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Aquifer Mapping in the Niger Delta Region: A Case Study of Edo State, Nigeria

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ABSTRACT

In Nigeria, potable water is in short supply to the greater population and where available, groundwater accounts for over 90% of the supply. Oil exploration and exploitation activities are carried out in the Niger Delta region of Nigeria and this has affected the environment in this region. However, naturally occurring traces of petroleum products in strata or petroleum losses through spillages can contaminate groundwater, thus aquifer mapping in the Niger Delta Region becomes crucial. The study involves collection, collation and analysis of relevant information and data required for successful development of groundwater in Edo state. Groundwater in Edo State occurs under different conditions in the various aquifers defined by the following geological units, namely: Coastal Plain Sands of the Benin Formation, Ogwashi- Asaba, Bende- Ameki and Imo Shale Group of the Tertiary Deposits, False-bedded Sandstones and the Nkporo Shale Group of the Cretaceous deposits and the Basement Complex Rocks which only contain groundwater in the overburden, faults and joints. From the information collated, groundwater levels are deepest in the Ishan Plateau where it is about 171 metres above mean sea level at Ekpoma. Away from the pleateau, groundwater rises southwards and northwards. At Aduwawa/Ikpoba Hill (Benin City), the groundwater level is 40 metres, at Iguiye (Lagos Road, Benin City) to the west, the groundwater level is 55 metres and at Fugar to the north, the groundwater level is 95 metres. The groundwater flow direction is from the Plateau to all other areas with higher groundwater levels. Therefore, aquifer mapping in the Niger Delta region is necessary, as it will help in assessing the availability and development methods to be adopted.

Keywords: Groundwater, Aquifer, Borehole, Formation, Sediment, Niger Delta, Mapping

1.0. Introduction

As a result of rapid population growth and local development, potable water is in short supply and this has led to the resurgence of groundwater potentials for steady and reliable water (Alabi *et al*., 2010; Anomohanran, 2011a & 2011b). Water in the zone of saturation is normally referred to as ground water and geology is therefore a controlling factor. Groundwater is very vital as it is a viable source of portable water for domestic use (Peter, 2013). An aquifer is a water saturated geologic unit that will yield water to well or spring at sufficient rate that can serve as practical source of water supply. It is therefore a water-bearing formation or ground water reservoir. In countries like Denmark, groundwater mapping is a high priority; the Danish government initiated the National Groundwater Mapping Programme to achieve a detailed description of Danish aquifers with respect to localization, extension, distribution and interconnection as well as vulnerability against contaminants (Stockmarr and Thomsen, 2012). Naturally occurring traces of petroleum products in strata (from which water is obtained) or petroleum losses through spillages can contaminate groundwater. This makes the aquifer mapping in the Niger Delta more significant as it is a region where oil exploration and exploitation activities are carried out.

A study on aquifer mapping and characterization in Anambra State indicated that Nanka formation in Anambra basin has a high level of groundwater potential (Emenike, 2001). Also, aquifer mapping in Onibode area, near Abeokuta South-West of Nigeria shows groundwater potentials (Oyedele, 2001).

Therefore, the occurrence of groundwater is controlled by geology and hydrogeology; hence groundwater does not occur in desired quantities and qualities anywhere and everywhere (Kogbe, 1989). To successfully locate and drill a water borehole, the favourable conditions must be identified (Egbai, 2012; Peter, 2013; Egbai *et al*., 2015). This is achieved by the water explorer or hydrogeologist, employing a number of investigative tools. One of the direct tools includes procurement and analysis of existing geological and hydrogeological information and maps. In addition, subsurface information from existing borehole logs and pumping test data are required. The indirect tool involves the use of geophysical surveys, most often the electrical resistivity survey to identify subsurface features. Hence, it is necessary to continue to improve the data base for groundwater development in a country in order to be able to identify a stable and steady ground water sources for water supply. Therefore, this study will focus on aquifer mapping in the Niger Delta Region of Nigeria using Edo State as a case study.

2.0. Materials and Methods

2.1. Study area

Edo State lies between latitude 05°44' to 07°34'N and longitude 05°04' and 06°45'E and covers a land area of about 19,635 square kilometres (see Figure 1). The State is bounded to the East and South by Delta State, to the North by Kogi State and to the West by Ondo and Ekiti States. It is located within the rainforest zone of Nigeria with mean annual rainfall in the range of 1500 mm to 2500 mm and the mean monthly temperature varying from 25 °C to 28 °C (Benin Kingdom/Edo State Weather, 2018). Edo State is situated in a zone with relatively high rainfall. The State has two distinct seasons. These are the wet (rainy) season and the dry season. The rainy season occurs between the months of April and October with a short break in August. The dry season on the other hand lasts from October to April with dry harmattan winds between December and February, but with the effect of global warming and climate change, rains have been observed to fall irregularly almost in every month of the year. The terrain consists of hilly or dissected country in the north and dry flat country, around Benin City towards the South. There are also abundant fresh swamp waters flanking the main rivers, particularly the Niger. The highest elevations are at the dissected and hilly terrains in the north with heights of about 300 m and above such as the Igarra and Ososo hills in Edo North. Further south of this zone lies the dissected areas around Auchi and Okpella with elevations decreasing southwards to about 200-100 m down south to about 15 m above mean sea level. In the central region there is also the Ishan Plateau with elevation reaching about 350 m above sea level.

2.2. Test methods

The method used for the study included the following;

a) Field work which includes:
   i. Geophysical survey using (Vertical Electrical Soundings, VES)
   ii. Water borehole drilling.
b) Data Processing and Plotting of Groundwater contours.

2.2.1. Electrical Resistivity Sounding (By Vertical Electrical Soundings)

Groundwater exploration was carried out in four geological regions (Quaternary Sediments, Tertiary Sediments, Cretaceous Sediments and Basement Complex) and this was done using vertical electrical soundings (VES) method with the aid of ABEM SAS 300 Tetrameters and other field accessories. Geographical coordinates were obtained from Garmin Handheld GPS 72 receiver. The quantitative interpretations of the VES data acquired at the regions were done initially with the aid of the conventional partial curve matching technique subsequently fine-tuned with the aid of computer assisted iteration techniques.

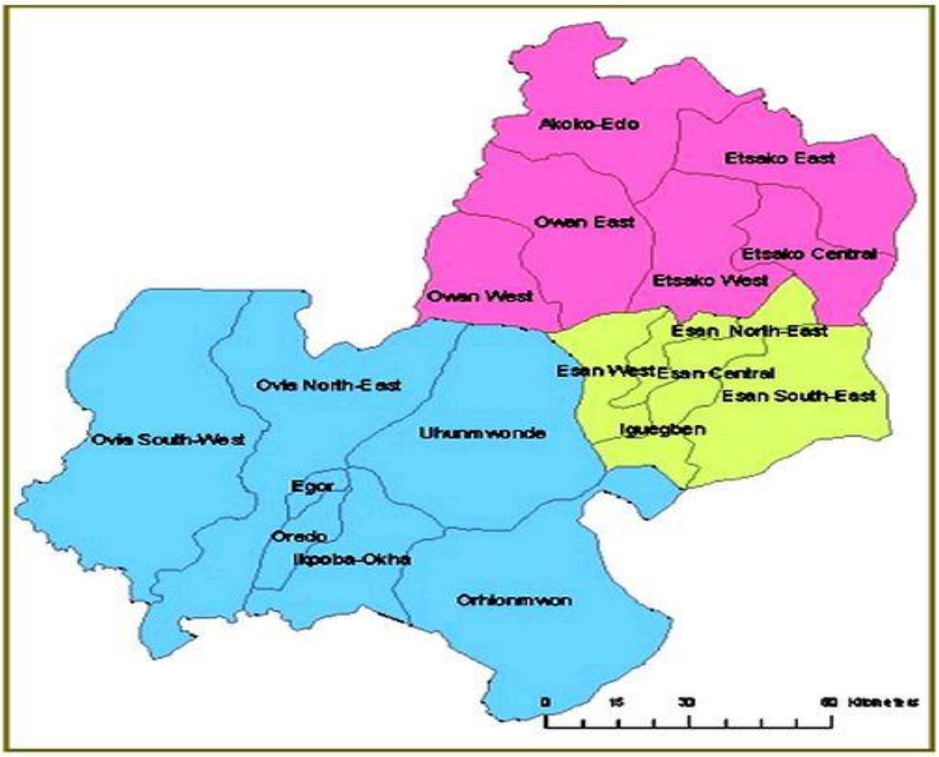


Figure 1: Map of Edo State
(Source: https://www.nigeriagalleria.com/Nigeria/States_Nigeria/Edo/Edo_State.html)

2.2.2. Water borehole drilling

Water boreholes were drilled in some selected area of Edo State to obtain boreholes data. The water borehole drilling involved drilling to a diameter of 8 inches using a water bore hole drilling rig (KW30). The drill's rotary machine (rotates at 30 rpm to ensure straight borings) was powered with a hydraulic pump and then, compressed air drives to down-the-hole-hammer to pulverise the rock. Dust and cuttings were flushed out of the borehole by compressed air.

2.2.3. Plotting of Groundwater Contours for Edo State

Contours were plotted using the groundwater levels obtained from the water borehole data in some selected areas of Edo State. The water level at each location was determined and established with reference to the ground elevation.

3.0. Results and Discussion

Table 1 show the classification of groundwater regimes.

Table 1: Classification of groundwater regimes

S/N	Region	Group	Nature of Aquifer
1	Recent deposits	Niger Alluvium, River Alluvium	Isolated minor sand lenses. Unimportant as aquifer in Edo state
2	Quaternary deposits	Benin formation	Thick, unconsolidated sands with minor clays. Highly permeable and productive aquifer
3	Tertiary deposits	(a) Ogwashi- Asaba formation (lignite series)	Thick fine to coarse grained sand with clays and lignite.
		(b) Bende- Ameki formation	Thick, fine to medium and coarse sand with sandy clays and shalely limestone
		(c) Imo shale	Very thick shale with lenticular sands. This is essentially an aquiclude
4	Cretaceous Deposits	False- bedded sandstone. Fugar sandstone	Thick moderately permeable aquifers
5	Basement complex	Meta sediments, migmatites, gneisses, and granites	Isolated aquifers in weathered zones, joints and faults. Aquifer has low to moderate yields.

From Table 1, the results indicated that the alluvium deposits does not present important aquifers in Edo State due to the isolated minor sand lenses it contains and that of the basement complex has low to moderate yield.

Table 2 show the location where Electrical Resistivity tests were conducted.

Table 2: Electrical resistivity data in the quaternary sediments

S/N	Location	Depth to top of Saturated Zone (inferred) (m)
1	Oghada	65
2	Uhie	71.20
3	Umelu	75.0
4	Iguododo	96
5	Oghede	83
6	Evboesi	73
7	Evbuekabua	93
8	Evbuekoi	102
9	Ugbineh	20

Electrical resistivity carried out at Ugbineh was used as a case study for Quaternary sediments. The resistivity data are presented in Table 3a and 3b while the curve is in Figure 2.

Table 3a: Resistivity data for Ugbineh

Synthetic Difference Spacing (m)		Array Geometric Factor (K)	Apparent Resistivity (Roa) (Ohm-m)
AB/2	MN		
1	0.5	5.8905	301.76
1.5	0.5	13.744	204.7
2	0.5	24.74	202.1
3	0.5	56.156	248.93
4.5	0.5	126.84	317.58
7	0.5	307.48	338.75
10	0.5	627.93	327.26
14.5	1	659.73	373.12
21.5	1	1451	453.8
32	2	1607	797.59
47	5	1384	1750
100	10	3134	1400
150	20	3519	1739
220	20	7587	1400
320	50	6395	2493

Table 3b: Geoelectric parameters and inferred lithology for Ugbineh

Layer	Thickness (m)	Depth(m)	Resistivity(ohm-m)	Lithology
1	0.5897	0.5897	335.4	Lateritic Topsoil
2	0.6154	1.205	109.2	Sandy Sub- soil
3	1.203	2.408	580.2	Sandy Clay
4	2.521	4.93	183.2	Clayey Formation
5	4.794	9.723	634.75842	Clay stone (Dry)
6	10.4	20.12	1456	Sandy Clay
7	61.29	81.41	3188	Sandy Clay
8	57.36	138.77	1453	Sand (Aquifer)
9	Undefined	Undefined	537.1	Sandstone (Aquifer)

Results in Table 3a and 3b were interpreted, using sounding curves as shown in Figure 2. Note that AB is the outer (current) electrode spacing and MN is the inner (potential) electrode spacing.

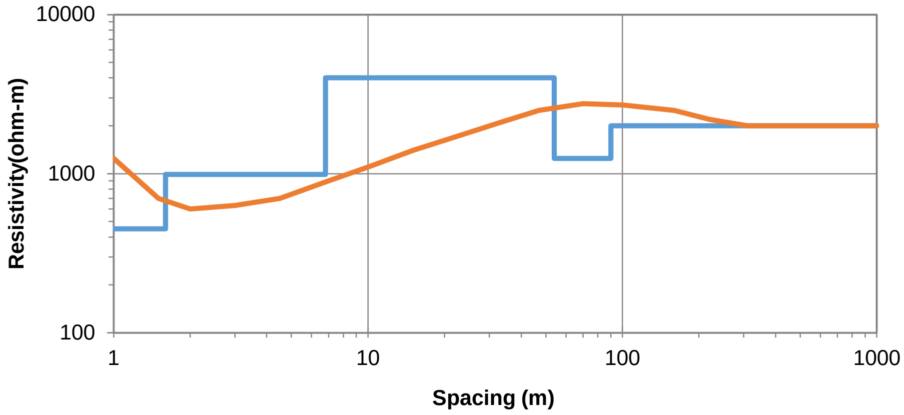


Figure 2: Resistivity curve for Ugbineh

Nine geo-electric layers were revealed for Ugbineh as indicated in Table 3b with the top of saturated sand layer at 20.12 m deep, while the depth to the top of the aquifer was 138 m and that of the base, undefined. This indicates that the groundwater may tend to be ferruginised (i.e. the groundwater may contain a sizable amount of Fe^{2+}). This result is in accordance with that obtained from the study conducted by Ako and Olorunfemi (1989), which show that one of the peculiarities of deep aquifer is that the groundwater tends to be ferruginised.

Electrical resistivity data in the tertiary sediments are presented in Table 4.

Table 4: Electrical resistivity data in the tertiary sediments

S/N	Location	Resistivity (Ohm-m)
1	Ehor	200
2	Ekpoma	264
3	Ubiaja	220
4	Eguaholor	174
5	Odiguetue	322

Electrical resistivity for Ekpoma was used as a case study for Tertiary sediments. The resistivity data are shown in Tables 5a and 5b.

Table 5a: Resistivity data for Ekpoma (VES1)

S/N	Synthetic Difference Spacing (m)		Data Resistivity (Ohm-m)	Synthetic Resistivity (Ohm-m)	Potential Difference (V)
	AB/2	MN			
1	2.00	0.500	158.0	154.60	2.11
2	6.00	1.00	158.0	173.1	-9.55
3	8.00	1.00	181.0	178.9	1.10
4	12.00	1.00	204.0	188.2	7.70
5	15.00	2.00	212.0	194.8	8.07
6	25.00	2.00	240.0	223.2	6.99
7	32.00	2.00	241.0	251.4	-4.31
8	40.00	5.00	251.0	291.1	-15.98
9	60.00	5.00	360.0	410.7	-14.10
10	100.0	10.00	656.0	670.7	-2.25
11	150.0	10.00	1056.0	989.7	989.7
12	200.0	10.00	1360.0	1296.1	6.27
13	250.0	15.00	1750	1588.8	9.21
14	300.0	15.00	2100	1866.7	11.10
15	350.0	15.00	2411	2129.3	11.68
16	400	15.00	2836.0	2376.2	16.21
17	450.0	15.00	2513.0	2607.3	-3.75
18	500.0	20.00	2237.0	2822.5	-26.17

Table 5b: Geoelectric parameters and inferred lithology at Ekopma [VES1]

Layer No	Apparent Resistivity (Ohm-m)	Thickness (m)	Lithology
1	150	1.56	Topsoil
2	181	2.83	Sub topsoil
3	195	23.23	Clayey layer
4	29305	236.1	Dry/resistive sandy layer
5	492	-	Saturated sand layer

Results in Table 5a and 5b were interpreted, using sounding curve as shown in Figure 3.

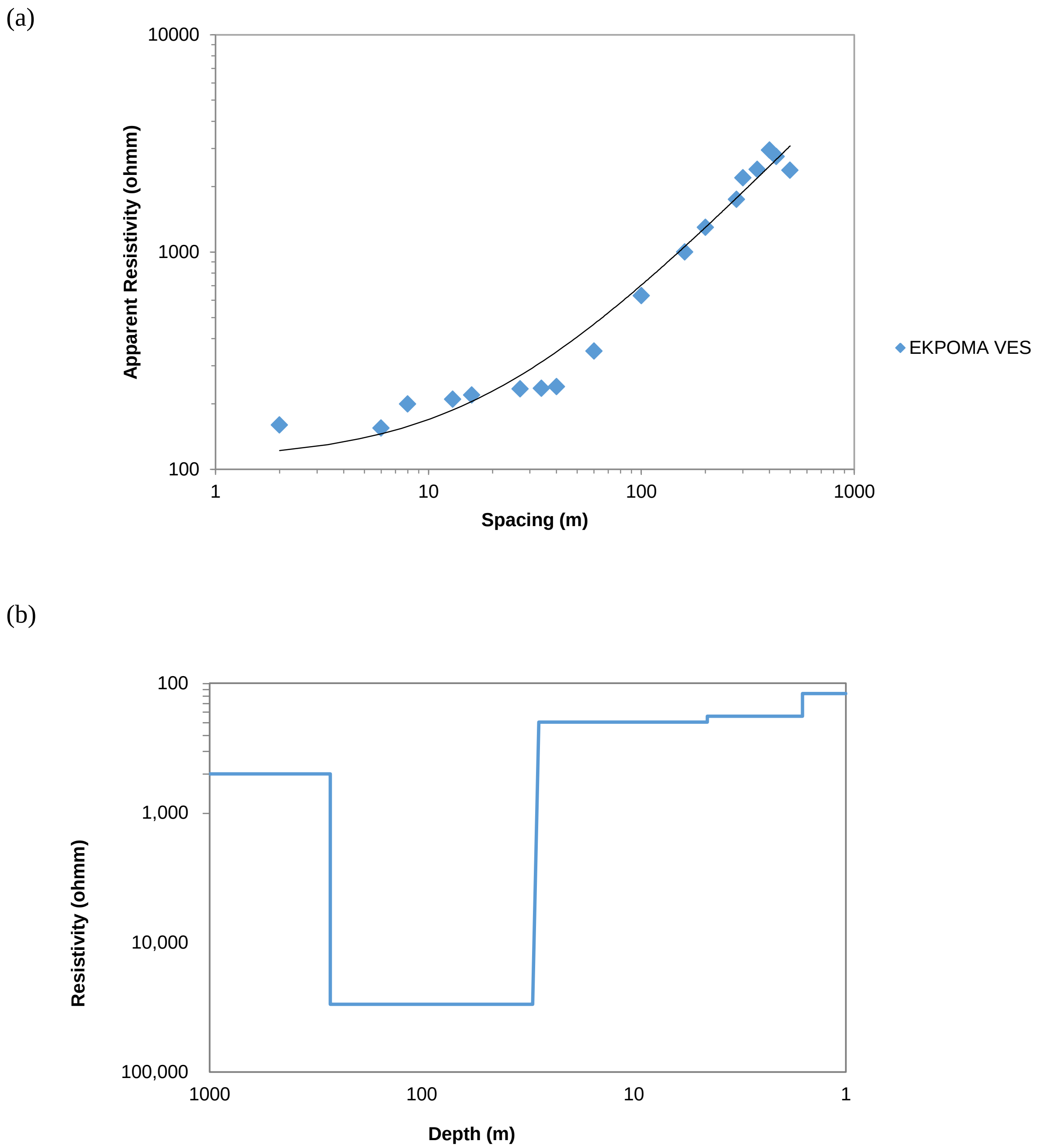


Figure 3: Resistivity curve for Ekpoma (VES1)

Table 5a and 5b show the interpreted VES data as well as the inferred lithology for Ekopma. This indicated that five geo-electric layers were revealed for Ekpoma with the fifth layer indicating the aquifer (i.e. saturated sand layer).

Table 6 presents the electrical resistivity data in cretaceous sediments.

Table 6: Electrical resistivity data in cretaceous sediments

S/N	Location	Data Resistivity (Ohm-m)
1	Afuze	129
2	Usen	102
3	Ugbogui	65
4	Uzebba	163
5	Agennobode	98
6	Auchi	150
7	Ovbiomu	150
8	Iyakpi	195
9	Egori	254

In the case of cretaceous sediments, electrical resistivity at Auchi is presented as shown in Tables 7a and 7b.

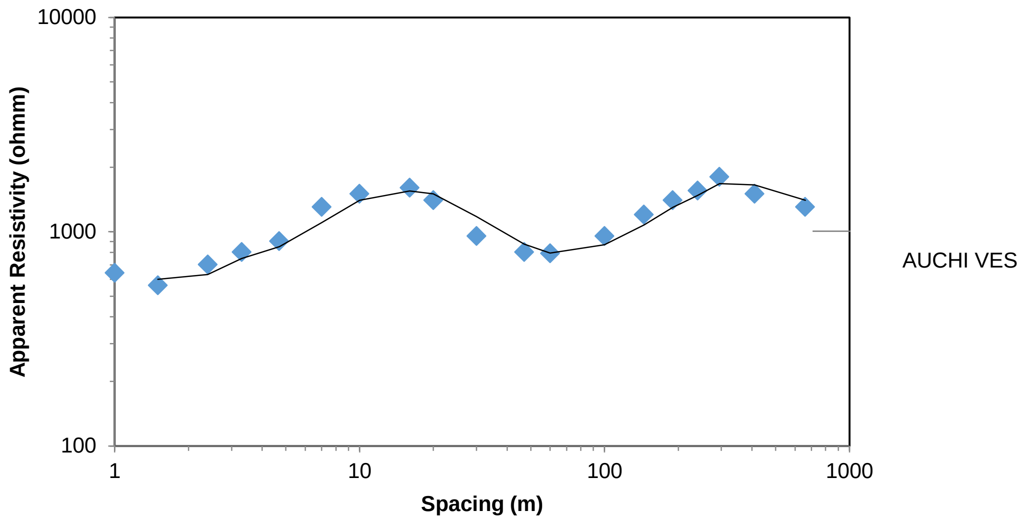
Table 7a: Resistivity data for Auchi at VES 2

No	Synthetic Difference Spacing (m)		Data Resistivity (Ohm-m)	Synthetic Resistivity (Ohm-m)	Potential Difference (V)
	AB/2	MN			
1	1.00	0.200	636.0	608.0	4.33
2	1.47	0.200	572.0	623.2	-8.96
3	2.15	0.200	700.0	668.9	4.43
4	3.16	0.200	800.0	783.3	2.07
5	4.64	0.200	947.0	984.0	-3.91
6	6.81	1.00	1213.0	1228.4	-1.27
7	10.00	1.00	1400.0	1425.9	-1.85
8	14.70	1.00	1600.0	1466.5	8.33
9	21.50	1.00	1262.0	1293.5	-2.49
10	31.50	5.00	961.0	996.2	-3.66
11	46.40	5.00	809.0	792.7	2.00
12	61.80	5.00	788.0	779.8	1.03
13	100.0	10.00	954.0	970.5	-1.73
14	133.0	10.00	1153.0	1153.9	-0.0821
15	178.0	10.00	1304.0	1352.0	-3.68
16	237.0	10.00	1512.0	1507.7	0.279
17	316,0	10.00	1697.0	1566.0	7.70
18	422.0	10.00	1433.0	1474.0	-2.86
19	562.0	10.00	1207.0	1222.8	-1.31

Table 7b: Geo-electric parameters and inferred lithology at Auchi (VES 2)

LAYER NO	Apparent Resistivity (Ohm-m)	Thickness (m)	Lithology
1	602	1.38	Topsoil
2	227	0.3	Sub topsoil
3	4073	4.54	Sandstone layer
4	260	7.45	Sandy/clayey layer
5	719	38.98	Sandy/Sandstone layer
6	5231	97.5	Dry sandy/Sandstone
7	155	< 150	Saturated sand layer

Results in Table 7a and 7b are interpreted, using sounding curves as shown in Figure 4.



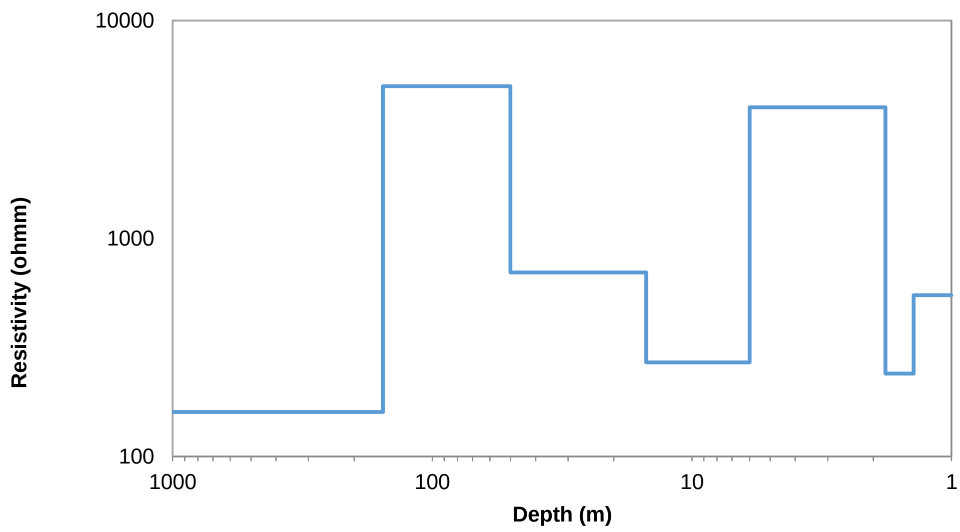


Figure 4: Resistivity curve for Auchi

Interpretation of the resistivity data revealed six geo-electric layers with the top of saturated sandy layer below 150 m deep as indicated in Table 7b.

Electrical resistivity data in some selected basement complex locations are summarized in Table 8. The data presented in Table 8 show the erratic nature of aquifers in the basement complex rocks. Thicknesses of overburden and weathered rocks vary widely from location to location. Data obtained from Oluma-Otuo and Iyeu-Otuo which is barely 2 km apart revealed a great deal of variation. At Ukhuse-Oke, weathered rocks are absent and the overburden provides the only aquifer in the location.

Table 8: Electrical resistivity data in the basement complex

Location	Thickness (m) of probable aquifer	Inferred Lithology
Igarra	19.52 33. 14 Below 52.66 m	Overburden Weathered Zone Fresh basement rock
Ikiran-Ile	7.01 6.12 Below 13.13m	Overburden Weathered Zone Fresh basement rock
Okpilla	8.09 33.50 Below 41.59 m	Overburden Weathered Zone Fresh basement rock
Ugboshi-Ele	9.17 8.28 Below 17.45 m	Overburden Weathered Zone Fresh basement rock
Ukhuse – oke	34.22 0 Below 34. 22 m	Overburden Weathered Zone Fresh basement rock
Oluma-Otuo	4.0 31.0 Below 35. 0 m	Overburden Weathered Zone Fresh basement rock
Iyeu-Otuo	5.75 23.5 Below 29.25 m	Overburden Weathered Zone Fresh basement rock

The results of the borehole drilled in selected location within the state are presented in Table 9. The groundwater levels show the direct relationship between topography of the borehole location and depth to static water level. The groundwater level is deepest in Ishan Plateau and also has the highest altitude. Ekpoma is on an elevation of about 342 m above the sea level while the groundwater is 176 m below ground surface. Away from the Plateau, groundwater rises towards all directions, North, East, West and South. To the North-East of the Plateau, at Idoa, the water level is 96 m below ground surface and to the South-East at Ogua, the water level below ground surface is 120 m. To the South-West at Ehor, the water level is 122 m below ground surface.

In the Benin Formation, groundwater level is low in Urhonigbe (7 m) and high in Ekiadolor (78 m), Aduwawa/Ikpoba Hill (72 m), Iguobazuwa (81m) and Iguiye (70 m). These are areas with the highest elevation in the Benin Formation. In Southern part of the Benin Formation, groundwater level is low in Ologbo (7 m) and a bit high in Abudu (32 m), Iyanomo (17 m) which also follows the pattern of topography.

In the Creteceous sediments, groundwater levels are deepest in Ogbona (190 m), Fugar (133 m) and Afuze (58 m). It was observed that in the Cretaceous, some boreholes are either semi-artesian or fully artesian. The boreholes at Sabongidda-Ora are fully artesian where groundwater flows freely out of the borehole to as much as 2-3 m above ground surface. It was also found that a borehole drilled at Sabongidda-Ora/Afuze road junction has been flowing freely since it was drilled (more than 2 years ago). At Uzebba and parts of Auchi, ground waters are semi-artesian.

Figure 5 show groundwater level of Edo State (3-Dimension). The map was plotted using the groundwater levels obtained from the borehole data in some selected areas of Edo State (see Table 9). The occurrence of groundwater in the Basement Complex areas does not lead to the plotting of the groundwater contour map. This is because the aquifers are localized and rarely have hydraulic contact with one another. For this reason, the basement complex areas of the state were not covered by groundwater contours.

Table 9: Summary of borehole data at selected area in Edo State

S/N	Borehole Locality	Elevation (ASL) (m)	Total Depth (m)	Final Water Level (m)	Water Level (ASL) (m)	Yeild (m^3/h)	Draw Down (m)	Specific Capacity ($m^3/h/m$)
1	Aduwawa/ Ikpoba Hill	102	148.3	72	40	136	4.05	33.6
2	Esigie St. Emmanuel	90	111.5	56.07	33.9	109.8	3.1	35.4
3	Iyaro	93	114.3	52.6	40.4	71.0	1.87	37.9
4	New Benin	92	143.3	54.5	37.5	-	-	-
5	Guiness	78	87	43.6	34.4	108.3	3.1	34.9
6	Edo Textile Mill	62	102	55.5	6.5	67.0	7.5	8.9
7	Obayantor	59	85.7	34.3	24.7	45.8	2.8	16.4
8	Iyanomo	31	106.5	17.00	14.00	23.8	4.7	5.01
9	Abudu	59	75.4	31.5	27.5	76.6	3.1	24.7
10	Ologbo	10	98	6.5	3.5	43.1	4.0	10.8
11	Urhonigbe	41	57	7.00	3.4	41.6	4.0	10.3
12	Okada Dry	87	114.0	51.7	35.3	79.5	3.1	25.6
13	Ugoneki	95	95.3	56.7	38.3	17.2	1.6	10.8
14	Iguobazuwa	138	117.8	81.0	57	40.1	3.7	10.8
15	Iguiye	125	110.6	69.8	55.2	41.4	5.0	8.3
16	Ogan	155.7	160.1	101	54.7	30.1	2.5	12
17	Ugo	98	155.7	63.6	34.4	55.1	1.2	46
18	Okhuo	-	141.7	18.7	-	45.4	3.1	14.6
19	Ogba	64	81	3.1	60.9	76.7	4.4	17.4
20	Iguovbiobo	109	79	64	45	52.2	1.6	32.6
21	Ehor	260	204.7	122	138	45.8	2.5	18.3
22	Ugieghudu	247	208.7	119	128	-	-	-
23	Iruekpen	337	-	171	166	-	-	-
24	Igieduma	259	-	122	137	-	-	-
25	Ekpoma	342	350	171	171	-	-	-
26	Evboerhen	214	-	91	123	-	-	-
27	Idoa	238	138	96	142	-	-	-
28	Ogua	250	200	120	130	-	-	-
29	Igbanke	224	220	119.6	104.4	37.2	7.2	5.2
30	Ugboha	146	168.5	86	60	37.9	20	1.9
31	Eguaholor	187	213	112	77	13.2	14.6	0.9
32	Afuze	88	140.8	57.6	30.4	55.1	3.7	14.9
33	Ihievbe	-	124.6	43.6	-	9.6	21.8	0.44
34	Auchi	224	203	96.6	126	41.3	31.1	1.3
35	Agenebode	79	169	114	-35	40	7.2	5.5
36	Fugar	218	175	133	95	26.5	1.6	16.6
37	Uzebba	-	127	Artesian		76.6	11.8	6.5
38	Sabongidda-Ora	94	141	Artesian		76.6	8.7	8.8
39	Ogbona	249	221	190	59	56.8	12.5	4.5
40	Oben	-	94	31	-	20	6.2	3.2
41	Sobe	-	148	43	-	15.5	31.7	0.5
42	Ekenwan Army Barracks	58	140	40	18	-	-	-
43	Amedokhian (Uromi)	-	296	199	-	-	-	-
44	Udo	120	1.31	72	48	26.5	6.2	4.3
45	Ekiadolor	-	162	78	-	-	-	-

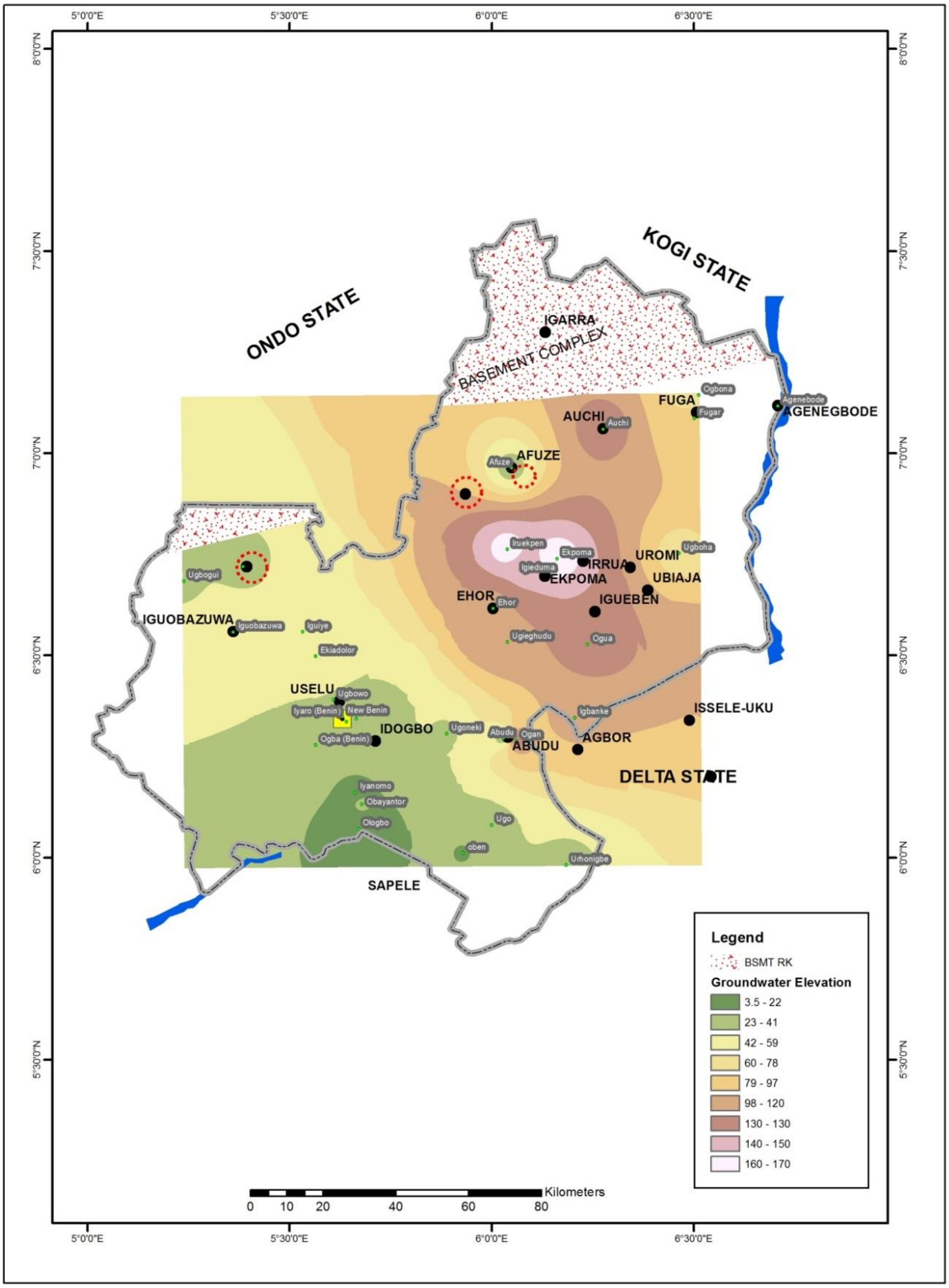


Figure 5: Groundwater level map of Edo State in 3-Dimension

4.0. Conclusion

The mapping of aquifers in Edo State has led to the collection, collation and analysis of relevant information and data required in the successful development of groundwater in the state. The study has revealed that drilling should not be done on a trial and error basis, but has to be guided by available geological and hydrogeological data. Therefore, it is necessary to continue to improve on the data base for groundwater development in the state. To achieve this, it is recommended that the State Government should compel all groundwater developers to lodge their data with the State Urban Water

Board. The Benin Owina River Basin Development Authority should also be encouraged to maintain a data bank for groundwater resources.

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