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Aquifer Vulnerability Assessment at Ipinsa-Okeodu Area, Near Akure, Southwestern Nigeria, using GODT

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Abstract
Aquifer vulnerability assessment has been undertaken at Ipinsa and Oke-Odu area, southwestern Nigeria using geoelectrically derived GODT model. One hundred and two (102) vertical electrical soundings (VES) data utilizing Schlumberger array were carried out at half-current electrode separation (AB/2) varied between 1-150 m. Qualitative interpretation of the VES data using partial curve matching and computer-aided inversion techniques yielded geo-electric parameters (layer resistivity and thickness) that were used in delineating the aquifers in the area and evaluating their vulnerability to pollutants. The geoelectric sections revealed that the area is underlain by three to four geo-electric layers namely the topsoil, weathered layer, partly weathered/fractured basement and fresh basement. The weathered layer and partly weathered/fractured basement constitute the major aquifers in the area. The GODT vulnerability model depicts that the area is characterized by four vulnerability zones which are very low, low, moderate and high vulnerable zones. According to the model, about 10% of the area is highly vulnerable while about 35% is of moderate rating. The low and very low ratings constitute 40% and 15% of the area respectively.
Keywords: Aquifer vulnerability, GODT model, vertical electrical sounding and geoelectric parameters.

1. Introduction

The search for groundwater has been on the increase across the globe and this is because it is considered all over the world to be the best source of potable and safe both for drinking, agricultural and industrial purposes (Hoque et al., 2009). Several tools ranging from geophysical, remote sensing, geographic information system (GIS) among others, have been utilized for proper location of this precious resource within the subsurface. However, location of this resource is not enough without proper protection from harmful substances that can degrade its quality and render it unfit for human use. Groundwater reservoirs are easily affected by pollution through a process that is slow and consequently dreadful (Baghvand *et al*., 2010). Prevention of aquifers pollution is considered as an important factor in the management of groundwater resources and as such aquifer vulnerability study becomes imperative within the domain of groundwater study. Hence, the assessment of groundwater vulnerability to pollution has been the subject of intensive research during the past years and a variety of index methods have been developed to evaluate aquifer vulnerability. These methods include DRASTIC (Aller *et al*., 1987), GOD (Foster, 1987), AVI (Van Stempvoort *et al*., 1993), SINTACS (Civita, 1994) e.t.c. and are all subjective to varied vulnerability parameters. The derivation of the various parameters required for the computation of the index vulnerability models is usually multi-disciplinary while the accuracy of the resulting models depends majorly on the available information and their authenticity. Meanwhile, site specific vulnerability assessments using these methods are not readily feasible since in most cases there might not be enough hydrogeological information to compute and thus they are usually applied at regional scale. Consequently, attempt is made in this study to compute hydrogeological parameters from geoelectric parameters for the assessment of aquifer vulnerability at Ipinsa and Oke-Odu area, near Akure, Southwestern Nigeria. Most geophysical assessments of aquifer vulnerability recorded in the literatures have engaged the use of longitudinal conductance, a second order geoelectric parameter to assess the protective capacity of the overburden units, (Abiola et al., 2007, Aweto, 2011; Akintorinwa and Olowolafe, 2013). This approach however, is insensitive to the possible presence of relatively high resistive geological formations like laterites that are good protective barriers for the underlying aquifers. More importantly, vulnerability models become more effective as more parameters influencing the disposition of contaminants are available as input for the model. Therefore, four aquifer vulnerability parameters namely groundwater occurrence (G), overlying strata (O), depth to aquifer (D) and topography (T) are integrated in this study to assess the aquifer vulnerability of the study area. The former three parameters GOD has been successfully integrated for aquifer vulnerability assessment in the past (Foster, 1987; Khemiri et al, 2013) while the fourth parameter (T, topography) is an added input parameter considered to improved the resulting vulnerability model since the topography of an area can influence the migration of contaminants. The ridges usually associated with run-off and less infiltration, while the opposite is the case for depression. Furthermore, studies have shown that contaminants can be topographically controlled whereby contaminants are held downslope by gravity and prevented from migrating upslope (Khemiri et al., 2013).

2. Site Description

The study area covers two communities namely; Ipinsa and Okeodu situated near Akure Ondo State (Figure 1). It lies within latitudes $7^0\,17^0\,44.7^1$N and $7^0\,19^0\,21.9^1$N and longitudes $5^0\,07^0\,49.23^1$E and $5^0\,09^0\,37.25^1$E. The study area occupies a total area of about 10 km^2. The terrain across the study area is undulating with surface elevation ranging between 355 m and 430 m above sea level with more depressions in the southeastern part relative to the northwestern part (Figure 2). The study area is underlain by the Precambrian Basement Complex rocks of Southwestern Nigeria. The two lithologic units recognized in the area include; undifferentiated Older Granite-Charnockites suites and Migmatite-Gneiss-Quartzite complex (Figure 3). The undifferentiated Older Granite-Charnockites suites are located in the southeastern part of the area and occur as extensive low-lying outcrop while the Migmatite-Gneiss-Quartzite complex essentially occupies the northwestern part of the area (Figure 3).

3. Methodology

One hundred and two (102) Vertical Electrical Soundings (Figure 1) data were acquired in the study area, using PASI 16GL Earth Resistivity Meter and its accessories. The Schlumberger array was adopted for the field survey, with half current electrode spacing (AB/2) varying from minimum of 1 to maximum of 40 to 150m depending on the depth to bedrock and spread allowance. Geoelectric sounding data were interpreted manually using the conventional partial curve matching technique involving the use of theoretical and auxiliary curves (Keller and Frishchnecht, 1966; Koefoed, 1979). The derived geoelectric parameters were further refined using a forward modelling computer algorithm, WinRESIST Version 1.0 (Vander Velpen, 2004). The geoelectric results were presented as curve types, distribution charts, and maps.

The GODT index which is used to evaluate the aquifer vulnerability in the area was calculated by multiplication of the influence of the four parameters such as Groundwater occurrence (confinement of the aquifer), Overall lithology overlying the aquifer, Depth to the aquifer and Topography of the area. These GOD parameters were interpreted from the geoelectric parameters (resistivity and thickness of the interpreted layers) while the topography was obtained from the surface elevations recorded in the area. Values from 0 to 1 were as assigned to these parameters as shown in Table 1.

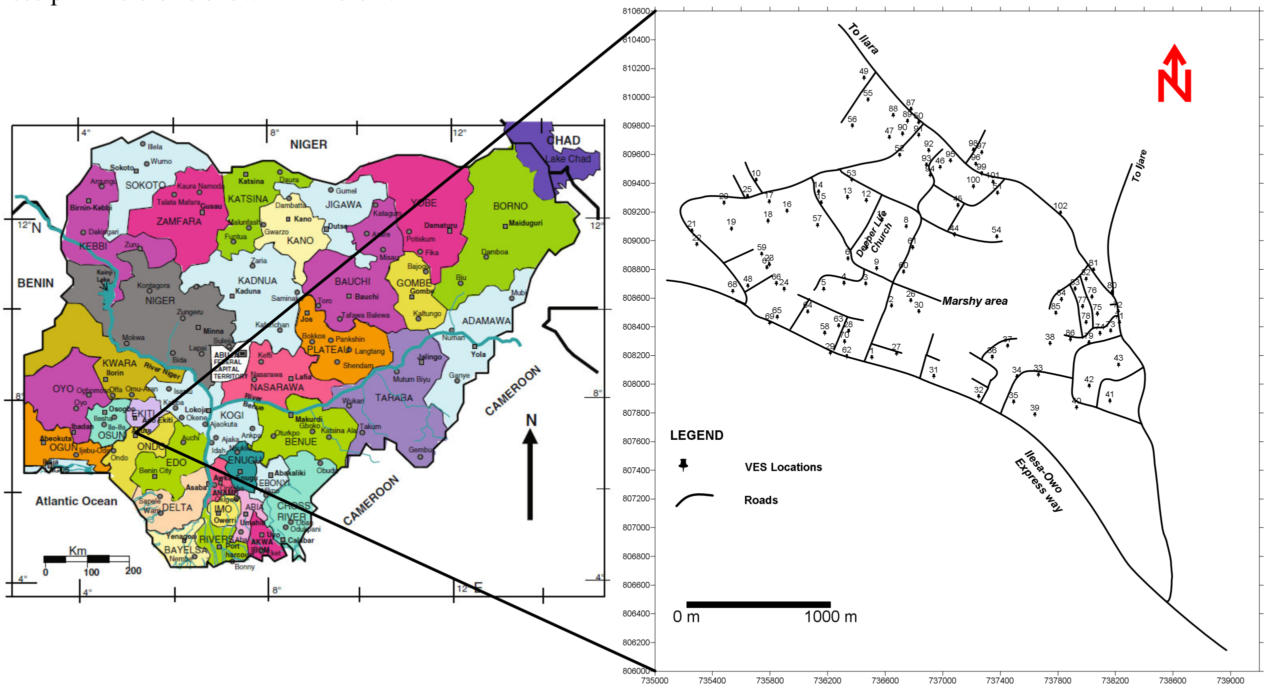

Figure 1: Base map of the study area showing the Vertical Electrical Sounding (VES) Stations Outset Administrative map of Nigeria, (After Obaje, 2009)

Table 1. Attribution of notes for GODT model parameters (modified after Khemiri et al., 2013)

Aquifer Type	Note	Depth to Aquifer (m)	Note	Lithology (Ω-m)	Note	Topography	Note
Non-Aquifer	0	<2	1	<60	0.4	Ridge	0.7-0.8
Artesian	0.1	2-5	0.9	60-100	0.5	Depression	0.9-1
Confined	0.2	5-10	0.8	100-300	0.7		
Semi-confined	0.3-0.5	10-20	0.7	300-600	0.8		
Unconfined	0.6-1	20-50	0.6	>600	0.6		
		50-100	0.5				

The GODT index was then calculated by multiplying the influence of the various parameters together as

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shown in equation 1

GODT Index = G × O × D x T 1

Where:

G = Type of Aquifer

O = Overburden Lithology

D = Depth to the Aquifer

T= Topography

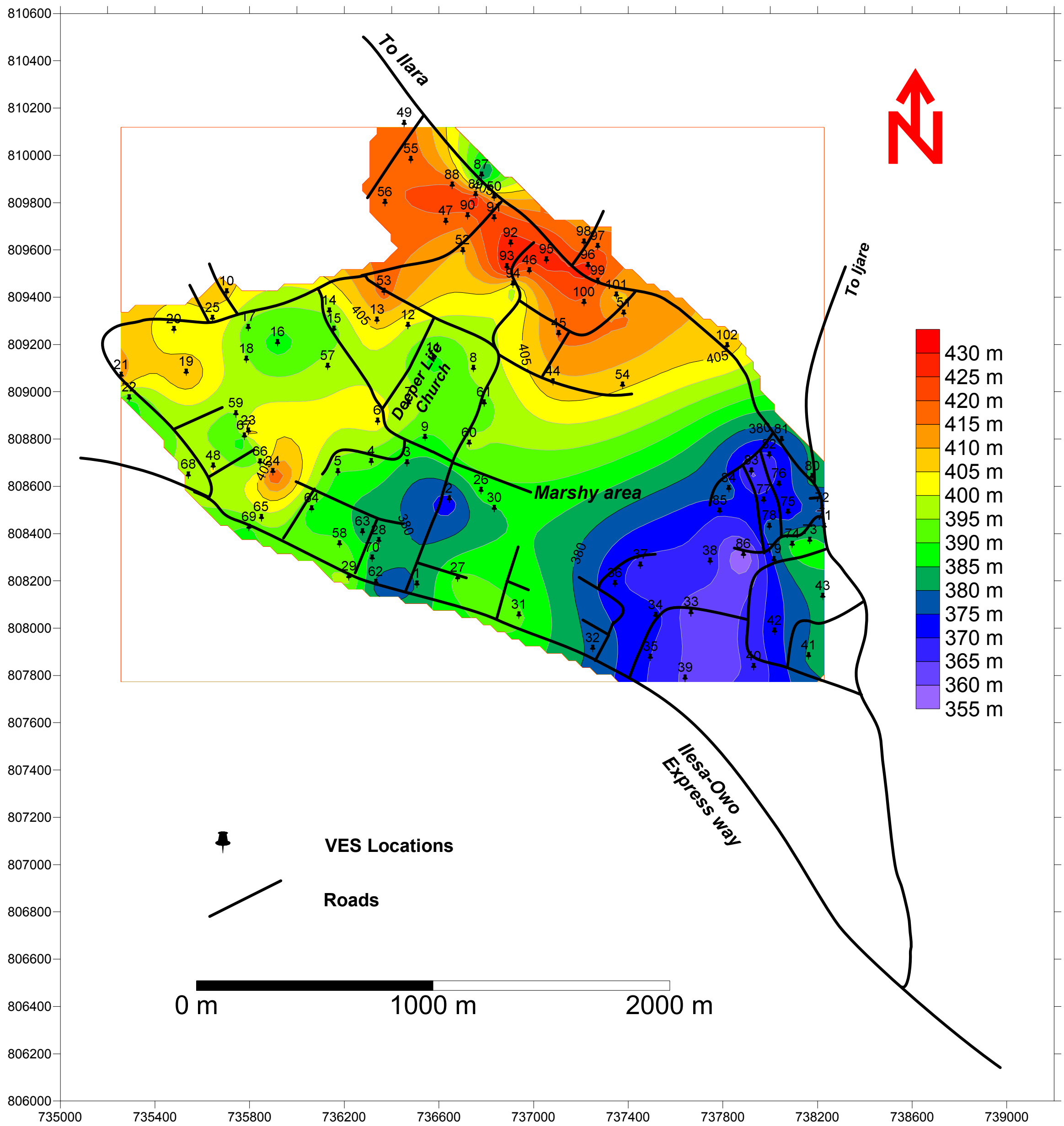

Figure 2: Topographic map of the study area showing VES locations

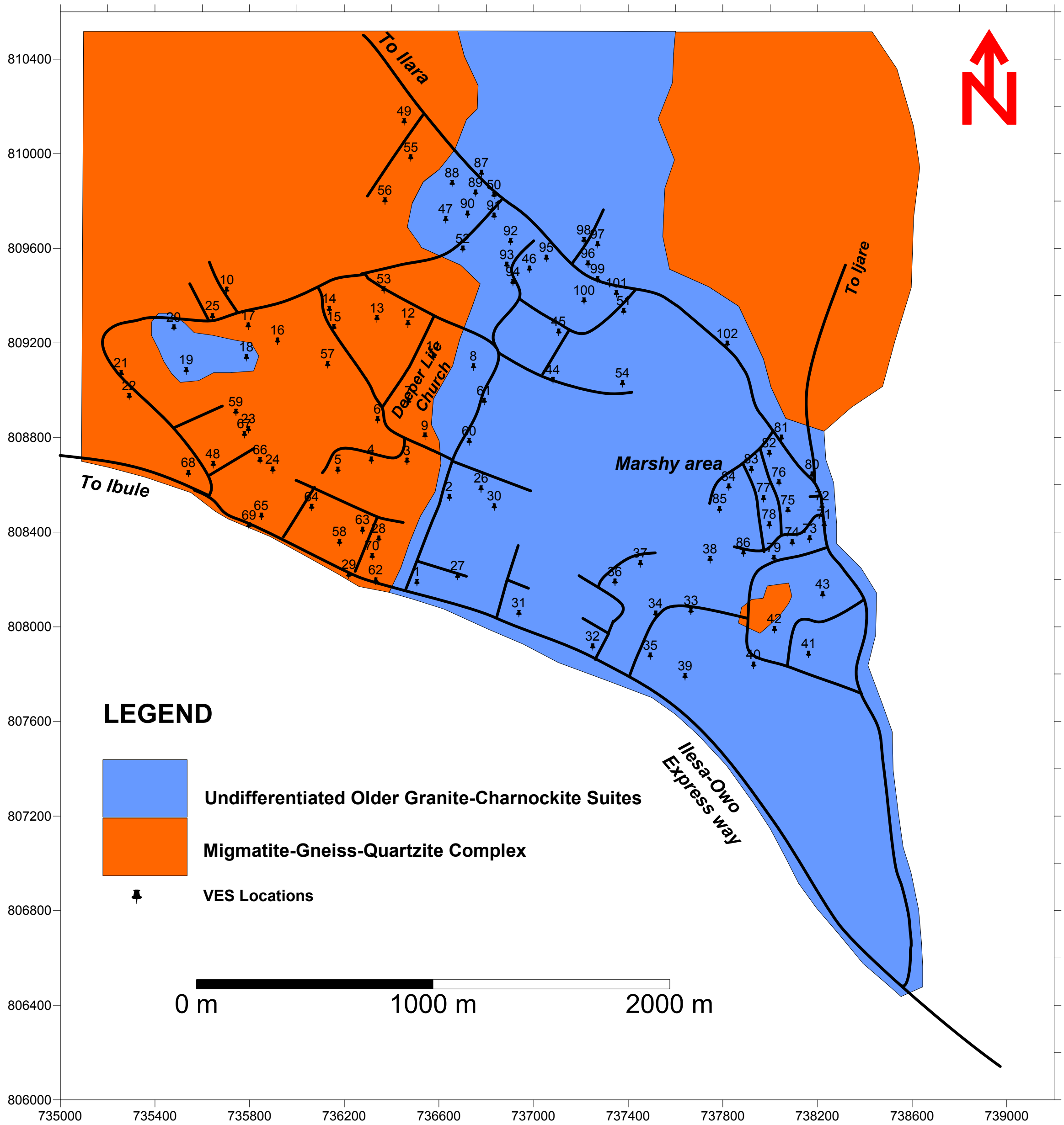

Figure 3: Geological map of the study area showing the VES points.

4. Results and Discussion

The summary of the interpreted results of the VES curves at each VES stations are as presented in Table 2. The characteristic curve types obtained in the area are A, H, K, HA, AA, QH, HK, AK, QKH, AKH and HKH. Figure 4 showed the order of predominance of the curve types obtained in the study area. The geoelectric sections generated along north-south and west-east directions revealed that the study area is underlain with four subsurface layers corresponding to topsoil, weathered layer, partly weathered/fractured basement and fresh basement with resistivity values in the range of (37-257 ohm-m), (33-784 Ωm), (710-772 Ωm) and (1614-9025 Ωm) respectively (Figures 5 and 6). The weathered layer and the partly weathered/fractured basement constitute the major aquifers in the study area. The topsoil on the other hand, constitute majorly the protective cover for these underlying aquifer but is generally thin (0.9-2.7 m) and characterized by relatively high resistivity values within the range of 60-600 Ωm which is considered to offer poor to moderate protection for the underlying aquifers. However, it could be observed that about 30% of the study area is characterized by low resistivity values (< 60 Ωm) and high resistivity values (> 600 Ωm) which suggest good protective capacity of the underlying aquifers (Figure 7).

Figure 8 shows the GODT vulnerability model generated based on four parameters: i) G, groundwater confinement, ii) O, overlying strata, iii) D, depth to the aquifer and iv) T, topography of the area. The ultimate integrated aquifer vulnerability index is the final product of component indices for these parameters (Foster *et al.*, 2002; Afonso *et al.*, 2008). The study area was categorized into four ratings viz; very poor, poor, moderate and high vulnerability zones based on the Vulnerability assessment presented in Table 4.3 (Murat et al., 2003). The vulnerability model shows that major part of the study area falls within the low and moderate vulnerability classes. The most vulnerable zones transect the southeastern axis of the area where low surface elevations are recorded. Thus, the aquifers in these areas are adjudged readily vulnerable to contamination from near surface pollutants.

5. Conclusion

Aquifer protection is essential for a sustainable use of the groundwater resources, protection of the dependent ecosystems, and a central part of spatial planning and action plans. The key expression for a quantification of aquifer protection is vulnerability. It is in view of this that this research has been undertaken to effectively characterize the vulnerability of the ambient aquifers to near surface contaminants around areas connecting Ipinsa-Okeodu, near Akure, Southwestern Nigeria. The GODT vulnerability model depicts that the study area is characterized by four vulnerability zones which are very low, low, moderate and high vulnerable zones. According to the model, about 10% of the area is highly vulnerable while about 35% is of moderate rating. The low and very low ratings constitute 40% and 15% respectively of the area. Therefore, it is highly recommended that the least vulnerable zone should be the primary target for future groundwater development in the area in order to ensure continuous supply of safe and potable groundwater for human consumption in the area and more importantly, location of septic tanks, petroleum storage tanks, shallow subsurface piping utilities and other contaminant facilities should be confined to these least vulnerable zones.

Table 2. Summary of VES results

VES No	Layer Thickness (m)				Layer Resistivity (Ωm)					Curve Type
	h_1	h_2	h_3	h_4	ρ_1	ρ_2	ρ_3	ρ_4	ρ_5	
1	2.7	7.3			238	*58	710			H
2	1.1	0.4	5.5		371	4135	*140	2769		KH
3	1.3	3.8	15.5		237	586	*148	561		KH
4	0.9	3.3	2.6	34.7	263	136	583	*162	∞	HKH
5	0.7	4.2	30.0		761	704	*113	4677		QH
6	0.7	1.0	3.9	26.7	348	110	1843	*96	4184	HKH
7	1.0	8.4	6.8		1142	1474	*570	1403		KH
8	1.0	3.1			434	*53	772			H
9	0.9	8.9			391	*187	9025			H
10	4.0	14.8			1889	851	*108			Q
11	1.0	3.0	11.3		213	448	*255	1940		KH
12	1.0	4.0	9.1	18.3	171	332	1531	*228	1432	AKH
13	1.3	0.6	9.0	14.7	437	158	721	*175	712	HKH
14	0.6	2.6	18.2		40	168	*70	708		KH
15	0.8	3.0			234	717	*82			K
16	1.0	1.7	13.1		143	1685	*30	1252		KH
17	1.0	10.8			101	573	*96			K
18	0.8	6.5	28.5		274	784	*33	98		KH
19	0.8	2.9	25.8		143	682	*131	820		KH
20	0.9	8.9	27.0		77	224	*128	1010		KH
21	2.5	4.5	11.0		483	152	*52	1039		QH
22	8.4	9.5			133	*74	3614			H
23	4.5	14.5	52.3		474	208	*46	∞		QH
24	9.9	1.9	13.6		692	1996	*63	5333		KH
25	1.1	12.6			159	767	*181			K
26	1.6	12.4			154	971	∞			A
27	4.6	7.9			73	*108	523			A
28	1.7	2.9	16.6		113	661	*60	1027		KH
29	0.6	8.2	5.0		82	*264	*58	638		KH
30	0.8	4.7	20.0		84	420	*86	293		KH
31	1.0	2.0	5.3		240	840	*416	3080		KH
32	1.0	1.7			47	30	*398			H
33	0.9	5.1			67	*32	380			H
34	0.8	1.9	22.9		233	401	*92	785		KH
35	0.9	3.3			122	*15	232			H
36	0.6	0.8	9.3		37	167	*107	2495		KH
37	1.2	2.8			143	*91	2859			H
38	2.0	11.2			121	*77	270			H
39	1.1	5.0			92	*19	587			H
40	0.7	0.4	9.8		178	117	*197	69		HK
41	1.6	1.8	4.3		80	195	*21	177		KH
42	1.1	4.0	11.2		103	491	*43	305		KH
43	0.6	6.5	28.0		86	377	75	817		KH

44	1.2	5.7			150	*211	8853			H
45	2.8	9.8			506	*188	4323			H
46	1.0	2.4			283	*183	1829			H
47	1.6	0.4			93	301	2635			A
48	1.0	6.9	29.4		198	579	*111	285		KH
49	1.8	5.0	19.0		150	479	1831	287		AK
50	1.0	2.5			72	3034	4166			A
51	0.8	2.8			106	592	1782			A
52	1.2	31.8			98	3163	1205			K
53	1.7	11.3	24.4		212	350	*333	1125		KH
54	0.9	1.8			128	181	2352			A
55	0.3	14.4			170	1148	*313			K
56	1.0	8.7			237	1177	*171			K
57	0.5	4.9	28.3		161	246	*85	1614		KH
58	0.8	2.1			810	1582	555			K
59	0.3	6.4	8.3		72	264	*97	239		KH
60	0.5	3.7			286	*161	5153			H
61	1.9	1.9			457	160	2697			H
62	0.6	0.9	2.3	10.5	88	45	789	*47	369	HKH
63	1.5	7.7	28.2		227	898	*266	638		KH
64	0.9	4.1	28.2		176	413	*69	934		KH
65	0.7	3.0	27.1		196	355	*86	988		KH
66	0.8	3.0	4.8	19.1	1673	492	6658	*38	739	HKH
67	1.0	3.5	47.6		99	353	*199	1403		KH
68	0.7	10.2	26.5		193	528	*72	318		KH
69	1.5	4.8	25.2		54	314	*68	1078		KH
70	0.7	2.0	13.2		716	803	*148	515		KH
71	0.8	3.1			87	*62	3064			H
72	0.6	4.2	29.2		56	88	*281	1018		AA
73	1.0	6.5			70	*132	1310			A
74	0.8	1.5			129	390	2163			A
75	0.7	30.1			88	*164	1550			A
76	0.5	2.2			40	41	1070			A
77	1.0	3.5			88	*33	633			H
78	0.3	0.2	13.1		40	672	*35	930		KH
79	2.0	36.3			259	2409	500			K
80	0.2	11.3	30.0		26	152	*73	1003		KH
81	0.5	3.8			187	*286	1488			A
82	0.6	1.9	3.5	13.0	566	388	1161	*479	1849	HKH
83	0.7	1.5			26	38	2262			A
84	0.2	13.3			154	*189	2138			A
85	0.6	1.4	9.7		167	228	*160	2070		KH
86	1.0	4.2			70	*82	4935			A
87	0.8	1.2			69	1020	1896			A
88	2.2	2.0			35	477*	∞			A
89	1.0	4.3			146	609	1744			A
90	1.2	6.4			77	216*	1116			A
91	1.0	4.2			42	217*	∞			A
92	0.6	0.5	9.5		40	594	121*	∞		KH
93	1.0	11.2			121	75*	3399			H
94	0.9	4.6	7.4		44	31	87*	∞		HA
95	1.7	9.9			89	324*	2645			A
96	3.8	1.8			86	145	∞			A
97	0.6	0.6	4.0		140	5603	484*	25334		KH
98	0.6	1.2	8.2		79	335	191*	∞		KH
99	0.8	7.2			38	298*	∞			A
100	0.6	7.5			211	104*	∞			H
101	0.7	1.7	3.9		76	122	94*	∞		KH
102	2.5	4.9			87	166*	5942			

*Major Aquifer

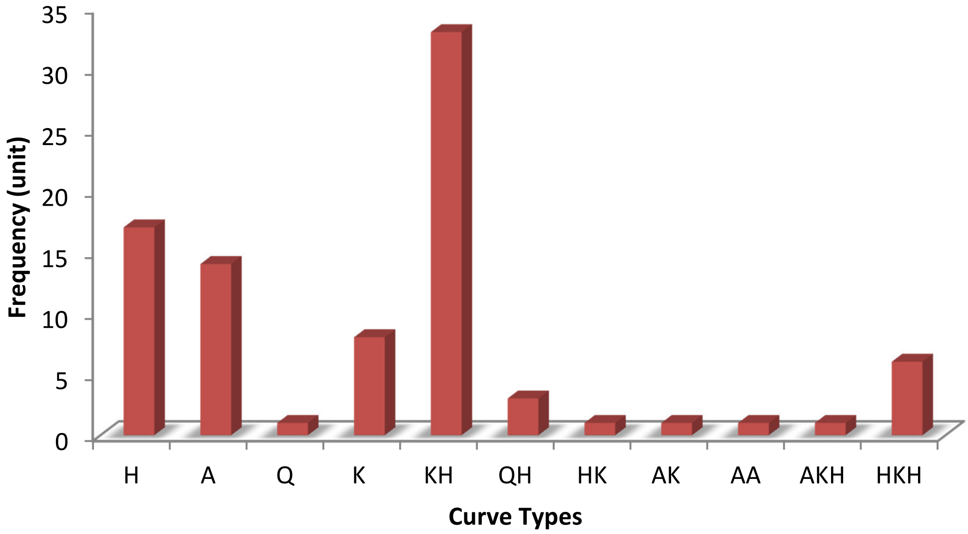

Figure 4: Frequency Distribution of Curve Types Obtained in the Study Area

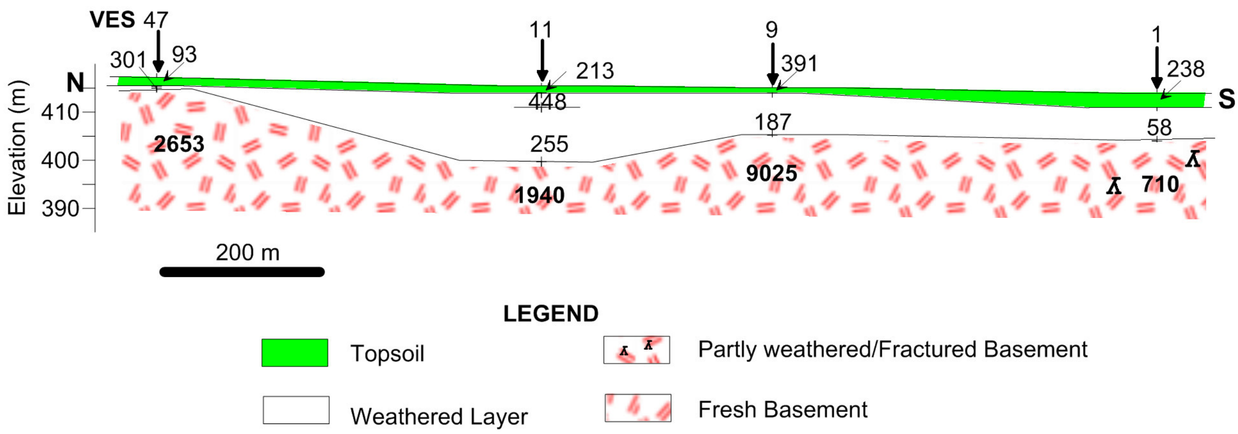

Figure 5: Geo-electric Section along North-South (N-S) direction.

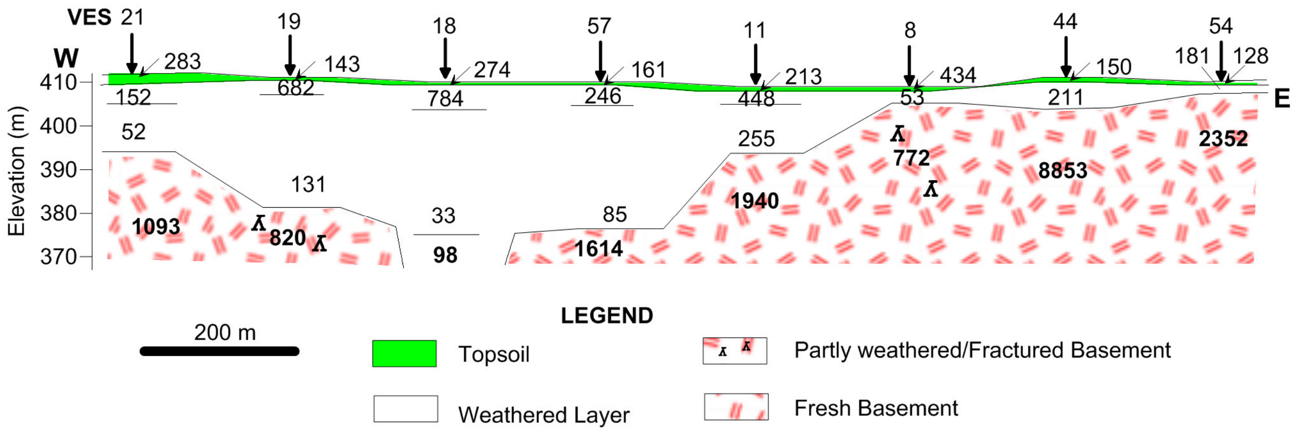

Figure 6: Geo-electric Section along West-East (W-E) direction

Table 3: Interval Values of the GODT Index and Corresponding Classes (Modified after Murat *et al*, 2003).

Index	Vulnerability Class
0-0.1	Very Low
0.1-0.3	Low
0.3-0.5	Moderate
0.5-0.7	High
0.7-1.0	Very High

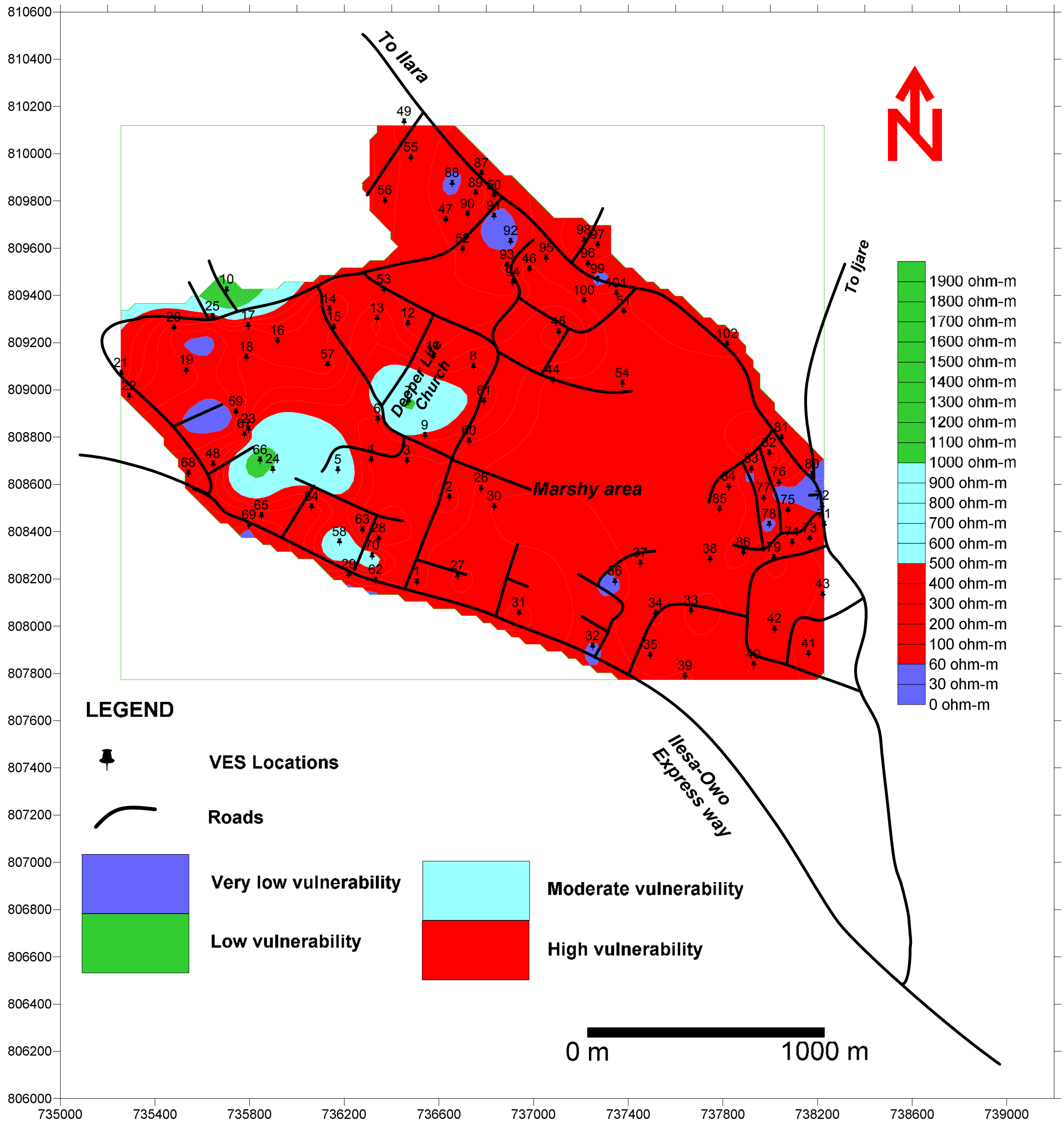

Figure 8: Topsoil resistivity map of the study area

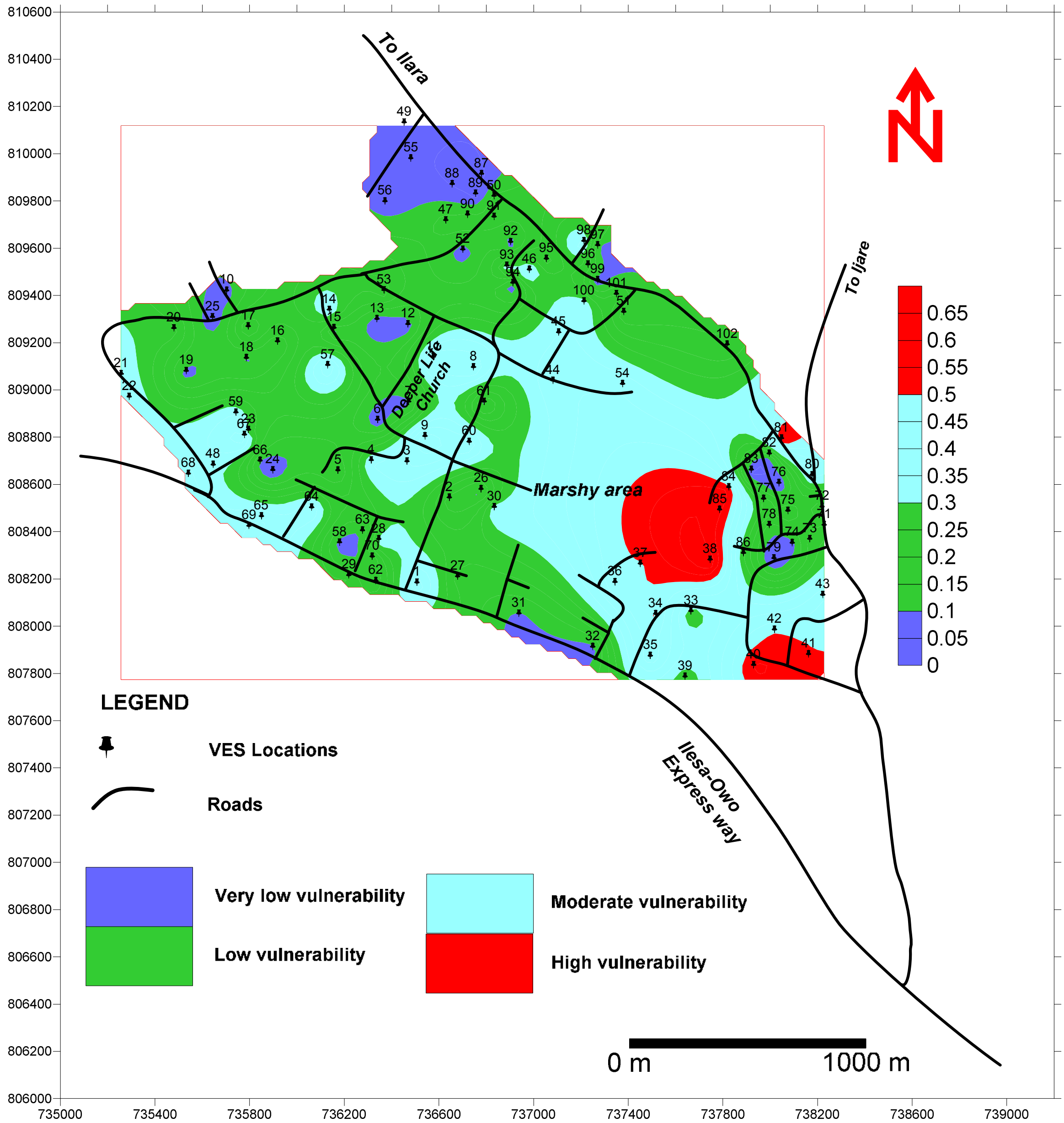

Figure 8: GODT vulnerability map of the study area

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