Underground Water And Pollution Vulnerability Assessment Of Lower Imo Sedimentary Basin Of Southeastern Nigeria (A Case Study Of Nwangele Local Government Area Of Imo State, Nigeria)

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Abstract: Water exploitation problems and population explosion are two major problems facing Nwangele Local Government, for this, underground water and pollution vulnerability assessment of Nwangele Local Government Area of lower Imo sedimentary basin of Southeastern Nigeria has been carried out as to examine the aquifer nature and pollution vulnerability, as water exploitation and population explosion problems have created problems in the area, since the emergence of the new Local Government. The method of study involves literature survey of previous work done in Imo River sedimentary basin and other works considered necessary for the study. A total of ten (10) vertical electricity soundings (VES) was conducted for data generation using terrameter 300 SAS employing Schlumberger configuration. Aquifer (sands) from boreholes within three (3) communities and ten (10) water samples were collected and used for statistical and geochemical analysis. The result shows that the lithology is made of sand, silty sand, clay and shale. Three (3) aquifer systems exits in the area confined, semi confined and unconfined aquifers, these occur as upper (33.5m), middle (82m) and lower (102 – 115m) aquifers. The lithology comprises 4 to 6 layers with water bearing bed occurring at the fifth layer. Average aquifer thickness measured 38 metres. Multiaquifer system exists in some localities. Hydraulic conductivity values range from 25.6m/day to 28.9m/day, transmissivity ranges from 450.84^2/day to $111.7m^2$/day while the storativity values ranges from 0.468×10^{-5} to 1.13×10^{-5}, all indicate aquifer of good yield. Aquifer thickness ranges from 12.5 to 45m. The water chemistry is neutral, mildly acidic to mildly alkaline. The underground water is of calcium by carbonate type ($CaHCO_3$) fresh and ideal for consumption, irrigation and laundry industry. None of the constituents exceeded the standard set by WHO (1984). Environmental pollution is only confined to upper aquifer. It is recommended that the three aquifer horizons can be tapped at the depth range of 18 to 102 metres. Multiple screen should be employed where there are more than one aquifer horizon. It is advisable that down the hole electric logging be conducted prior to the installation of screen. The middle and lower aquifers are preferable. The middle aquifer is ideal for domestic boreholes while the lower aquifer should be developed for community and industrial boreholes.
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Introduction

Nwangele Local Government Area of Imo State, Nigeria has witnessed an increase in population growth since its creation. The rise in population led to the need for subsurface water resource, since the surface water has been polluted as a result of population explosion and improper landuse. Cases of water exploitation failures have been reported by Offodile (2005). The study was carried out to examine the nature of underground water aquifer, causes of water exploitation, problems and aquifer pollution potentials. Recently there exists a lot of studies on different aspects of the geology of the region, some of which includes the works of Etuefotor 2001, Okonny 2001, Etuefeotor and Ogidi 2003, Enuvie et al. (2005) and Uma (1989). They observed that the sedimentary sequences of the area are known to contain several aquiferous units. They also observed that the characteristics of the aquifers such as transmissivity hydraulic, conductivity and storage potentials are not fully known, and it has not been possible to design management strategies for their optimal exploitation. Ekwe et al (2006) also observed that the problem is further compounded by poor knowledge of the aquifer been tapped (their geometry and nature of their hydraulic boundaries).

Although numerous boreholes have been drilled in various parts of Imo River Basin, there have not been any systematic and comprehensive studies to establish the nature and distribution of the aquifers beneath the basin (Uma and Egboka 2001). This must have been one of the reasons for numerous water borehole drilling failures encountered in the area. The stratigraphy within Imo River Basin has been determined by Reyment (1965), Short and Stauble (1967). They observed an alteration of sand and clay layers. Uma (1989), carried out a study on the ground water resources of Imo River Basin using hydrological date from existing boreholes. He concluded that three (3) aquifer systems (shallow, middle and deep) occur in the area as confined, unconfined and semi-confined forms. The present study is aimed at evaluating the aquifer parameters, mapping our prospective aquifer zones through the study of subsurface lithologies and causes of subsurface water exploitation failures as well as assessing the pollution potentials of the aquifers through borehole logs and water chemistry analysis.

Methodology

Description Of The Study Area

The study area is located within latitudes 5^{0}'41N to 5^{0} 45'N and longitudes 7^{0} 05E to 7^{0} 09E (Fig. 1).

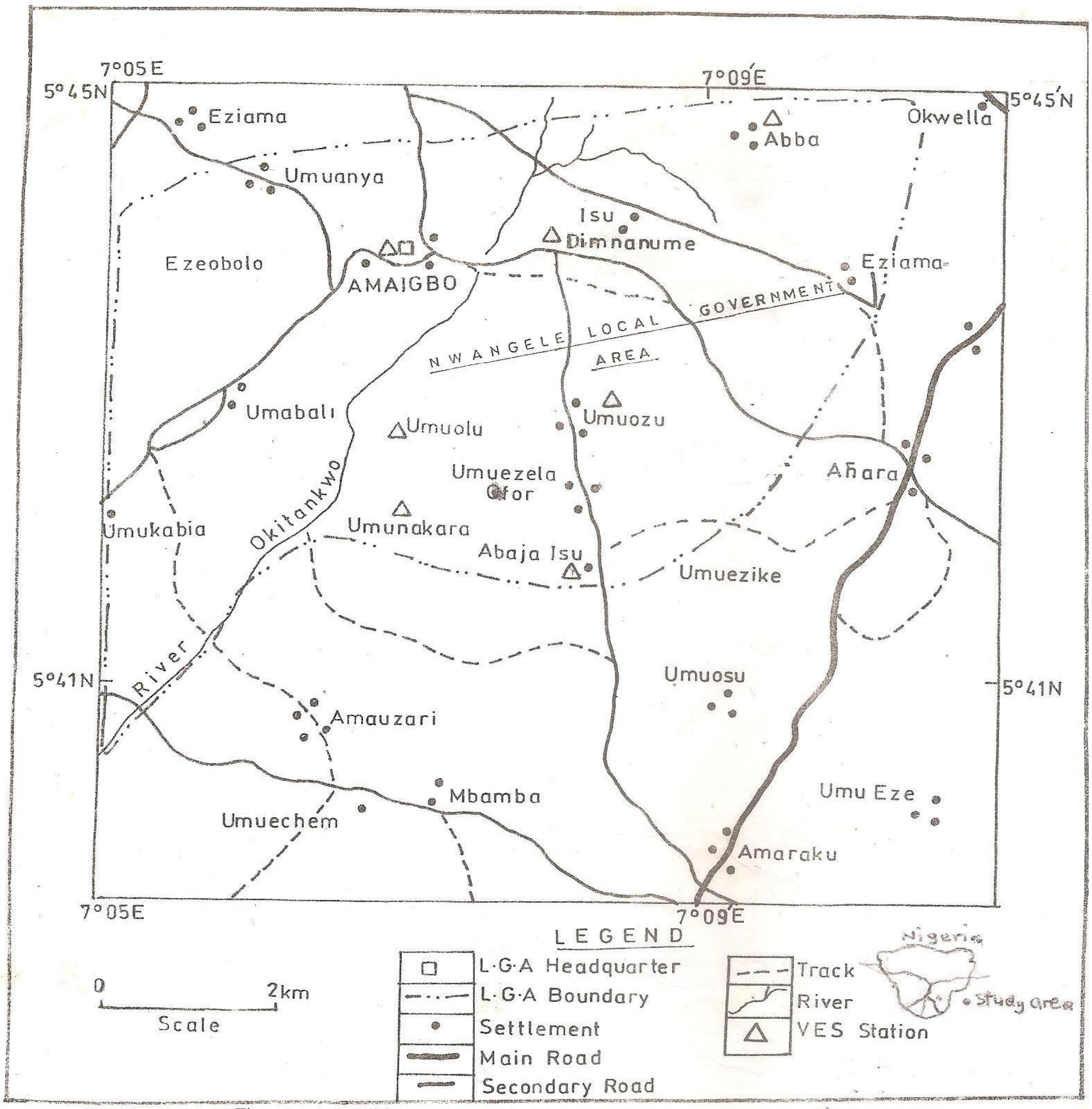

Fig 1 Location map of the study area showing VES station

It covers an area extent of approximately 600.50 sqkm (Nigeria population commission figure, 1991). The major communities covered in the study area include Amaigbo, Abba, Dinanumeisu, Umuozu, Agbaja Umumakara and Umuotu Isu. Two types of land forms characterize the topography of the area, they include high undulating ridges and nearly flat topography (Ibe et al. 1992). Geologically, the study area is characterized by coastal plain sand (Miocene to recent) with stratigraphic successive as shown in table 1 (Uma, 1989 and Reyment, 1965).

Table 1: General Stratigraphy of the Study Area (After Uma, 1989, Reyment 1965)

Age	Formation	Max. (m) thickness	Characteristic
Miocene-Recent	Benin	200	Unconsolidated, yellow and white sands, occasionally pebbly with lens and grey sandy clay.
Oligocene to Miocene	Ogwashi Asaba	500	Unconsolidated sand stones with carbonaceous mud stones, sandy clays and lignite seams
Eocene	Ameki	1460	Sandstones grey to green argillaceous sand stones shales and thin limestones
Paleocene	Imo	1200	Blue to dark grey shales and subordinate sandstones. It includes two sandstone members the Umuna and Ebenene sandstones.

Materials And Methods

The method of study includes literature survey of some previous work done in Imo River sedimentary basin and other works considered necessary for the present study. An extensive field work involving acquisition of 10 vertical electrical sounding data across the study area using Schlumberger configuration was undertaken. Water samples were collected from water boreholes for geochemical analysis. Aquifer samples from borehole cuttings were collected for the computation of aquifer parameters such as transmissivity, storativity hydraulic conductivity and permeability. These were achieved through statistical analysis of grain sizes.

Vertical Electrical Soundings (Ves)

VES furnishes information concerning the vertical succession of different conducting zones, their individual thicknesses and resistivities (Zondy 2000 and Keofoed 2001). In the electrical sounding method, the midpoint of the electrode configuration is fixed at the observation station while the length of the configuration is gradually increased. As a result, the current penetrates deeper and deeper, the apparent resistivity being measured each time the current electrodes are moved outwards. For Schlumberger array, apparent resistivity according to Zondy, 2000 is given by:

$Pa = \wedge R (a^2/b – b/4)$………..….(1)

Where a = half current electrode separation and b = potential electrode spacing.

Ten (10) Schlumberger array soundings with maximum current electrode spacing (AB) of 1000 were conducted in the study area. The equipment used was ABEM SAS 300B Terrametre, a digital averaging instrument for direct current resistiivty work. The sounding points are as shown in table 2. Field data was converted to apparent resistivity values by multiplying with the Schlumberger geometric factor. The geometric factor is given by

$G – \wedge (a2/b – b/4)$………………………(2)

Where a = ½ current spacing and b = potential electrode spacing. The sounding curve for each point was obtained by plotting the apparent resistivity on the ordinate against half electrode spacing on a bilogarithmic transparent paper. Parameters such as apparent resistivity and thickness obtained from both partial curve matching and the method of asymptotes were used as input data for computer iterative modeling (Zondy, 2000). Detailed quantitative interpretation was done using offix soft ware.

Water Samples For Geochemical Analysis

A total of ten (10) water samples were collected for geochemical analysis. Analysis was carried out using atomic absorption spectroscopy for $Ca^{2+,}$ Na^+, Mn^{2+}, Cl^- lead (Pb^{2+}) Cadmium (Cd), Zinc (Zn) and Copper ($Cu^{\ 2+}$). This was achieved with the aid of spectrophotometer, while K^+ was determined using photometer method. pH was measured with standard pH meter, while the concentrations of total iron (Fe^{2+}) were determined calorimetrically using Spekker absorption meter. Total dissolved solids (Tds) was determined using glass fibre Filter. The concentrations of Ca^{2+}, mg^{2+} and Na^+ in milliequivalent were used to obtain sodium absorption ratio (SAR). pH and dissolved oxygen were measured insitu in the field with appropriate standard meters, while anions like Hco_3, were estimated by titrimetric method. All details of analytical procedure are reported in Omidiran (2000). Clean plastic containers were used to contain the water samples. They were rinsed several times with the same water sample to be analyzed, then covered with airtight cork and carefully labeled and sent to the laboratory for geochemical analysis within 24hours of collection.

Aquifer Samples For Statistical Analysis Of Aquifer Parameter

Aquifer samples were collected from boreholes cutting at Amigbo, Agbaja and Umuozu. The particle, size analysis involves the determination of the percentage by weight of particles within different size ranges, each fraction containing grains of approximately the same size. The sand samples (aquifer) for particle size distribution were thoroughly disintegrated and sieved through 3.35mm, 0.425mm to 0.075mm. The particle size distribution of the sand often referred to as grading was accomplished using British standard electric shaker machine. It was determined by passing a sample of soil through a series of sieves and weighing the portions retained. The particles size distribution curves indicates the range of sizes of the various grain fractions present.

Result And Discussion

The following formats were adopted in the presentation of results

(1) Lithologic logs results from 10 VES soundings.

(2) Aquifer analysis.

(3) Sieve analysis results.

(4) Aquifer parameter computation.

(5) Water quality analysis results.

Lithologic logs result from, 10 VES soundings: The result of 10 VES soundings is shown in table 2.

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Table 2 Aquifer nature and lithologies (computed from VES soundings)

VES No	Geo-electric layer	Resisitivity Ohm-m	Depth	Lithology	Prospective Aquifer material	Aquifer type
1 Umunakara Isu	1 2 3 4 5	2768 1250 1150 1290 578	7.2 41.2 66.1 102.9 > 102	Top soil Sand claylenses Sandy clay Sand units Shaley	Sand	Semi confined
2 Umuehoke (Amigbo)	1 2 3 4 5 6 7	830 439 5760 338 1845 1925 340	8.7 18.5 48.0 77.5 98.4 115.8 > 115.8	Top soil Sandy clay Sand Clay Sand Sand Shale	Sand	Confined
3 Umueziali Amigbo	1 2 3 4 5 6 7	2390 5400 1040 5560 5050 1980 920	6.9 19.0 41.3 63.9 93.9 109 > 71	Top soil Sand stone Silty/clay Sand stone/sh Sand/gravel Sand clay Shale/clay	Sand	Semi confined
4 Umuopara Abba	1 2 3 4 5 6	800 7300 532 6310 2400 431	1.0 3.4 10.9 31.6 65.8 > 65.8	Top soil Sand stone Silt stone/clay Sand stone Sand Shale/clay	Sand	Confined
5 Dimnaute Amigbo	1 2 3 4 5	316 195 205 195 820	8.1 47.4 64 107 < 107	Top soil Soil Clayey Clayey sand Sh Shale	Sandy clay	Semi confined
6	1 2 3 4 5 6	1030 590 1040 5060 960 388	11.7 23.9 31.5 60.3 89.6 104 > 104	Top soil Clay/silt stone Sand Sand Sand clay Shaley sand Shale	Sandy	Semi confided
7 Umuozu	1 2	316.0 125.0	8.1 47.4	Top soil Clay		Confined

	3 4 5	202.0 125 950	64 107 135 > 135	Clay Shale Clayey sand Shale		
8 Umuolu Isu	1 2 3 4 5 6 7	316 125 202 125 950 890 320	13 25 32.5 62.1 90.1 108 > 108	Top soil Clay-silt Clay-shale Shale Sandy clay Sand Clay/shale	Sand	Semi confined
9 Umudii Amigbo	1 2 3 4 5	990 2270 1220 1872 792	34.6 68.6 117.0 118 >118	Top soil Sand Sandy clay Sand Shale/clay	Sand	Semi confined
10 Umudinaogwu (Abba)		232 4440 626 232 1120 2760 286 950 11.6	0.4 1.3 2.5 5.0 7.5 16.0 39.6 77.4	Top soil Sand stone Clay sand Clay Sandy clay Sand Clay Shale Shale	Sandy shale	Confined

From table 2, lithological and aquifer units were delineated as shown in fig 3 and 4 respectively.

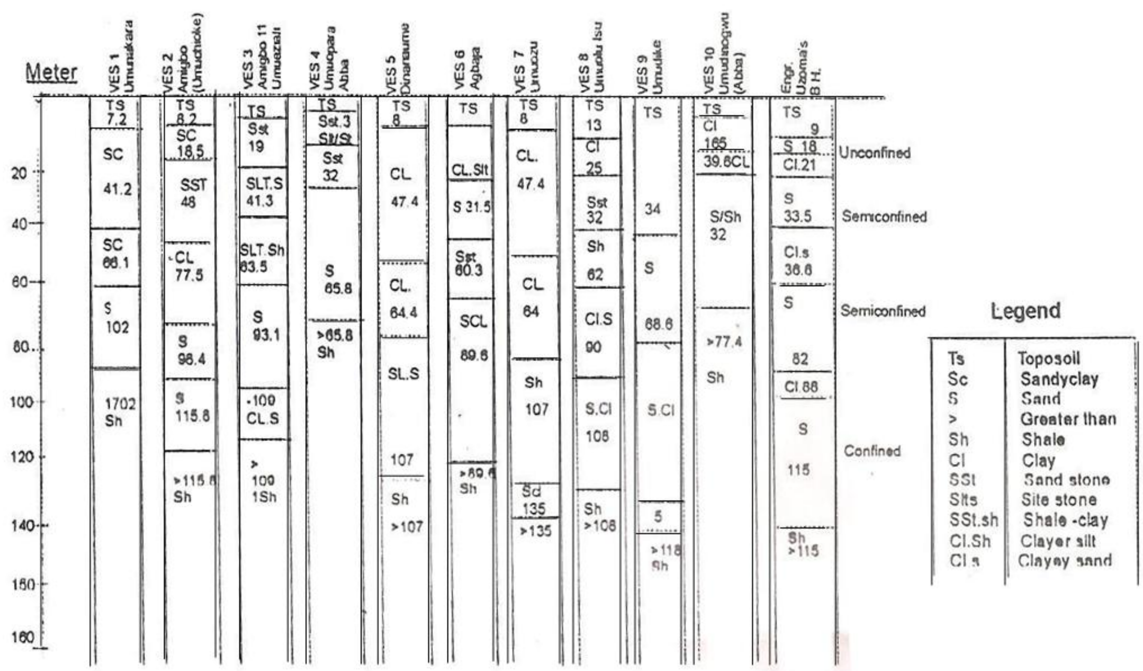

Fig 3: Lithologic picture of the area from the 10 sounding stations including physical observations of well cuttings.

Aquifer Statistical Analysis:

The result of aquifer sieve analysis and computations is shown in table 5, 6 and 7 respectively. Aquifer samples were taken from three communites – Amigbo, Agbaja and Umuozuzu.

Table 5: Aquifer Sieve Analysis from Amigbo

Sieve size (mm)	Weight retained (grams)	Weight % retained	Mass passing (g)	Mass % passing
2.00	0.74	0.40	240.20	99.42
1.00	12.80	6.21	217.01	92.94
0.60	40.20	22.81	170.11	80.11
0.425	20.22	8.85	112.8	50.05
0.30	48.00	23.5	62.43	20.55
0.10	32.12	24.77	0.21	0.062
0.075	30.12	0.300	0.10	0.02
0.063	0.72	0.043	0.01	0.01
Pan	6.10	2.48	0.00	0.00

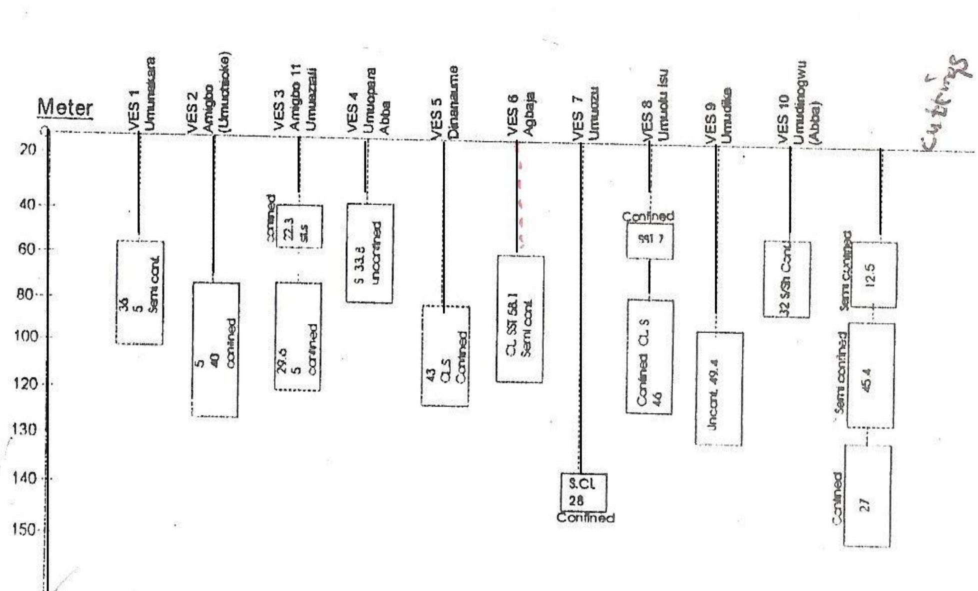

Fig 4: Aquifer units and thicknesses, across the area:

Table 6: Aquifer Sieve Analysis from Agbaja

Sieve size (mm)	Weight retained (grams)	Weight % retained	Mass passing (g)	Mass % passing
0.850	0.78	1.59	48.42	98.41
0.800	5.28	10.73	43.14	87.68
0.600	8.00	16.26	35.14	71.42
0.425	15.78	32.07	19.40	39.43
0.250	6.80	13.82	12.56	25.53
0.125	9.50	19.31	3.06	6.22
0.063	0.92	1.87	2.14	4.35
Pan	2.14	4.35	0.00	0.00

Table 7: Aquifer Sieve Analysis from Umuozuzu

Sieve size (mm)	Weight retained (grams)	Weight % retained	Mass passing (g)	Mass % passing
0.850	0.51	0.86	58.75	99.14
0.800	7.93	13.38	50.82	85.76
0.600	9.31	15.71	41.51	70.05
0.425	16.92	28.55	24.59	41.50
0.250	9.43	15.91	15.16	25.58
0.125	11.22	18.93	13.94	6.65
0.063	0.93	1.57	3.01	5.08
Pan	3.01	5.08	0.00	0.00

Table 5 to 7 was used to plot the graph of cumulative percentage of grain size against the partial diameter. The values d_{10} was computed from the graph for the various communities of Amigbo, Agbaja and Umuozuzu, d_{10} signifies the particle size such that 10% is finer than the total sieve size.

The value d_{10} for Amigbo gives 0.17mm, Umuozuzu 0.17mm, while Agbaja is 0.16. These values were used to compute various aquifer parameters such as hydraulic conductivity (k) transmissivity (I) and storativity (Ss) using Todd (1985) principle.

For hydraulic conductivity (k) computation of the three representative communities.

$K = 1000d^2_{10}$ m/day (Todd, 1985)………………(4)

Where d_{10} is the particle size such that 10% is finer than the total sieve size.

For Amigbo with d_{10} = 0.17, K = 28.9m/day
Umuozuzu with d_{10} = 0.17 K = 28.9m/day
Agbaja with d_{10} = 0.16 K = 25.6/day

Transmissivity computation: Transmissivity is defined as the rate of flow of water through a vertical section of an aquifer and this given as

T = Kb………………………. (5)

Where K = hydraulic conductivity and b is aquifer thickness. For Amigbo sample with K = 28.9 m/day and aquifer thickness of approximately 29m, Transmissivity value gives 838.1m^2/day. In the same way Umuozuzu and Agbaja have the value of T = 450.84m^2/day and 118.72m^2/day.

Storativity computation: According to Omidiran (2000) and Onunkwo and Uzoije (2011), the storativity (storage coefficient, Ss) of an aquifer is defined as the volume of water released from or taken into storage per unit surface area of the aquifer per unit change in head normal to the surface. Logan (1984) suggested a rule of thumb mean for estimating coefficient of aquifer as

$S = 3 \times 10^{-b}$……………………. (6)

Where b is the saturated thickness of the aquifer

For Amigbo sample, storativity

$S = 8.7 \times 10^{-7}$

Umuozuzu and Agbaja, sample, the storage coefficient are 4.68×10^{-5} and 1.31×10^{-4} respectively.

Analysis of the results of aquifer parameter computation shows that Umuozuzu in terms of rating, Umuozuzu has moderate potential, Amigbo and Agbaja have high potential, (Maslov 1997).

Table 6: Water Analysis Result

parameters	Amaigbo	Umuozu	Agbaja	Abba 1	Dinanume	Umuolu	Amaigbo	Abba 2	Umunaichara	Amaigbo	Average	WHO standard (1984)
pH at 25^{0}C	7.28	6.98	7.34	7.13	6.93	8.49	7.20	6.74	8.00	7.30	7.33	6.5 to 8.5
Fe 2+	0.08	0.09	0.18	0.06	0.11	0.18	0.07	0.05	0.19	0.10	0.11	0.3
No3	0.04	0.03	0.02	0.01	0.10	0.04	0.21	0.05	0.06	0.08	0.06	0.1
TDS	85.9	82.0	90.4	100	78.2	71.0	68.1	99.1	85.2	75.0	83.5	500
D04	0.51	0.72	0.68	0.50	0.90	0.21	0.31	0.33	0.11	0.70	0.50	10
S042-	7.21	8.21	6.88	5.92	6.45	9.00	8.70	6.00	5.27	4.38	7.00	400
Ca2+	11.20	12.70	13.22	10.00	9.27	8.82	12.1	12.00	11.99	11.60	11.28	200
HC03-	40.02	45.00	43.0	39.27	36.55	38.20	40.18	37.8	41.2	40	40.12	500
Mg2+	1.08	1.04	1.14	1.18	1.09	1.04	1.07	1.02	1.14	1.16	1.09	250
K+	2.78	2.92	2.76	2.45	3.40	3.22	2.44	2.62	2.57	3.40	2.86	200
Na+	5.11	5.00	6.20	6.30	5.18	5.22	4.90	4.72	5.41	4.72	5.28	200
Total hardness	7.80	7.90	8.20	8.50	7.72	9.00	6.49	7.2	8.22	8.50	7.80	500
E+ conductance	120	140	122	138	110	100	124	136	118	115	122.3	500
Cl-	5.0	6.0	5.22	4.66	4.20	4.00	6.77	5.48	5.17	4.90	5.14	200

From water analysis result, table 6, none of the measured constituents constitute pollution (WHO, 1984).

Employing the result of water quality analysis of table 6. It was possible to determine the water class using pipers method. Piper (1944) suggested trilinear diagram approach for representing and comparing water class by establishing the concentrations of major elements (Hco_3, So_4, $Ca^{2+,}$ $mg^{2+,}$ Na^+, $SO4^{2-}$, Hco_3, Co_3) in milli-equivalent per litre. Table 7 shows the conversion of the constituents in meq/l using the relation

$$\frac{\text{mg/l}}{\text{equivalent mass}} \ldots\ldots\ldots\ldots\ldots\ldots \text{(6)}$$

Table 7 conversion of milligram per litre of the major constituents to milli-equivalent per litre.

Ions	Average mg/l conc.	Conversion factor	Meq/l	% concentration in meq/l
Ca^{2+}	11.29	0.04990	0.05	58.9
Mg^{2+}	1.09	0.08226	0.09	9.5
Na^{+}	5.28	0.04350	0.21	22.1
Ic^{+}	2.86	0.02557	0.09	9.3
cl^{-}	5.14	0.02821	0.15	13.8
$SO4^{2-}$	7.00	0.02082	0.14	12.8
HCO_3^{-}	4.12	0.01639	0.80	73.4

Employing the value of major anions and cations converted to milliequivalent per litre in table 7, Fig 5 was plotted as to characterize the water class of the study area.

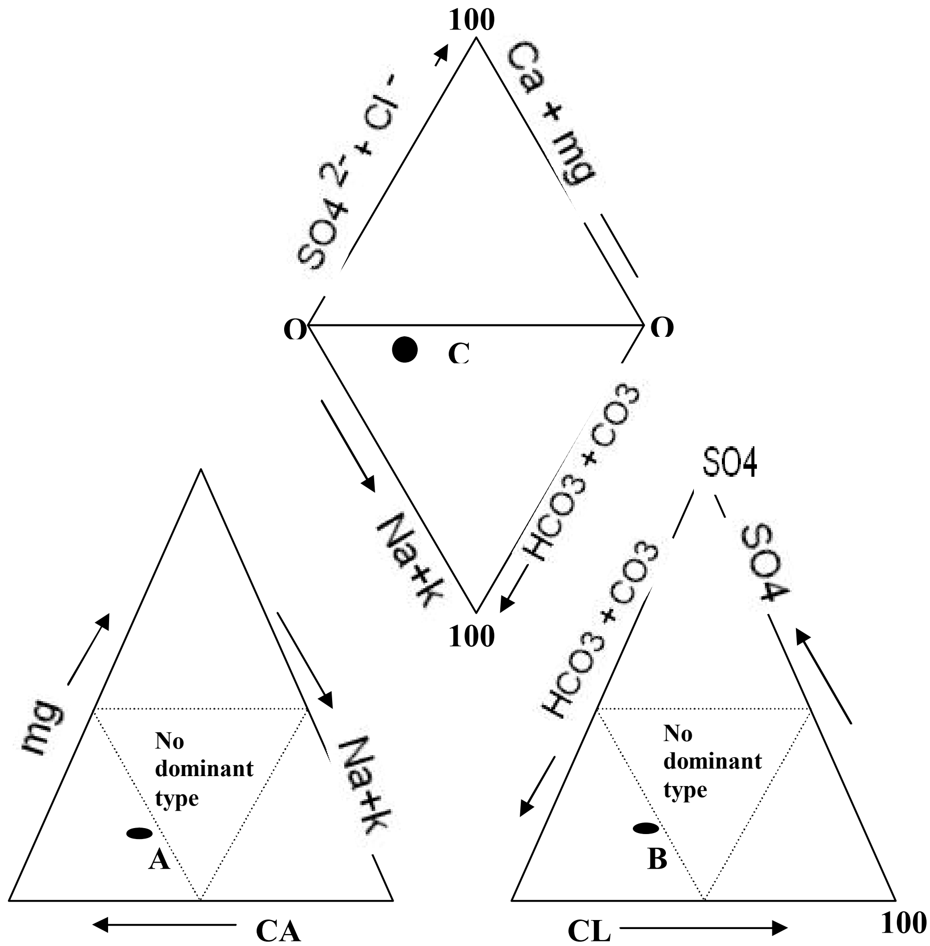

Fig. 5, Piper trilinear plot for anion and cation percentages in milliequivalent per litre (meq/l)

Cation plot = A
Anion plot = B
Fresh water plot = C

From Fig 5, the water plots within a calcium bicarbonate type and also plots on the left side of the diamond shape of the pipers plot indicating a fresh water. Cation and anion relation in milliequivalent, per litre shows that the basic cation constituents are in the following order Ca^{2+}>mg^{2+}>$Na^{2+}{}_{+}K^{+}$. For the anion values the relation holds as HCO_3>C^{l-} +NO_3>$SO4^{2-}$. This indicates the dominance of $CaHCO_3$ giving $CaHC_3$ water.

Sodium Absorption Ratio (SAR). Sodium content was used to classify water quality for irrigation purpose because of its reaction with soil to reduce permeability Etu Efeotor (2000).

Thus, the relation Sodium Absorption Ratio

$$SAR = \frac{Na+}{(Ca2+ + mg2+)^{1/2}} \text{ meq/litre} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (7)$$

Was employed to determine the suitability of the water for irrigation purposes. According to Etuefeotor (2000), water class based on SAR is classed as 0-10 excellent, 10-18 Good, 18-26 fair while > 26 is poor. Using equation 7, the SAR for the average components derived from table 7 is 3.518 indicating that the water is excellent for agriculture. Etuefeotor (2000).

Discussion And Conclusion

The resistivity values across the area ranges from 11.60hms to 7,3000 ohms. This signifies the absence of hard sandstone formation. This values indicates that the subsurface consists of sandy, silty clay and shaley formations. Their lithological compositions gave rise to three aquifer systems – confined, semi confined and unconfined aquifers. The aquifer occurs at the upper, middle and lower horizons. This corresponds with the work of Uma 1989. The upper aquifer occurs at a depth of 33m (108.24ft), the middle aquifer occurs at a depth of 82.31 – 91.46m (270ft – 300ft), while the lower aquifer occur at a depth of (106.70 – 121.95m) (350ft – 400ft respectively).

The middle and lower aquifer are preferable since the upper shallow aquifer is likely to be contaminated (Uma, 1989). Aquifer relationship is significant in the area. The aquifer either occur in one location as unconfined, semi confined or confined conditions. The aquifer also occurred in combination of two or three aquifer horizons in different proportions of confined, unconfined and confined conditions as in the case of Umoluisu and Umuazali-Amigbo. It was discovered that the confined aquifer mostly occurs at depth ranging from 106.70m to 121.95m. Unconfined and semi confined aquifers occur mostly at the upper (33m) and middle horizons (82.31 – 91.46m). This signifies that ground water can be exploited at various horizons. Multiple screens can be employed to tap the aquifer where they occur in combination of two or three aquifer horizons as this ensures greater yield. Aquifer thickness vary across the area with the shallow middle and deep aquifers having an average thickness of 38 metres. Aquifer parameters (Hydraulic conductivity) transmissivity and storativity also show characteristics of high yield (Todd, 1985), also the aquifer materials consist of medium to coarse sand of high permeability. The lithologic layers is 5 on the average with water bearing horizon occurring in the fifth layer. According to Offodile (2005 Raymond, 1979) environmental pollution occurs where the aquifer is not protected by clay or silty clay. Upper aquifers are polluted since they are not protected. The lower and middle aquifers are protected, since they are either confined or semi confined. The result of water quality analysis indicates that the acidic content of the water ranges from 6.98 to 8.40 with cumulative average of 7.3 indicating a neutral to mildly acidic to alkaline conditions. This accounts for the low solvent property of the underground water as most elements in water occur in insignificant quantity, hence no water pollution by World Health Organization (WHO) guidelines (WHO, 1984). Pipers plot indicates calcium by carbonate water ($CaHCO_3$) also fresh and ideal for human consumption. The value 3.52 obtained for sodium absorption ratio (SAR) shows that the water is ideal for irrigation and agricultural purposes (Beidou (2005) and Etuefeoto (2000).

Conclusion And Recommendation

Portable underground water occurs significantly within Nwangele Local Government Area of lower Imo River Basin, at depths ranging from 18m to 102 metres. Multiaquifer system exists in the area, at the uppers, middle and lower horizons, a condition where multiple screen should be applied for maximum water yield.

The middle aquifer should be tapped for domestic purposes, while the lower aquifer is ideal for industrial and community boreholes. Where funds are not available, average family can drill hand dug well to tap the upper aquifer and treated before use. Geophysical survey using resistivity Schlumber configuration should be conducted prior to drilling of water boreholes in the area. Multiple screen should be employed where the three aquifer horizons exist.

Down the hole electric logging should be carried out to confirm the lithologies. It was discovered that water borehole drilling failures in the area is due to the activities of quacks who neglect the predrilling geophysical surveys.

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