	12	-	95	429	983	-
20	2.0	11.5	11.0	174	233	186	538
21	0.8	16.0	-	367	268	815	-
22	2.0	14.0	-	220	311	591	-
23	0.8	11.0	-	327	218	678	-
24	1.4	19.0	-	166	274	958	-
25	0.7	14.0	-	341	252	599	-
26	1.3	10.0	7.3	200	132	392	644
27	0.6	10.8	8.1	218	57	240	882
28	1.0	4.0	10.2	88	81	248	576
29	2.5	12.0	-	86	336	870	-
30	0.9	16.0	-	358	272	819	-
31	0.8	10.8	-	160	108	383	-
32	0.7	12.0	-	178	124	965	-
33	0.7	6.7	7.9	83	92	918	473
34	0.9	7.3	7.3	87	93	1033	605
35	1.6	5.7	-	142	108	328	-
36	0.8	5.5	-	213	97	401	-
37	1.1	3.6		182	76	466	-
38	0.9	5.0	-	169	91	591	-
39	2.6	14.0	-	95	345	431	-
40	0.9	17.3	-	322	208	610	-
41	1.0	16.0	-	265	193	609	-
42	1.8	17.5	-	520	350	842	-
43	0.6	7.0	8.0	160	98	437	934
44	1.4	2.2	9.1	152	83	282	425
45	1.4	15.9	-	361	134	568	-
46	0.6	2.2	8.1	147	87	257	438
47	0.7	13.0	-	418	351	780	-
48	0.7	12.0	-	291	258	435	-

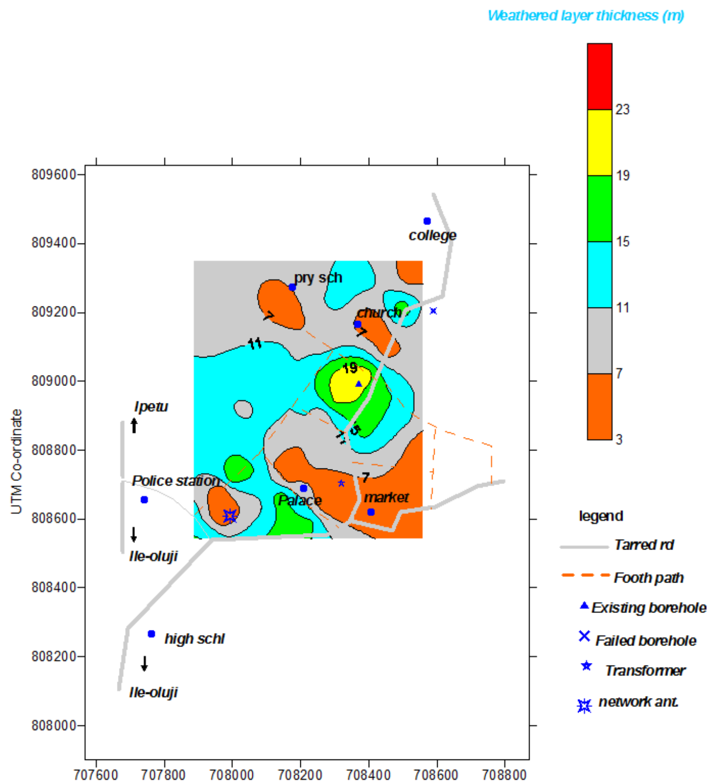

Figure 7. Map showing thickness of unconsolidated weathered layer delineated from VES interpretation.

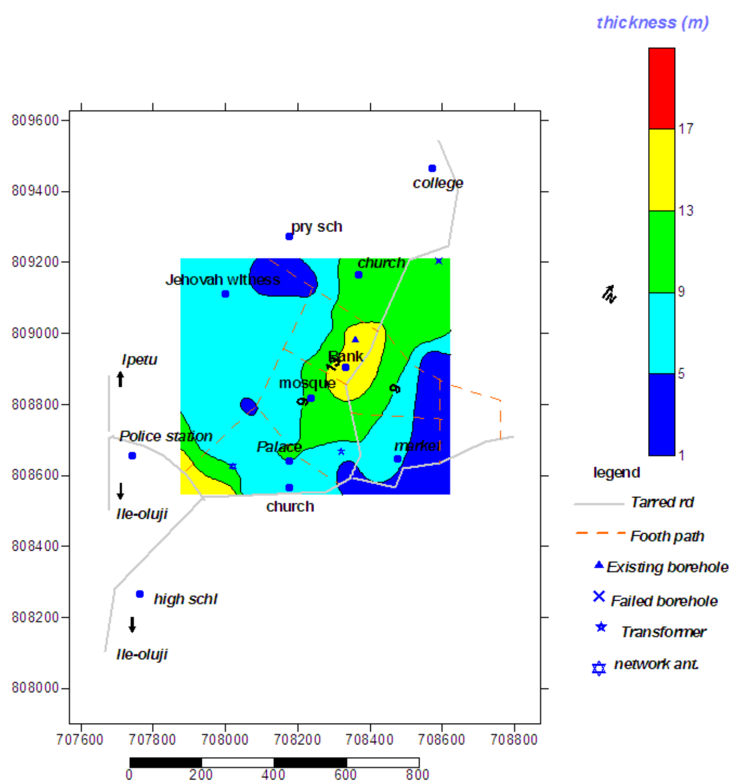

Figure 8. Map showing depth to bedrock determined from wells at Bamikemo.

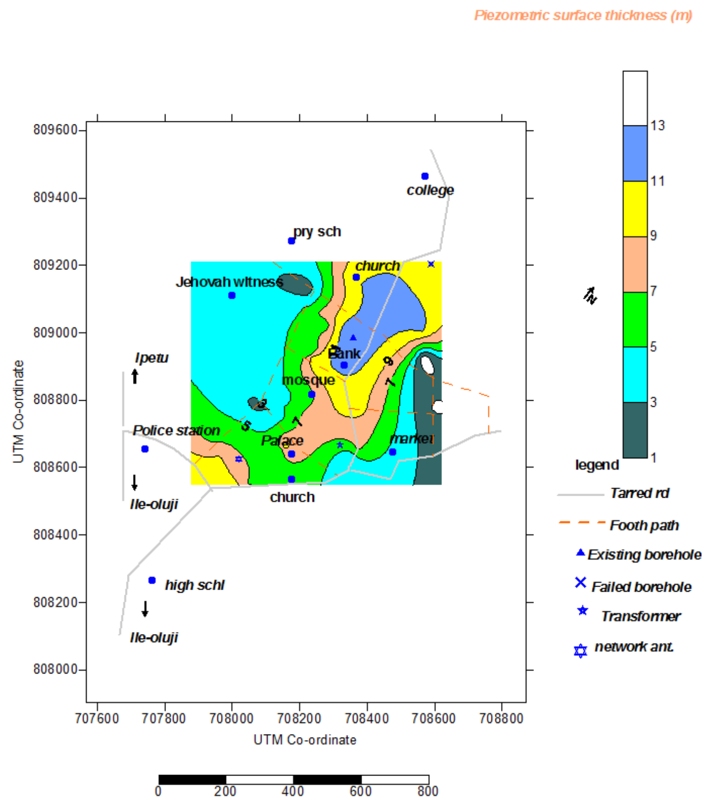

Figure 9. Potentiometric surface map of Bamikemo.

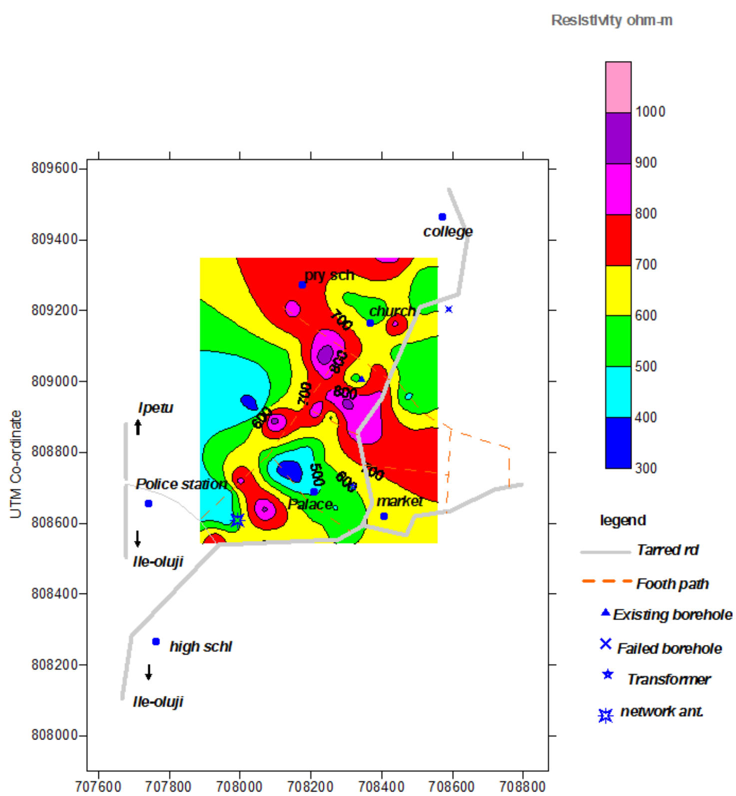

Figure10. Bedrock resistivity map of the area.

groundwater in the area. Consequently, the weathered overburden, especially the central/western portion is considered groundwater prospect specific area.

Beyond the results concerning the main objectives of the study, the survey had also justified the reliability in integrated application of hydrogeologic data, VLF-EM and resistivity depth sounding in the delineation of groundwater prospect specific areas in a typical basement setting.

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