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Evaluation of Groundwater Potentials of the Calabar Coastal Aquifers

E. A. Amah[1], A. N. Ugbaja[1] & E. O. Esu[1]

[1] Department of Geology, University of Calabar, Calabar, Nigeria

Correspondence: E. A. Amah, Department of Geology, University of Calabar, Calabar, Nigeria. E-mail: amahedet@yahoo.com

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Abstract

This article presents the results of groundwater site evaluation scheme and quality assessment of coastal aquifers in Calabar, South-eastern Nigeria based on ground water potential index (GWPI) scale, developed for this study. The GWPI consists of ten input parameters, namely: lithofacies (L), aquifer thickness (b), transmissivity (T), storativity (S), specific capacity (SC), static water level (SWL), formation resistivity (FR), chloride (Cl) contents, total dissolved solids (TDS) and *Escherichia coli* (*E-coli*). The groundwater potential index (GWPI) is computed as the sum of the products of weights and ratings assigned to each of the input parameters. The GWPI index varying between 20 and 60, is divided into three classes: high (> 40), medium (30-40), and low (< 30). The GWPI index, is then used to demarcate the study area into three hydrogeologic ground water potential zones. These are:

(i) Northern zone 1 (transitional, low GWPI)

(ii) Central zone 2 (coastal plain sands, high GWPI)

(iii) Southern zone 3 (coastal alluvium, medium GWPI).

The central zone 2 has the highest GWPI rating. The implication of this rating is that the aquifers in the central and southern zones 2 and 3 are more prolific water bearing than the transitional zone 1 that lies between the Coastal Plain Sands and the argillaceous sediments of the Calabar Flank. This is in agreement with the mean specific capacity (SC) and transmissivity (T) recorded for the central (355.6 m^3/d/m, 2640 m^2/d); southern (150.0 m^3/d/m; 2150 m^2/d) and northern (52.1 m^3/d/m, 750 m^2/d) zones respectively. Lithofacies, saturated thickness of the aquifer, static water level, transmissivity and storativity are the most important parameters which influence ground water availability in the study area. The GWPI results further reveal that E-coli (3-50 counts/100ml), chloride (Cl^-) (2.5-21.0 mg/l) and static water level (SWL) (2.3-28.7 m) remain the most significant parameters that contribute to groundwater pollution particularly in the southern zone of the study area. In the near future, water quality in aquifer will be affected due to poor management of human waste-disposal/salt water intrusion, thereby limiting the availability of potable water for domestic and industrial uses.

Keywords: groundwater, evaluation, GWPI, Calabar

1. Introduction

Groundwater is the major source of potable water in Calabar and its environs, South-eastern Nigeria. Hundreds of boreholes have been drilled by private firms, individuals and government agencies such as the Cross River State Water Board (CRSWB), Rural Water Supply and Sanitation (RUWASSA) to provide the teaming population with potable water. However, the sitting and installation of these boreholes were done mostly on wildcat basis without rigorous geological, hydrogeological /geophysical and technical planning. These factors have led to the high rate of borehole failure in the study area. The supply of good quality water in the area remains grossly inadequate (Amah, 2007). In order to demarcate areas of groundwater availability and groundwater pollution potential, a site evaluation scheme and quality assessment called groundwater potential index (GWPI) have been developed for the Calabar area.

The GWPI is a point count index method modified after some existing aquifer vulnerability methods such as DRASTIC and CALOD to produce groundwater potential/vulnerability maps. These maps are designed to show respective areas of greatest potential for prolific groundwater availability / contamination on the basis of hydrogeologic and anthropogenic (human) factors. DRASTIC is an acronym for the seven factors considered in the method: Depth to water, net Recharge, Aquifer media, Soil media, Topography, Impact of vadose zone media and hydraulic Conductivity of the aquifer (Aller et al., 1987). CALOD is derived from Clay layer thickness (C), Aquifer media character (A), Lateritic layer thickness (L), Overlying layer character (O) and the Depth to groundwater level (D) (Edet, 2004). The factors which influence groundwater availability are most likely to influence its pollution potential. DRASTIC and CALOD methods are modified by the GWPI factors and used as a site evaluation model and groundwater quality assessment method. The GWPI consists of ten input parameters namely: lithofacies (L), aquifer thickness (b), transmissivity (T), storativity (S), specific capacity (SC), static water level (SWL), formation resistivity (FR), Chloride (Cl^-), total dissolved solids (TDS) and Escherichia coli (E-coli).

In the study area, few of the published works have been on location of aquifers and borehole sitting using electrical resistivity (Edet, 1993; Okereke et al., 1998; Okon-Umoren, 1999) as well as delineation of Coastal Plain Sands into upper and lower aquifers (Edet & Okereke, 2002; Amah & Esu, 2008). Edet (2004) on the basis of CALOD index concluded that the upper aquifer was more vulnerable to surface contaminants than the lower aquifer. This paper describes how GWPI has been used as a site evaluation model and pollution index to demarcate the study area into groundwater potential zones.

1.1 Location and Geology of Study Area

The study area lies between latitudes 4°45′ N and 5°15′ N and longitudes 8°05′ E and 8°45′ E. It covers the Calabar South, Calabar Municipality, Akpabuyo and parts of Odukpani Local Government Areas of the Cross River State (Figure 1). The Calabar area belongs to the lowland and swampland of South-eastern Nigeria (Iloje, 1991). Elevations, here are generally less than 100m above the mean sea level. Three main rivers dominate the landscape of the study area. These are the Calabar, Great Kwa and Akpayafe rivers – flowing southwards into the Cross River. The climatic data show that the monthly temperature varies between 23.1°C and 28.7°C and the monthly precipitation varies from a low of 26.7 mm (February) to a high of 459.1 mm (July) (Edet & Okereke, 2002).

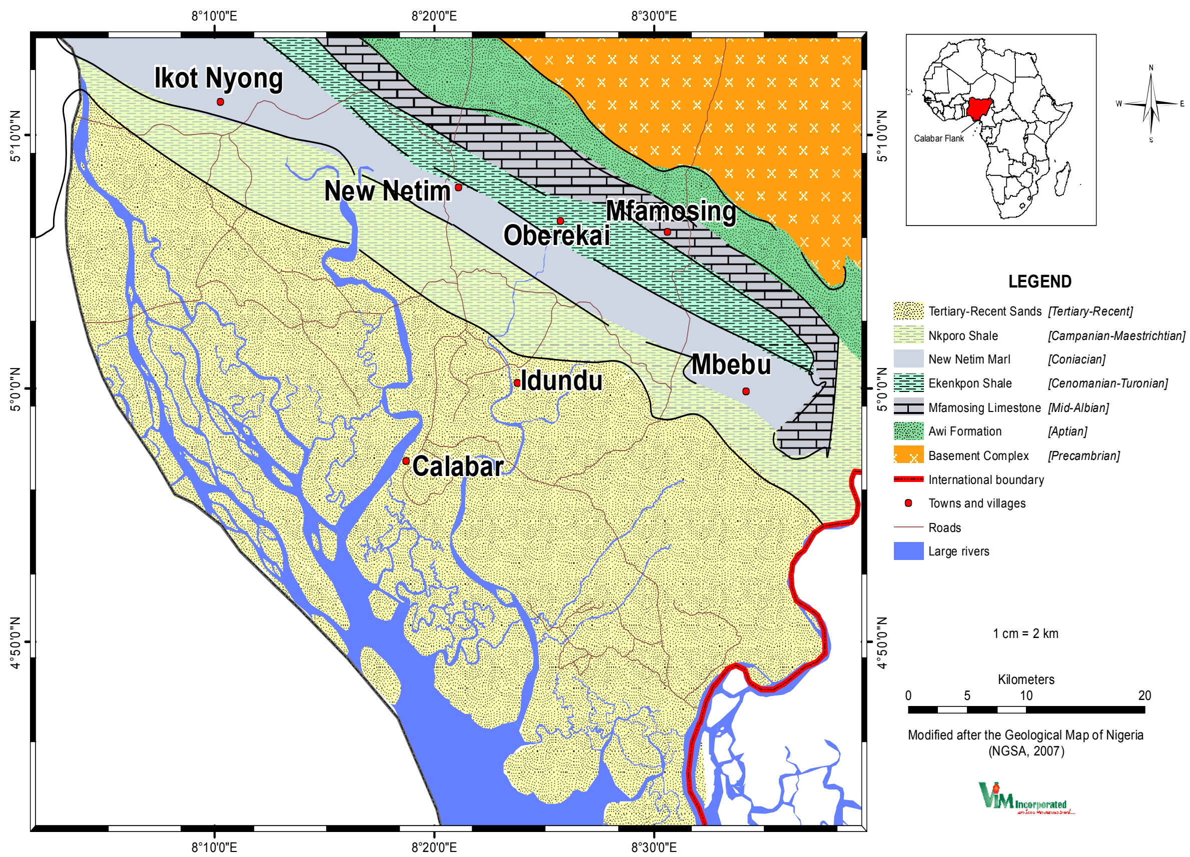

Figure 1. Geologic map of the study area

Geologically, the area is composed of Tertiary to Recent, continental fluvialite sands and clays, known as the Coastal Plain Sands. This formation is characterized by alternating sequence of loose gravel, sand, silt, clay, lignite and alluvium (Short & Stauble, 1967). It is underlain mostly by rocks of the Cretaceous Calabar Flank and pre-Cambrian Oban Massif (Figure 1). The Coastal Plain Sands (Benin Formation) is by far the most prolific aquiferous hydrogeologic settings in the area and all the water boreholes are located in this Formation (Esu & Amah, 1999). Alluvial deposits aquifer overlies the Benin Formation in the Southern parts of the study area. Recently, (Edet & Okereke, 2002; Amah & Esu, 2008) identified two water bearing units within the Coastal Plain Sand of the area. These are upper gravelly sand aquifer (UGSA) and lower fine sand aquifer LFSA.

2. Method of Study

The data employed in this study (Table 1) were compiled from surveys carried out by the authors between 2005 and 2010 in co-operation with the water development agencies and private drilling companies. These include data from vertical electrical sounding (VES), litho-logic logs, pumping tests and water quality. The details of all the techniques are found in (Amah, 2007; Amah & Esu, 2008).

Forty-six Schlumberger vertical electrical sounding (VES) of maximum electrode spacing AB = 1000 m were conducted in fairly well distributed locations within Calabar and environ for delineation and hydro-stratigraphic correlation of Coastal Plain Sand aquifers. Concurrently with the geophysical investigations, depths to water table and pumping test of wells were undertaken to determine their hydraulic parameters. Water samples from existing boreholes were also collected and tested for water quality. VES measurements were done with the aid of the ABEM Terrameter SAS 300B. The VES points and borehole locations were accurately surveyed using the Garmin 76 Global Positioning System (GPS) to obtain their latitude and longitude as well as the relative elevation data. The sampled localities are presented in Figure 2 and Table 1.

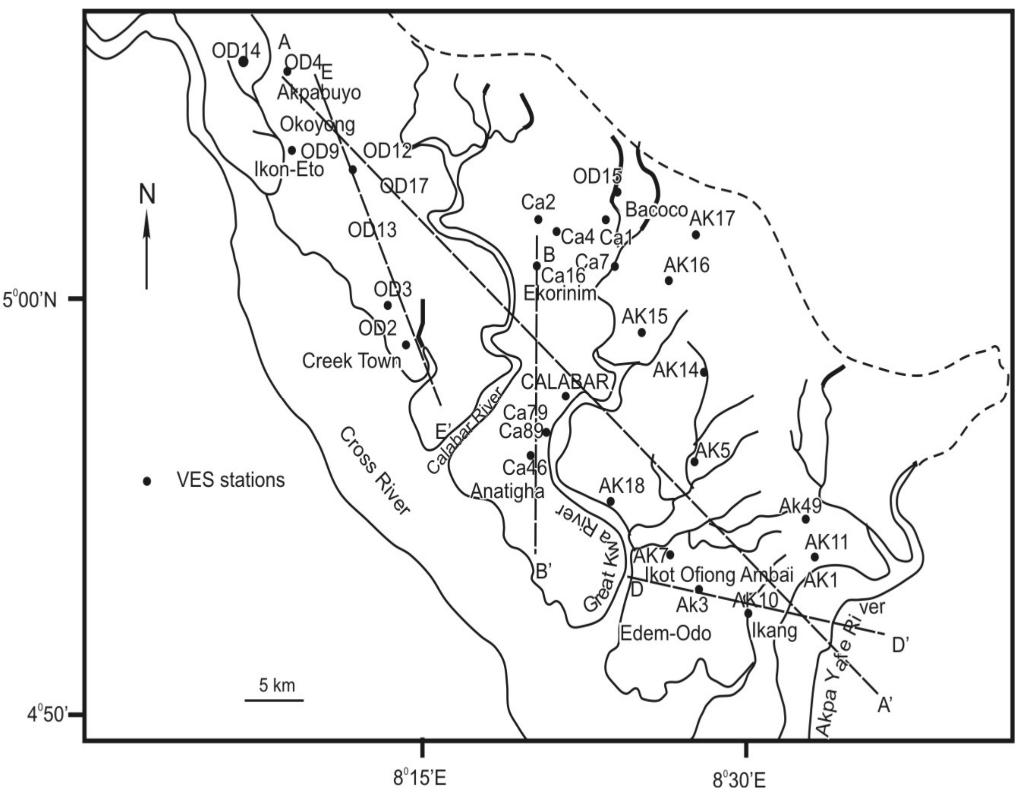

Figure 2. Map of study area including VES/Borehole locations (see Table 1)

Table 1. GWPI input data for the study area

Location Name	Sample number	Lat. N	Long. E	Zone	SWL(m)	Q(m^3/d)	SC m^3/d/m	T m^2/d	S (no unit)	b (m)	FR Ω-m	TDS mg/l	Cl mg/l	*E.Coli (count/100ml)*
Bacoco	Ca1	5.004.573	8021.517	1	44.3	86.4	7.7	1.6	6.00E-05	20	617	195	0.05	1
Ikot Ekpo	2	5.004.756	8020.793	1	50.2	72	51.4	75	-	27	1200	-	0.20	0
Ikot Efangha	3	5004.635	8021.397	1	70.1	1080	32.2	301	5.20E-05	17.5	500	-	1.00	1
Ikot Efangha	5	5002.161	8021.155	1	70.1	2565.2	105	394	-	25	1040	-	1.40	1
Ikot Efangha	6	$5^0$02..589	8020.55	1	70	1584	52.5	370	-	20	-	-	1.20	1
Ikot Efangha	7	5002.221	8021.144	1	69	2186	58	286	-	40	1250	48.6	6.40	0
Fed. Housing	10	5002.071	8020.627	1	62.8	721.1	52	1450	-	40	800	233	1.20	0
Fed. Housing	11	5002.997	804.418	1	60	780	67	1584	1.50E-04	45	-	-	1.50	1
Fed. Housing	12	5002.82	8021.413	1	62.8	721.1	52	1621	-	41	-	-	0.40	1
Ecorinim	16	5003.203	8021.608	2	5	715.2	420.7	1427	1.20E-04	40	1200	-	6.00	10
Egerton	74	5001.875	8020.151	2	37.5	224.6	367.4	2406	-	30	1200	289	2.30	5
Hawkins	26	5000.771	8020.042	2	36.4	737	103.4	1580	-	40	1290	-	5.30	2
Edgerly	76	5001.308	8020.005	2	21.6	2.76	258	950	-	65	-	136.4	4.40	5
White house	78	5001.304	8020.004	2	33.2	1.2002	37.7	1456	-	41	1250	-	3.90	6
Ediba	79	5001.201	8019.814	2	52.4	3135.8	84	1639.6	1.15E-04	48	1500	-	1.20	3
Ediba	80	4053.969	8019.801	2	53	4363.2	545.4	1112	-	45	-	-	5.00	4
MCC	81	4059.979	8019.895	2	54	4360.5	436.3	1450	1.80E-04	60	-	-	2.30	4
State Housing	82	501.047	8019.895	2	50.1	3069.6	194	1495	-	45	-	-	1.30	5
State Housing	83	4059.9	8020.069	2	54	4065	532.1	2240	1.50E-04	50	-	-	5.30	6
Atimbo	84	4059.439	8020.026	2	30	1562.7	58.4	2581	1.60E-05	45	1500	246	6.50	7
Edim Otop	85	4058.695	8019.754	2	23.6	115.2	6.7	2810	2.10E-03	55	1200	-	0.98	3
Fed. Girls	86	4058.302	8019.571	2	47.1	720.2	197.2	5730	3.00E-03	50	1300	243	2.40	4
UNICAL	87	4056.734	8020.895	3	28.7	184.2	113.4	2595	-	48	500	48	2.50	0
Anantigha	46	4055.831	8020.274	3	2.3	172.8	28.5	2930	2.00E-02	45	138	300	2.60	0
UNICAL	71	4050.105	8033.001	3	28	768	258	840	1.50E-04	50	360	-	3.40	0
UNICAL	72	4053.821	8024.599	3	47.9	552	51.6	950	-	4.5	-	-	3.30	1
Goldie	73	4055.915	8025.383	3	40	1416	93.2	560	1.80E-03	60	-	-	6.20	2
Eyo Ita	77	4054.601	8022.501	3	20.8	2980.8	191.2	2412	-	65	-	-	1.50	3
Ikang	AK1	4052.465	8035.45	3	5.6	160.5	29.7	1180	2.10E-04	70	1620	245	21.0	12
Ikot Edem Edo	3	4050.056	8040.605	2	27.8	184.3	18.1	2248	2.00E-03	48	450	230	5.40	30
Ikot Oyom	7	4052.064	8045.401	2	28.9	115.2	17.3	3310	9.20E-02	50	1440	230	8.50	7
Ikot Mbakara	9	4059.045	8015.729	2	28.2	184.3	10.5	2248.7	2.10E-03	55	1800	250	1.00	4
Akwa Obio Inwang	10	5006.376	8008.845	3	31.6	172	344	629.5	3.00E-03	65	120	220	20.0	50
Ikot Ekpo	11	5004.52	8009.257	3	20.5	108	9.02	1156	2.20E-03	50	1250	290	1.50	30
Creek Town	OD2	5010.486	8011.279	3	15	161.74	770.2	4388.2	-	40	1200	200	3.00	5
Obom Itiat	OD12	5006.385	8009.125	1	2.6	184.3	158.4	3416	4.93	45	1400	-	2.40	6
Atan Eki	OD13	5011.681	8009.784	1	14.2	158	6.8	4.39	9.20E-04	30	1600	-	4.50	7
Inu Akpa	OD14	5004.132	8020.423	1	28.2	13070	568.3	1881.1	-	45	350	-	1.40	1
Okuri Ikan	OD15	4056.734	8020.895	1	52.6	140.2	60.9	200.7	-	35	150	-	1.20	2
Maximum					70.1	4363.2	770.2	5730	4.93	70	1800	300	21.1	50
Minimum					2.3	72.0	6.7	1.6	0.000016	4.5	120	48	0.05	0
Mean					37.9	1373.9	165.3	1638.7	0.0024	43.5	1008.0	212.8	3.35	6

The VES stations were located to be as close as possible to settlements, but for the urban area, choice of the measurement points was influenced by space and the need to avoid power transmission lines. A maximum current electrode spread of AB = 1000m was maintained whenever possible. The apparent resistivity (ρ_a) was calculated from the Schlumberger electrode array at each station using the relation:

$$\rho_a = KR,$$

where K is the geometric factor and R, the ground resistance.

$K= \pi MN\,[(AB/2MN)^2 - 1/4]$. MN and AB are the potential and current electrode separations respectively. The recorded data were plotted as depth sounding curves and these were qualitatively and quantitatively interpreted. The former involved visual inspection, while the latter was effected by partial curve matching using standard curves and computer iteration techniques. The computer modeled curves are shown in Figure 3. Thirty seven boreholes were also drilled for water supply, providing litho-logic information about aquifers and VES interpretation. Pumping tests were undertaken in wells equipped with submersible pumps. Single hole pumping tests were employed in places where no observation well was available. The data generated in such cases were used for the estimation of the transmissivity of the aquifer. For wells in places where an observation well was available, both transmissivity T and storativity S, were computed from a semi-log plot of time-drawdown graph (Figure 4). The slope of this graph is equivalent to

$$\Delta s=2.3Q/4\pi T\text{, hence } T=2.3Q/4\pi\Delta s$$

Also,

$$S=2.25Tt_0/r^2$$

Where Q=pumping rate

Δs = drawdown difference per log cycle of time, t

t_0 = time when drawdown is zero

r = radial distance from a pumping well to an observation well

The combined geo–electric and lithologic sections from VES interpretation and drillers' logs, respectively (Figure 5) enable the determination of formation resistivity (FR) variation with depth; thickness (b) and delineation of aquifers and litho-facies or character of aquifer media (L). The specific capacity (SC), depth to water table (or static water level) (SWL), transmissivity (T) and storativity (S) were obtained from the analyses of pumping test data while the bio-chemical tests gave information about water quality based on the presence of *Escherichia coli/100ml of water*, total dissolved solids (TDS) and chloride contents of the groundwater (Table 1). These parameters are the most important mapable factors which control the groundwater availability and pollution potentials (Amah & Esu, 2008). Golden software SURFER 8 was used in the development of groundwater potential index (GWPI) maps for the area.

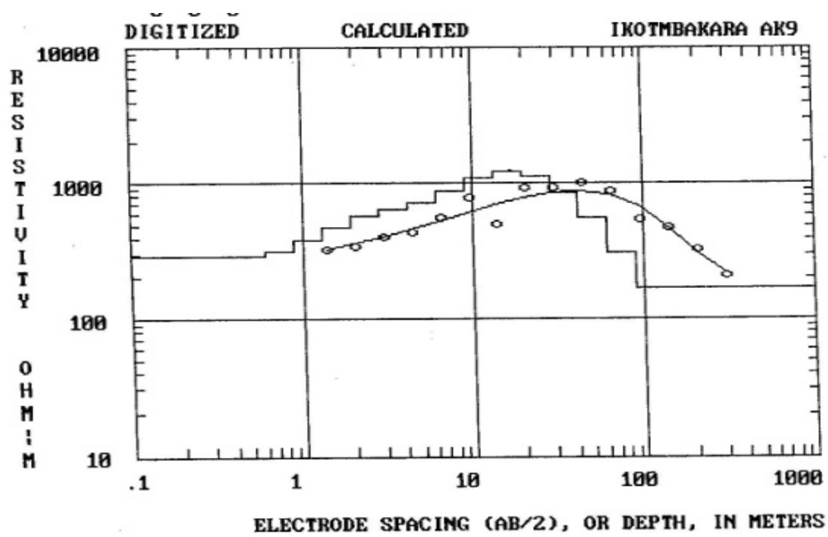

Figure 3. Typical resistivity sounding curves for Ikot Mbakara (AK 9)

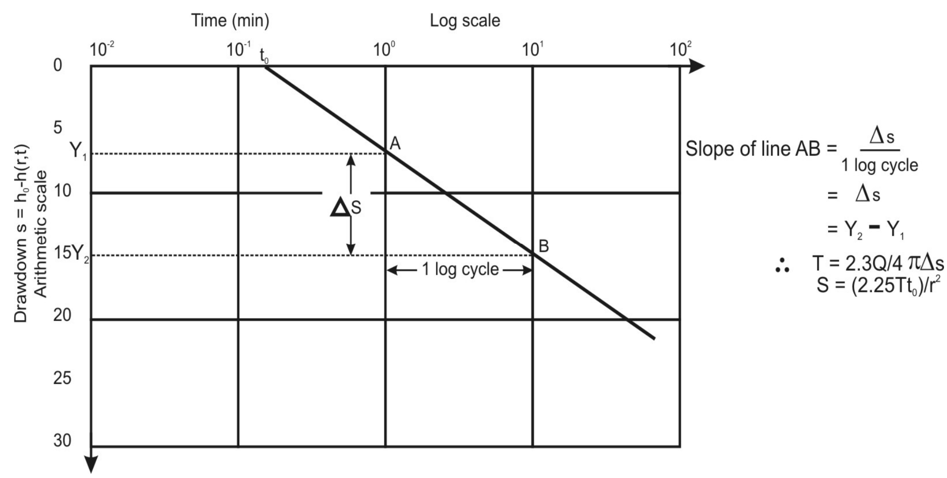

Figure 4. Hypothetical semi-log plot of time- drawdown graph for computation of transmissivity, T and storativity, S

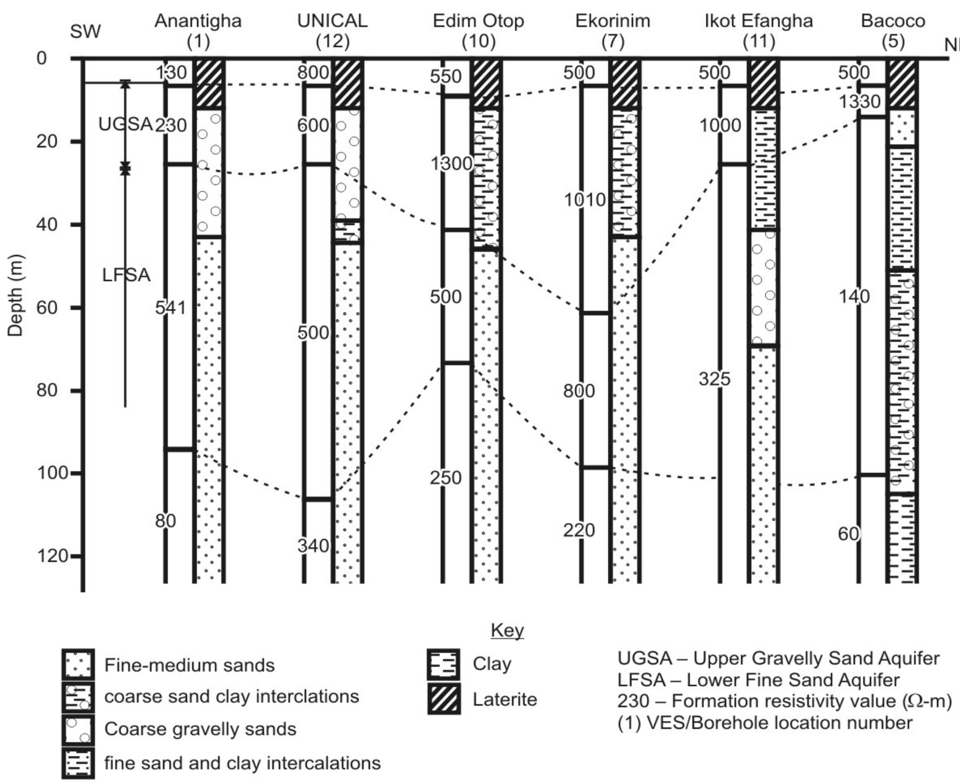

Figure 5. Geo-electic and lithologic sections across parts of the study area

2.1 Development of GWPI Method

The method of computing the groundwater potential index GWPI involves three steps. The first step is to assign weights to GWPI parameter, the second is to divide parameter value into ranges and the third is to compute GWPI index.

2.1.1 Weights

On the basis of their relative importance in groundwater exploration and evaluation, each GWPI parameter was assigned a weight ranging from 1 to 3 (Table 2). The most significant parameter has a weight of 3 and the least, weight of 1. Lithofacies (L) and thickness (b) which determine the hydrogeologic properties (porosity and permeability) with a weight of 3 were the most significant parameters while *E. coli* and chloride representing the bio-chemical quality of water were given a weight of 1. These biochemical parameters were given the least weight of 1 due to the filty-plant function of aquifers which asserts that the unsaturated zone overlying an aquifer can act as a waste treatment system (Fetter, 1980).

Furthermore, other important parameters such as static water level (SWL) transmissivity (T), formation resisitivty (FR) total dissolved solids, (TDS) that affect the productivity of an aquifer were assigned a weight of 2. However storativity S was given a weight of 1 in this study because certain factors like lithology and stress history show that T affects productivity of an aquifer more than S in tight formation (Amah, 2007).

2.1.2 Ratings

The GWPI parameters were divided into different class intervals and a rating assigned to each class interval (Table 3). The most significant interval has a rating of 3 and the least, a rating of 1.

2.1.3 Evaluation of the Groundwater Potential (GWPI) Index

The groundwater potential index (GWPI) was then computed by taking the sum of the products of weights with rating over all the 10 parameters.

Mathematically,

$$GWPI = L_w.L_r + b_w.b_r + T_w.T_r + S_w.S_r + SC_w.SC_r + WL_w.SWL_r + FR_w.FR_r + TDS_w.TDS_r + Cl_w.Cl_r + E_w.E_r$$

Where w = weight and r = rating for the different GWPI parameters.

The computed GWPI values are then used to develop a semi quantitative overall rating scale, (R) for the groundwater potential of each zone (Table 4).

From Table 4, $R \geq 40$ is considered to be high, $30 \leq R < 40$, medium and $R < 30$, low groundwater potential (classes A, B and C respectively).

Table 2. Assigned weights to some hydrogeologic parameters

S/N	Parameters	Weights
1.	Lithofacies, L	3
2.	Thickness of aquifer, b	3
3.	Transmissivity, T	2
4.	Storativity, S	1
5.	Specific capacpity, SC	2
6.	Static water level, SWL	2
7.	Formation resistivity, FR	2
8.	Total dissoved solid, TDS	2
9.	Chloride, Cl	1
10.	*Escherichia coli*	1

Table 3. Assigned rating to various catgeories of hydrogeologic parameters

S/N	Parameters	Very Good 3	Slightly Good 2	Poor 1
1	Lithofaceies L	Coarse sand	Fine sand	Sandy clay
2.	Thickness of aquifer b, m	> 50	20-50	<20
3.	Transmissivity T, m^2d^{-1}	> 5000	500-5000	<500
4.	Storativity S	>0.005	0.005 – 0.00005	< 0.00005
5.	Specific Capacity SC, $m\text{-}^3d\text{-}^1m\text{-}^1$	>300	50-300	<50
6.	Static Water Levels SWL , m	< 35	35-45	>45
7.	Resistivity FR, Ω-m	< 500	500-1000	>1000
8.	Total Dissolved Solid TDS $mgl\text{-}^1$	< 500	500-1000	>1000
9.	Chloride Cl, $mgl\text{-}^1$	< 200	200-600	>600
10.	*E. coli* counts/100ml	< 2	2-10	>10

Table 4. Relation between groundwater potential index, GWPI and water potential of a borehole site

Class	GWPI (R)	Groundwater Potential
A	> 40	High
B	30 – 40	Medium
C	< 30	Low

3. Results and Discussion

The results of GWPI as applied to the entire area of study are presented in Table 5, and Figure 6. The results indicate that all boreholes within the central, southern and northern fall into zones 2, 3 and 1 respectively. This is an indication of high, medium and low ground water potentials.

3.1 Hydrogeologic Zonation and Ground Water Potential Index Map

Based on variations in GWPI parameters and the general evaluation chart (Tables 5 and 6), three smaller hydrogeologic settings (zones) have been proposed for the entire Coastal Plain Sands of Calabar and its environs (Figure 6), viz. the northern (zone 1), central (zone 2) and the southern (zone 3).

Table 5. Computed groundwater potential index (GWPI) for some localities within the study area

Location	Zones	Local Geology	GWPI	Groundwater Rating
Bacoco Ca 1		Sandy clay	29	Low
Ikot Effange Ca 7	1	Lignite	33	Medium
Federal Housing Ca 10		Gravel	31	Medium
Okurikang OD 15	North	Interbeds	29	Low
Obom Itait OD 12			29	Low
Egerton Ca 74		Gravel	37	Medium
Akpab Okoyong OD³	2	Sand	40	Medium
Ikot Mbakara AK9		Clay	42	High
Edgerly Ca 76	Central	Lignite	41	High
Atimbo Ca 84			55	High
Fed Girls Ca 86			60	High
Anantigha Ca 46		Sand	35	Medium
UNICAL Female Hostel Ca87		Gravel	30	Medium
Ikang AK 1	3	Clay	33	Medium
Ikot Edem Odo AK 3			31	Medium
Ikot Oyom Eneyo AK 7			32	Medium
Creek Town Pri Sch OD 2	South		40	High

3.1.1 The Central (Zone 2)

The studies have shown that the central (zone 2) has the highest GWPI rating (40-60) followed by the medium rating of the southern (zone 3) with a GWPI of (30-40). The implication of this rating is that aquifers in the central and southern zones (2 and 3) are more prolific water bearing than that of northern (zone 1). Moreover, zone 2 is the best area to be targeted for potential groundwater development within the Calabar area. The mean thickness of aquifer, $20 < b \leq 50$m, uniformity in grain sizes (lithofacies L) of aquifer materials (gravels and sands) with excellent mean hydraulic parameters (SC = 355.6m^3/d/m, T = 2640 m^2/d, K = 60.4 m/d, Q = 2945 m^3/d) and fairly – good bio-chemical quality (Table 6) favor the development of groundwater in this zone.

3.1.2 The Southern (Zone 3)

Despite the high saturated thickness of the aquifers (b > 50 m), moderately high hydraulic parameters (SC = 150 m^3/d/m, T = 2150 m^3/d, K = 58.5 m/d, Q = 375 m^3/d), the groundwater potential of southern (zone 3) is not as good as that of central (zone 2). This zone is located near the Atlantic coastline. Its mean static water level, SWL is close to the ground surface (< 17.5m) and the biochemical quality (Tables 1 & 6) is poor. This zone is the most highly vulnerable to surface and near surface contamination (Edet, 2004). The contamination is due to a wide variety of human activities such as bad practices of waste disposal methods from both domestic and industrial sources as indicated by the presence of *E-Coli* (3-50 counts/100 ml) above the World Health Organisation (WHO, 2001) standard(< 1 count/100 ml), thereby making groundwater unsuitable for drinking and domestic purposes. In addition, there is possibility of salt water intrusion into the aquifers in this zone in the nearest future, therefore this should be monitored.

3.1.3 The Northern (Zone 1)

The northern zone has a low groundwater potential and the least vulnerability potential. This zone may pose serious problems for future groundwater development. This zone marks the transitional boundary between the clastic sedimentary rocks of the Benin Formation (Tertiary to Recent) and the argillaceous sediments of the Calabar Flank (Early to Middle Cretaceous). There is a rapid lithofacies (L) change in zone 1 between gravely sand interbeds and clays. Moreover the aquifers in this zone are thin (b < 20m), lie at great depths with a mean static water level SWL $\geq$ 45.5m in comparison with the other two zones (Figure 6). Though the biochemical quality is good (not highly vulnerable to surface contamination) its hydraulic properties SC = 52.1m^3/d/m, T = 750 m^2/d, K = 48 m/d, Q = 295 m^3/d) are low in comparison with the aquifers in the central and southern zones (Table 6).

Table 6. Aquifer rating and ground water potential of the study area

Zone	Lithofacies	Aquifer thickness b (m)	Mean Hydraulic parameters	Mean static water level SWL (m)	Bio-physicochemical quality	Aquifer type	Aquifer rating	Ground water potential	Remarks
North	Sands, clays, lignite gravel and shales	< 20	T=750m^2/d K=46m/d S= 0.00045 Q=795.0m^3/d SC=52.1 m^3/d/m	45.5	1	LFSA and UGSA	3	3	Low
Central	Gravel, sand, lignite, clay	20<b<50	T=2150m^2/d K=60.4m/d S= 0.0009 Q=2945m^3/d SC=355.6 m^3/d/m	35.8	2	UGSA and LFSA	1	1	High
South	Gravel, sand and clay	>50	T=2640m^2/d K=58.5m/d S= 0.0015 Q=375m^3/d SC=150.0 m^3/d/m	17.5	3	UGSA , LFSA	2	2	Medium

UGSA-Upper gravelly sand aquifer

LFSA-Lower fine sand aquifer

1-Good; 2-Fairly Good; 3-Fair

3.2 GWPI Vulnerability Map

The computed GWPI map (Figure 6) was also made to serve as a vulnerability potential map for the study area. The resulting map indicates that the northern (zone 1) has the least groundwater availability and pollution potential (GWPI < 30). The central (zone 2) has a high GWPI > 40, but medium pollution potential while the southern (zone 3) is a region with a medium GWPI, but a high pollution potential. Thus, groundwater contamination zone lies entirely between the southern (zone 3) and some parts of central (zone 2) with the GWPI ranging from 30 to 40.This is also in agreement with the work of Edet (2004) who concluded that the upper aquifer in the south was more vulnerable to surface contaminants than the lower (deeper) aquifer in the north of the study area.

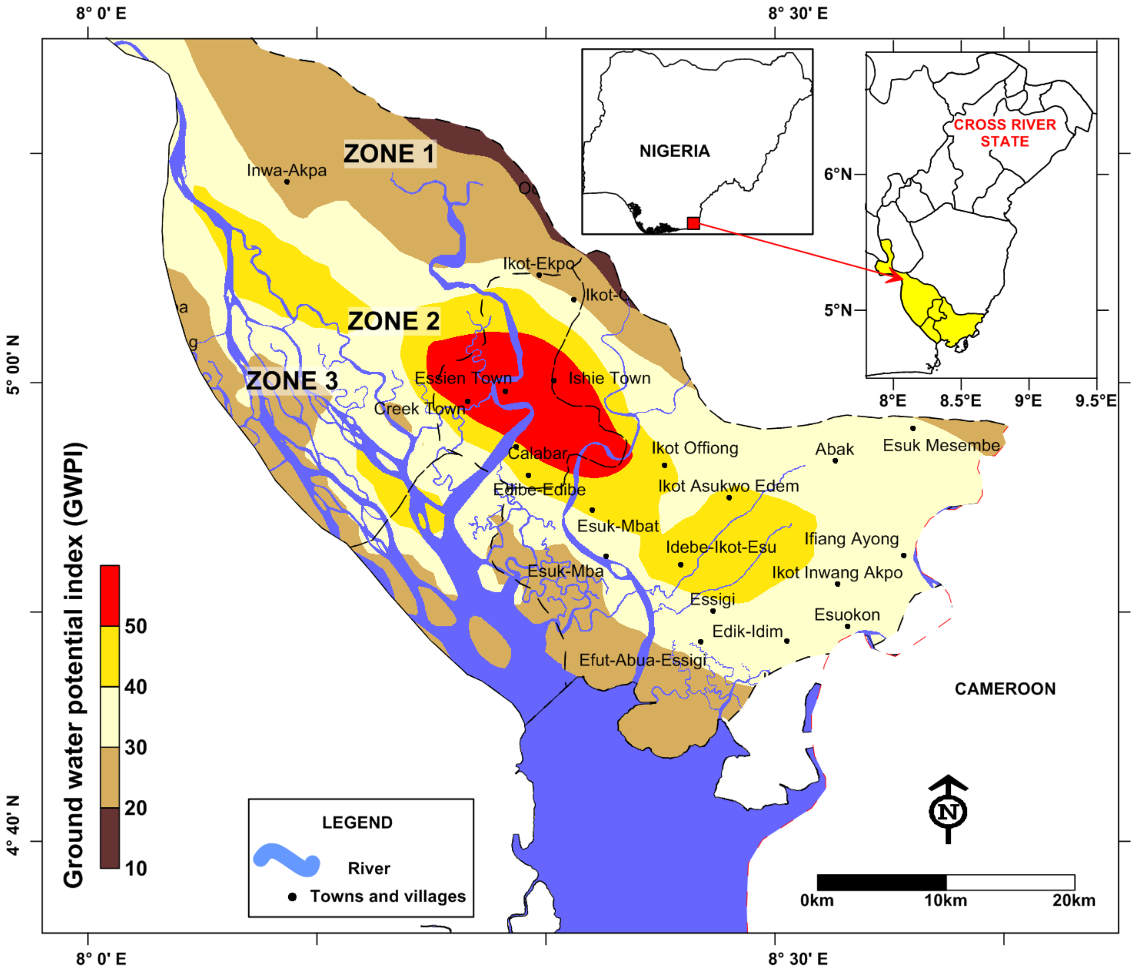

Figure 6. Zonation and ground water potential index (GWPI) map

4. Conclusion

The groundwater site evaluation model and quality assessment based on GWPI have been developed for the Calabar area. The procedure used in this study is similar to that of aquifer vulnerability techniques described for DRASTIC and CALOD. However, GWPI is modified to map both areas of groundwater availability and pollution potential in using simple and readily available data from driller logs and field measurements.

The results of GWPI have enabled the demarcation of Coastal Plain Sands of the Calabar area into smaller hydro geologic zones suitable for detailed pollution studies: northern zone (areas of low GWPI; least pollution potential), central zone , (areas of high GWPI, medium pollution potential) and southern zone (areas of medium GWPI, but high pollution potential).

The most important parameters which contribute to water availability include lithofacies (L), saturated aquifer thickness (b), static water level (SWL), transmissivity (T) and storativity (S); while E-coli, chloride (Cl^-) and static water level (SWL) remain the most significant parameters that will influence the ground water pollution in the southern zone of the study area.

Groundwater quality deterioration in coastal aquifers is due to poor management of human waste-disposal and saltwater intrusion. These factors will combine to limit the availability of potable water for domestic and industrial uses in the nearest future and should be monitored.

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