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Resistivity Methods of Aquifer Mapping and Pollution Vulnerability Assessment of a Part of Imo River Basin of South-Eastern Nigeria (A Case Study of Mbaitoli Local Government Area of Imo State, Nigeria)

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Abstract: Aquifer mapping and pollution vulnerability assessment of a part of Imo River basin of South-eastern Nigeria has been carried out with the aim of addressing the underground water exploitation problems inherent in the area. The instruments used for the study include aerial photographs, satellite images, topographic and geologic map of the area. Geophysical investigations were carried out with the aid of terrameter 300 SAS employing vertical resistivity soundings. Eleven selected locations were sounded using Schulumberger array with maximum electrode separation of 900 meters. Result shows that the area has average lithology of eight (8) layers with under ground water occurring between the fourth and fifth layers. The lithology is dominantly sand (about 90%) sandstone (about 2%) clay / shale (about 8%). Average depth to top of aquifer ranges from 100 to 228 meters. Depth to the base of aquifer ranges from 88m to 278m while the average aquifer thickness is 33.7m. Three aquifer systems exist in the area-confined, unconfined and semi-confined. Semi-confined aquifer is dominant, while unconfined aquifer is less common. The former offers natural protection against pollution of under ground water by waste effluents while the later is prone to pollution. Average resistivity of the formations is relatively high indicating a formation likely to contain abundant conglomeritic and sandstone beds capable of promoting loss of circulation and difficulty in drilling bit penetration during under ground water exploitation. Areas to the west are relatively shallow while the South (Egbeada) is very deep. There is an insignificant relationship between aquifer depth and elevation. This section of Imo River basin is promising for underground water development, but requires caution since conglomeritic and sandstone traces can effect adversely underground water exploitation. Down the hole electric logging is necessary considering the aquifer depth. The problem of unprotected aquifer against environmental pollution should be noted and addressed.

Key words: Underground Water · Pollution · Mapping · Aquifer · Imo Sedimentary Basin · Nigeria

INTRODUCTION

Since the creation of Mbaitoli Local Government Area of Imo State, population explosion has called for sustainable ground water development. Absence of springs has forced the inhabitants travel many kilometers in search of portable water. Geophysical exploration involving the use of electrical resistivity method has been confirmed a reliable approach in aquifer mapping [1] Abundant ground water exists in Imo river basin of the tropical rain forest zone of Southeastern Nigeria. Within the local government, the development of groundwater resource has been relatively slow with isolated bore holes producing variable and unpredictable yields, while others are abortive [2]. Imo State government has embarked on the development of water resources but supply is inadequate. The area is devoid of springs and streams. Although there is no up to date data on the daily water supply, demand and use, empirical observations have shown that domestic needs account for a substantial part of the consumption. This is due to limited number of factories which would otherwise require substantial quantities of water. As the government is unable to meet ever increasing water demand, inhabitants have had to look for alternative sources such as shallow hand dug wells and boreholes.

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Since the quality of water is affected by the characteristics of the environment of circulation and occurrence, such sources are invariably exposed to anthropogenic, agricultural and industrial pollutants. [3, 14, 15]. It was stated that complete appraisal of available water resources in any area is commonly accomplished when aspects of water quality are included [6]. Consequently, this study is borne out of the need to evaluate both the aquifer nature and pollution vulnerability. This would minimize the rate of underground water exploitation failure and identify areas most vulnerable to environmental pollution due to poor protection by natural processes.

MATERIALS AND METHODS

Description of Study Area: The study area is located within the Imo River drainage basin of Southeastern Nigeria. It is bounded by latitude 5° 31'N to 5° 40' N and longitude 6° 56' E to 7° 08' E and comprises such communities as Umunoha, Afara Ifakala, Orodo, Ubomiri Egbeada, Idem Ogwa, Awo Mbieri, Alaenyi Ogwa, Abazu Ogwa and Ochi Ogwa among others Fig 1

Uma [2] carried out a study on the ground water resources of Imo River using hydrological data from existing boreholes and concluded that three aquifer systems (confined, unconfined and semi confirmed aquifers), exist in the area. The area lies within the humid tropical rainforest belt of Nigeria with mean annual rainfall of about 1, 500mm to 2,000mm [7, 8]. Two major climatic changes are dominant, the rainy and dry season. The dry season is relatively short from November to March [8]. Rainy season lasts from April to October. The topography is even and ranges from 100m–500m above sea level; such a variation influences the water table which follows topography [5]. The area is drained by Okitonkwo River which flows west wards and represents a recharge zone with high infiltration capacity, [9-11].

Geologically, the area lies within Anambra-Imo drainage basin of Southeastern Nigeria. Benin formation is the major lithologic unit that predominate the study area. It ranges from Miocene to recent age and was formerly designated coastal plain sand by [12]. The generalized regional stratography is shown in Table 1,

While Fig 2 is the geologic map of the area indicating outcrop pattern of the geologic formation. The geology consists of thick friable sands which are medium to coarse grained, pebbly and poorly sorted [12].

According to the author, aquifers are predominantly sand beds with minor clays, lignite and conglomerate intercalation. The sands are very fine to coarse grained subangular to subrounded. Benin formation is underlain by Ogwashi Asaba and is the youngest in Imo sedimentary basin [5, 12].

Data Acquisition: The instruments used for data acquisition include topographic map of the area, geologic map aerial photographs, fracture maps, satellite images, of Imo drainage basin. Hydrogeological investigations were carried out by identifying areas of ground water seepage. Geophysical investigations were carried out with the aid of Terrameter 300 SAS by employing vertical electrical resistivity soundings in eleven communities within the local government. The eleven sounding stations are Umunoha (VES 1) Afara (VES 2) Ifakala (VES 3) Orodo (VES 4), Ubomiri (VES 5) Egbeada (VES 6), Idem Ogwa (VES 7), Mbieri (VES 8) Umuebe Ogwa (VES 9), Abazu Ogwa (VES 10) and Ochi Ogwa (VES 11). The aim of the soundings is to identify geoelectric stratification of the sub surface materials. Schlumberger array with maximum current electrode separation of 900 meters was used for the purpose of data generation. In the interpretation of the resulting curves, both the approximate method of curve matching and computer assisted interpretation technique employing digital linear filters for the computation of the resistivity function were used [13]. The result of curve matching led to the definition of a number of geoelectric layers that constitute the sub surface, hence the aquifers.

Table 1: The General Geology of the Study Area (After Uma, 1989)

Age	Formation Name	Max. Approx. Thickness (m)	Character
Micocene-Recent	Benin	200	Unconsolidated, yellow and white sands, occasionally pebbly with lens of gray sandy clay.
Oligocene-Miocene	Ogwashi/ Asaba	500	Unconsolidated sst with carbonaceous mudstones, sands, clays and ignite seams.
Eocene	Ameki	1460	Sandstones gray to green argillaceous sandstone, shale and thin limestone.
Paleocene	Imo Shale	1200	Blue to dark grey shale and subordinate sandstones. It includes two sandstones members: the Umunna and Ebenebe sandstones.

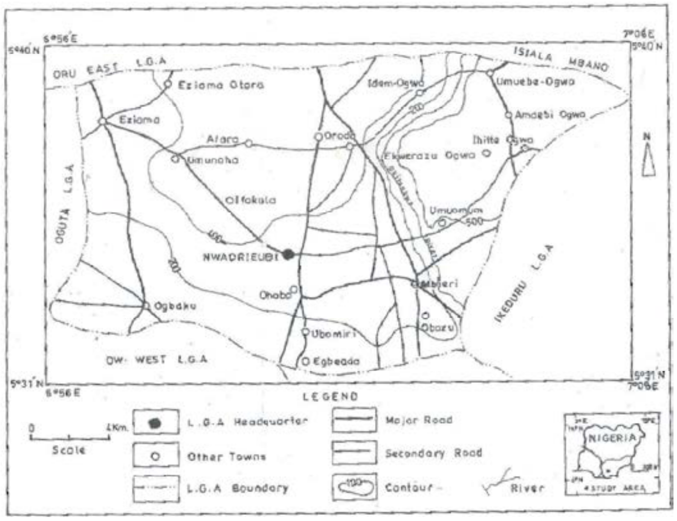

Fig. 1: Showing Topographical Location Map of the Study Area

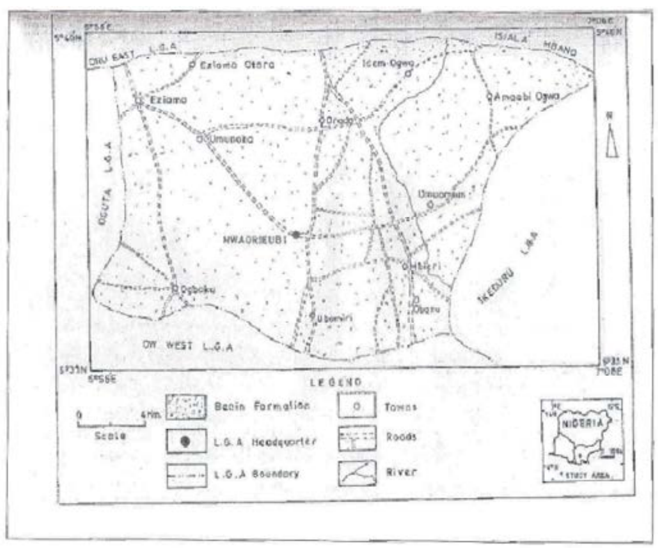

Fig. 2: Geologic Map of the Study Area

RESULTS

The result of resistivity soundings of the selected eleven communities is shown in Table 2.

From Table 2, aquifer top, bottom and thickness were delineated as shown in Table 3 and Fig 3.

DISCUSSION

It should be observed that lithology consists dominantly of sand with minor layers of clay and sandstone. The average thickness of clay is 18 meters and occurs at an average depth of 20 m. In few locations like Ifakala, Egbeada, Idem Ogwa, Awo Mbieri and Ochi Ogwa, clay layers occur at upper horizon about 10 m depth. Sandstone beds occur in few locations such as Umunoha, Ifakala, Ubomiri and Idem Ogwa at the average depth of 100 m . In Alaenyi and Abazu Ogwa, the lithology is homogenous made of sand with no natural protection of the aquifer by clay layers against environmental pollution [14]

The lithological configurations gave rise to three aquifer systems, namely: confined, unconfined and semi confined aquifers. Earlier Uma [2] discovered same composition. Confined aquifers, occur in Afara, Idem Ogwa and Ochi Ogwa. Unconfined aquifers are found within Umunoha, Egbeada, Alaenyi and Abazu Ogwa. The semi confined aquifers occur at

Table 2: Results of vertical electrical Soundings across the area

No.	Location	Resistivity (ohms)	Depth (m)	Lithology	Aquifer Thickness (m)	Depth to Aquifer (m)	No of Layers	Water bearing Layer	Aquifer Type
1	VES 1	2890	0.6	Top soil	32	139	9	7th-8th	Unconfined
	Umunoha	15100	2.8	Sand					
		5500	8.3	Sand					
		6750	23.5	Sand					
		3700	45.2	Sand					
		16100	77.9	SSt					
		7290	107	Sand					
		3450	139	Sand					
		470	>139	Shale					
2	VES 2	102	1.3	Clay	47	75	4	3rd	Confined
	Afara	480	28	Clay					
		1520	75	Sand					
		185	> 75	Clay/Shale					
3	VES 3	296	0.3	Top Soil	Undefined	147+	Undefined	8th-9th	Semi Confined
	Umuagwu	1640	1.4	Sand					
	Ifakala	860	9.6	Clay					
		1840	20	Sand					
		31700	56.5	SandStone					
		6530	84	Sand					
		4320	113	Sand					
		3030	147	Sand					
4	VES 4	920	0.6	Top Soil	33	164	7	6th -7th	Confined
	Orodo	9500	2.2	Sand					
		840	7.6	Shale					
		9500	62.1	Sand					
		9000	131	Sand					
		4080	164	Sand					
		547	> 164	Shale					
5	VES 5	219	1.1	Top soil	Undefined	142+	8	7th -	Semi Confined
	Ubomiri	1180	4.9	Sand					
		230	15.2	Clay					
		850	26.2	Clay					
		4230	43	Sand					
		10600	78.7	Sand					
		13400	142	Sandstone					
		4900	>142.0	Sand					
6	VES 6	380	1.7	Top soil	50	228	9	5th -8th	Semi Confined
	Egbeada	536	15.5	Clay					
		1320	37.8	Sand					
		4260	79.6	Sand					
		3080	127	Sand					
		2110	178	Sand					
		1510	228	Shale					
		960	278						
7	VES 7	470	0.5	Top soil	Undefined	148+	9	9th -	Semi Confined
	Idem Ogwa	4150	2.3	Sand					
		516	9.5	Clay					
		3960	18.3	Sand					
		39000	Semi confined/ unconfined 4.3	Sst					
		25300	83.6	Sst					
		9400	120	Sst					
		4830	140	Sand					
		1490		Sand					

Table 2: Continue

No.	Location	Resistivity (ohms)	Depth (m)	Lithology	Aquifer Thickness (m)	Depth to Aquifer (m)	No of Layers	Water bearing Layer	Aquifer Type
8	VES 8	790	1.1	Top soil	25	135	9	4th -7th	Semi Confined
	Umudata	960	2.9	Silt					
	Awo Mbieri	334	6.7	Clay					
		1120	11.2	Sand					
		6980	18.9	Sand					
		1800	56	Sand					
		9100	109	Sand					
		4356	135	Sand					
		705	>135	Shale					
9	VES 9	2040	17.4	Sand	Undefined	100+	6	6th -	Unconfined
	Umuegbe	2410	25.7	Sand					
	Alaenyi Ogwa	1640	43.5	Sand					
		1060	70	Sand					
		1030	100	Sand					
		3750	>100	Sand					
10	VES 10	3700	0.5	Sand	Undefined	186+	8	8th -	Unconfined
	Abazu Ogwa	8400	2.2	Sand					
		3050	27.4	Sand					
		9300	58.5	Sand					
		7830	92.5	Sand					
		4160	137	Sand					
		2680	186	Sand					
		1840	>186	Sand					
11	VES 11	980	3.8	Top soil	37	88	6	3rd -5th	Confined
	Ochi Ogwa	324	9.8	Clay					
		4180	20.2	Sand					
		16200	51.2	Sand					
		7380	87.7	Sand					
		411	>88	Shale					

Table 3: Depth to Aquifer top, base and thickness

Station	Aquifer Depth Top (m)	Aquifer Base	Aquifer Thickness (m)	Infered Water Table	Aquifer Type	Probable Total Drill Depth (m)
Umunoha 1	107	139	32	107	Unconfined Consolidated sand	139
Afara 2	75	125	50	Piezometric	Confined	125
Ifakala 3	147+	162	15	150	Semi confined	162
Orodo 4	164	170	6	131	Semi Confined	170
Ubomiri 5	142+	180	38	139	Semi confined	180
Egbeada 6	228	278	50	175	Semi Confined	278
Idem Ogwa 7	140+	162	22	140	Semi Confined	162
Awo Mbieri 8	109	135	26	109	Semi Confined	135
Alaenyi Ogwa 9	100+	162	62	100	Unconfined	162
Abazu Ogwa 10	186+	218	32	186	Unconfined	218
Ochi Ogwa 11	52	88	36	51	Confined	88

Table 4 : Shows average and range of resistivity values of the geological lithologies across the sounding areas.

	Station	Av. Resistivity	Max Resistivity	Min. Resistivity	Range
1	Umunoha	6805	16100	470	15650
2	Afara	572	1520	185	1335
3	Ifakala	7171	31700	1640	30060
4	Orodo	5578	9500	547	8953
5	Ubomiri	5056	13400	230	13170
6	Egbeada	2022	4200	536	3664
7	Idem Ogwa	11080	25300	516	24784
8	Awo Mbieri	3169	9100	334	8766
9	Alaenyi Ogwa	2386	3750	1030	2720
10	Abazu Ogwa	5322	9300	1840	7460
11	Ochi Ogwa	5699	1600	324	15870

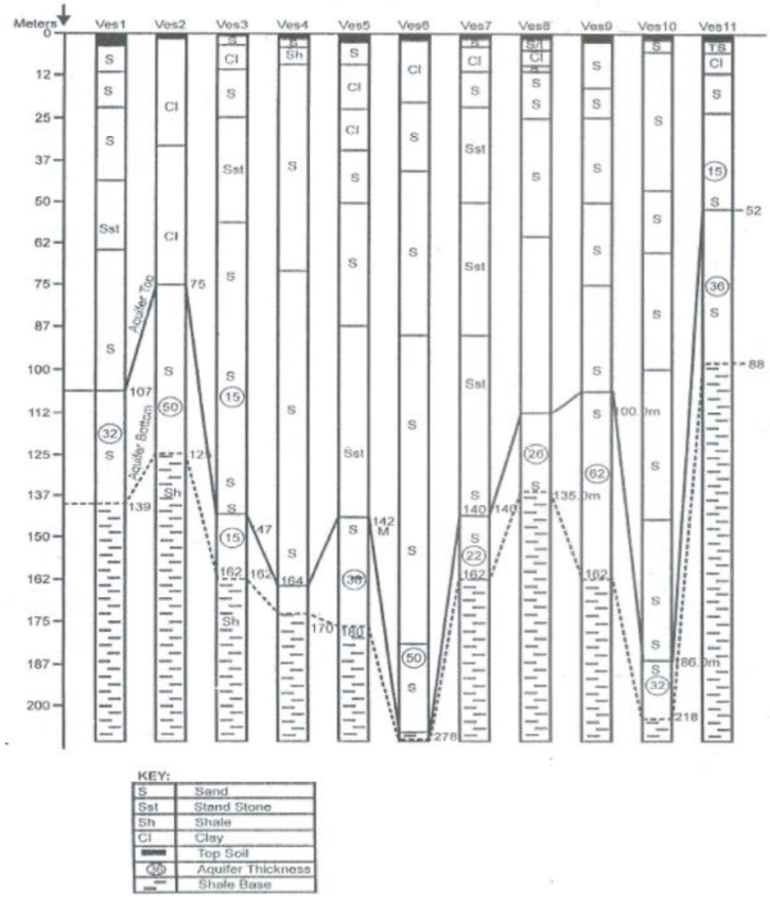

Fig. 3: Vertical Section of Lithological Variations across the Study Area

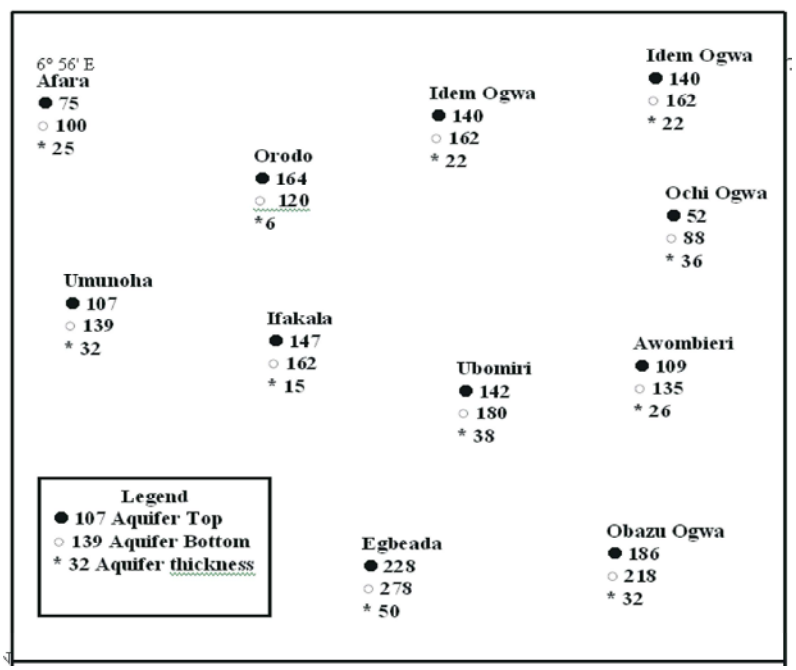

Fig. 4: Shows a map of the selected communities showing distribution of depth to aquifer top, bottom and thickness

Ifakala, Ubomiri, Idem Ogwa and Awo Mbieri. These features offer natural protection against environmental pollution.

The aquifers were confined between the overlying clay and the underlying shale, a feature that offers best protection against environmental pollution [15-18].

The resistivity values of the sampling areas decreased in this manner; Idem Ogwa >Umunaoha>Awo Mbieri>ObazuOgwa>fara>Ifeakala>Orodo>Ubomiri> Egbada > Alaenyi . This explains the nature of lithology of each area . For instance, the highest resistivity value of Idem ogwa is evident on its sand-stone lithology. On the other hand, the lithologies of those areas where low values of resistivity are recorded is predominantly clay. From fig. 3, it should be noted that the depth to aquifer is relatively shallow around Umunoha, (107m), Afara (75m), Awo Mbieri (109m), Alaenyi Ogwa (100 m) and Ochi Ogwa (52 m)

Aquifer is relatively deep around Ifakala (147 m) Obazu Ogwa (186m), Orodo (164m). The deepest aquifer is recorded in Egbeada where an average depth of 228m was obtained. From 7° 08'E fig. 3 water aquifer occurs within the range of 6^{th} to 7^{th} layers. Aquifer thickness also fluctuates within the area with places like Umunoha (32m), Ifakala (15m), Idem Ogwa (22m) Ochi Ogwa (36m), Orodo (6m) Ubomiri (38m), Egbeada (50m), Awo Mbieri (26m), Alaenyi (62m) and Obazu Ogwa (32m). Depth to aquifer base also varies across the area. Depth to aquifer base at Umunoha gives 139m, Afara 125m, Ifakala 162m, Orodo 170m, Ubomiri 180m, Egbeada 278m, Idem Ogwa 218 m and Ochi Ogwa 88m.

Conclusion and Recommendation: This work assessed the sub surface lithology, aquifer depth, base, thickness, type and aquifer pollution vulnerability within a section of Imo drainage basin of South eastern Nigeria. The aim is to minimize the rate of ground water exploitation failures inherent in the area and assess areas most vulnerable to underground water pollution.

Aquifer within the area is confined, semiconfined or unconfined. Both confined and semi-confined aquifers are dominant and are found in such areas as Afara and to an extent Ubomiri. Semi confined aquifers abound in Ifakala, Orodo, Egbeada, Idem Ogwa, Awo Mbieri and Ochi Ogwa. Aquifer is unconfined at Umunoha, Umuegbe, Alaenyi Ogwa and Abazu Ogwa. Aquifer thickness is variable with highest value at Afara (50 m), Egbeada (50 m) Umuenyi (62). Others in decreasing order are Ubomiri (38 m), Ochi Ogwa (36 m), Umunoha (32 m). Smallest values are recorded at Ifakala (15 m), Orodo (6 m) Idem Ogwa (22) and Awo Mbieri (26). Water bearing horizon occurs between 6^{th} and 7^{th} layers. Depth to top and base of aquifer also varies across the area.

Some areas are shallow while others are deep. Aquifer is relatively shallow at Umunoha (139 m), Afara (75 m) Alaenyi Ogwa (100 m) and Ochi Ogwa (52 m). Aquifer is relatively deep at Orodo (164 m), Umuagwu Ifakala (147 m), Ubomiri (142 m), Egbeada (228 m), Idem Ogwa (140 m), Abazu Ogwa (218 m) and Awo Mbieri (135 m).

Recommendation: Water drillers in the area should be prepared to encounter the following problems:

- High resistive layers are likely to be hard sandstones or gravel beds.
- Deep aquifer (147-228m)
- Problems of pollution prone areas should be addressed.

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