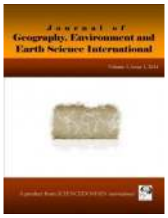

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# Groundwater Pollution Potential Index (GWPPI) as a Tool for Vulnerability Study of Coastal Plain Sand Aquifers of Calabar, South Eastern Nigeria

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### *Authors' contributions*

*This work was carried out in collaboration between all authors. Author EAA designed the study, wrote the protocol and wrote the first draft of the manuscript. Author EEUN managed the literature searches and the analyses of the study. Author GJU managed the experimental process. All authors read and approved the final manuscript.*

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## ABSTRACT

The work documents a vulnerability study of coastal aquifers based on Groundwater Pollution Potential Index (GWPPI). The parameters used in GWPPI include Lithofacies (L), aquifer thickness (b), Transmissivity (T), Storativity (S), Static Water Level (SWL), Total Dissolved solids (TDS), Chloride ($Cl^-$), Nitrate ($N0_3^-$) and *Escherichia coli* (*E-coli*). GWPPI is computed as the sum of the products of weights and ratings assigned over all the parameters. The GWPPI varies between 27 and 56 is divided into three classes; High (>40) Medium (30-40) and Low (<30). The results show that the most vulnerable areas are located in the southern part (zone 3) of the study area (GWPPI>40) which are mostly influenced by the nearness of SWL to the ground surface and biochemical pollution indicators (*E-coli*, $NO_3^-$, $Cl^-$). The correlation matrices of parameters show moderate positive correlation between *E-coli* and $No_3^-$ (r=0.642) and moderate negative correlation between *E-coli* and SWL (r=-0.624). The coastal aquifer is thus affected mostly by the influence of

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anthropogenic (human) activities based on the concentrations of $NO_3^-$ (0.43–10.25 mg/l) and *E. coli* (1-50 counts/100 ml) in ground water than geogenic factors. GWPPI can be applied not only to Coastal Plain sandy environment but other sedimentary basins with similar conditions.

*Keywords: Ground Water Pollution Potential Index (GWPPI); coastal aquifer; vulnerability map; bio-chemical indicators.*

## 1. INTRODUCTION

Groundwater is the major source of potable water in Calabar and its environs, South-eastern Nigeria. However, this valuable source of drinking water may pose a serious health hazard if contaminated. This contamination can be due to a wide variety of human activities such as bad practices of waste disposal methods from both domestic and industrial sources. In addition, the interaction between the surface water and groundwater bodies increases the salinity of the groundwater. These factors combine to degrade the groundwater quality thereby making it unsuitable for drinking and domestic purposes. In order to map the possible areas of groundwater pollution, a site evaluation tool and groundwater quality assessment model called, "ground water pollution potential index (GWPPI)" have been developed for the Calabar area. The GWPPI is a point count index method modified after some existing aquifer vulnerability methods. Several matrix rating and point counting system methods have been used to assess the vulnerability of groundwater to pollution. Some of these methods include GOD rating system [1], DRASTIC point counting system [2], AVI rating system [3], SINTACS methods [4], ISIS method [5] and CALOD [6]. These methods generally consider geology, hydrogeology, soil topography and recharge. The present work on the vulnerability of coastal aquifers is based on GWPPI factors which consists of soil litho-facies (L), aquifer thickness (b), transmissivity (T), storativity (S), static water level (SWL) and biochemical indicators (*E-coli*, $NO_3^-$, $Cl^-$, TDS). They are used to produce a groundwater vulnerability map for the Calabar area. The vulnerability maps are designed to show areas of greatest potential for ground water contamination on the basis of hydro-geologic and anthropogenic factors.

In the study area, few of the published works have been on groundwater quality with little emphasis on the GWPPI parameters. These include the works of [7-9]. However, [6] used a method known as CALOD for the vulnerability study of aquifers in Calabar without considering the influence of bio-chemical indicators. Recently, [10] evaluated the groundwater potential of the study area based on Groundwater Potential Index (GWPI). This paper examines for the first time the GWPPI as a tool for evaluating vulnerability of coastal aquifers to surface contaminants. The work is also a contribution towards aquifer protection from management of human waste-disposal practice in the area.

### 1.1 Area Description

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 (Fig. 1). The area belongs to the lowland and swampland of South-eastern Nigeria [11]. 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 to a high of 459.1 mm [12].

Geologically, the area is composed of Tertiary to Recent, continental fluviatile sands and clays, known as the Coastal Plain Sands (Benin Formation). This formation is characterized by alternating sequence of loose gravel, sand, silt, clay, lignite and alluvium [13]. It is underlain mostly by rocks of the Cretaceous Calabar Flank and pre-Cambrian Oban Massif (Fig. 1). The Coastal Plain Sands (Benin Formation) is by far the most prolific aquiferous hydro-geologic settings in the area and all the water boreholes are located in this Formation [7,14]. Alluvial deposits aquifer overlies the Benin Formation in the Southern parts of the study area. Recently, [12] and [9] 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).

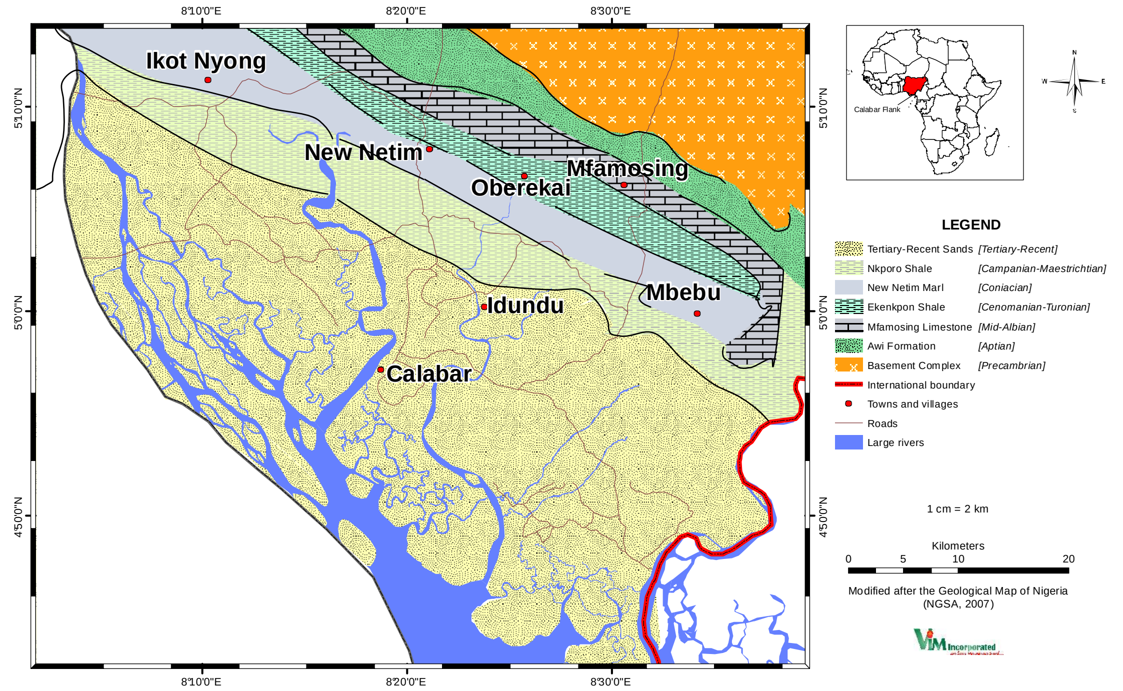

**Fig. 1. Geologic map of the study area**

## 2. METHOD OF STUDY

The data employed in this study (Table 1 in the appendixes) 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 litho-logic logs, pumping tests and water quality. The details of all the techniques are found in [15,9].

A total of 39 borehole locations were considered for the vulnerability study of coastal aquifers to ground water pollution. The boreholes were drilled for water supply and to provide litho-logic information about aquifers. These 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. 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. The sampled localities (Fig. 2) and measured parameters of interest are also presented in Table 1.

The litho-logs enable the examination of soil and aquifer characters, litho-facies (L) and delineation of aquifer thickness (b). The transmissivity (T) and Storativity (S) were obtained from the analysis of pumping test data. The depths to groundwater level SWL were measured from existing boreholes and wells during the field survey using a water level recorder (Type KLT - Du) while the biochemical tests provide information on pollution indicators (TDS, $N0_3^-$, $Cl^-$, *E-coli*). These parameters are the most important factors which control the groundwater pollution potentials [10] (Table 1). The parameters were assigned weights on the basis of their importance. The most significant parameters have a weight of 5 and the least, a weight of 1 (Table 2).The parameters were divided into different class intervals and a rating assigned to each class. The most significant interval has a rating of 3 and the least, a rating of 1 (Table 2). The sum of the product of weights and ratings assigned over all the GWPPI parameters was computed and points of equal GWPPI were contoured with the aid of ArcGIS software to produce a GWPPI vulnerability map.

**Table 1. GWPPI input data for the study area**

| Location name | Sample number | Lat. °N | Long. °E | Zone | SWL(m) | Aquifer media/ lithosfacies (L) | T $m^2/d$ | S (no unit) | b (m) | $NO_3$ mg/l | TDS mg/l | Cl mg/l | *E.-coli (count/100 ml)* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Bacoco | Ca 1 | 5.004.573 | 8021.517 | 1 | 44.3 | Clayey sand | 1.6 | $6.00 \times 10^{-05}$ | 20 | 0.43 | 195 | 0.05 | 1 |
| Ikot Ekpo | 2 | 5.004.756 | 8020.793 | 1 | 50.2 | Sand | 75 | - | 27 | 0.53 | 1.42 | 0.20 | 0 |
| Ikot Efangha | 3 | 5004.635 | 8021.397 | 1 | 70.1 | Sand | 301 | $5.20 \times 10^{-05}$ | 17.5 | 2.90 | 48.6 | 1.00 | 1 |
| Ikot Efangha | 5 | 5002.161 | 8021.155 | 1 | 70.1 | Sand | 394 | - | 25 | 3.00 | 40.5 | 1.40 | 1 |
| Ikot Efangha | 6 | 5002.589 | 8020.55 | 1 | 70 | Sand | 370 | - | 20 | 2.85 | 45.0 | 1.20 | 1 |
| Ikot Efangha | 7 | 5002.221 | 8021.144 | 1 | 69 | Sand | 286 | - | 40 | 2.60 | 48.6 | 6.40 | 0 |
| Fed. Housing | 10 | 5002.071 | 8020.627 | 1 | 62.8 | Sand | 1450 | - | 40 | 1.45 | 233 | 1.20 | 0 |
| Fed. Housing | 11 | 5002.997 | 804.418 | 1 | 60 | Sand | 1584 | $1.50 \times 10^{-04}$ | 45 | 2.01 | 55.10 | 1.50 | 1 |
| Fed. Housing | 12 | 5002.82 | 8021.413 | 1 | 62.8 | Sand | 1621 | - | 41 | 2.45 | 150.50 | 0.40 | 1 |
| Ekorinim | 16 | 5003.203 | 8021.608 | 2 | 5 | Sand | 1427 | $1.20 \times 10^{-04}$ | 40 | 3.00 | 160.20 | 6.00 | 10 |
| Egerton | 74 | 5001.875 | 8020.151 | 2 | 37.5 | coarse sand | 2406 | - | 30 | 1.54 | 289 | 2.30 | 5 |
| Hawkins | 26 | 5000.771 | 8020.042 | 2 | 36.4 | Coarse sand | 1580 | - | 40 | 11.21 | 295 | 5.30 | 2 |
| Edgerly | 76 | 5001.308 | 8020.005 | 2 | 21.6 | Coarse sand | 950 | - | 65 | 3.40 | 136.4 | 4.40 | 5 |
| White house | 78 | 5001.304 | 8020.004 | 2 | 33.2 | Coarse sand | 1456 | - | 41 | 2.90 | 120.5 | 3.90 | 6 |
| Ediba | 79 | 5001.201 | 8019.814 | 2 | 52.4 | Medium sand | 1639.6 | $1.15 \times 10^{-04}$ | 48 | 2.95 | 85.60 | 1.20 | 3 |
| Ediba | 80 | 4053.969 | 8019.801 | 2 | 53 | Medium sand | 1112 | - | 45 | 3.25 | 93.40 | 5.00 | 4 |
| MCC | 81 | 4059.979 | 8019.895 | 2 | 54 | Medium sand | 1450 | $1.80 \times 10^{-04}$ | 60 | 2.10 | 105.2 | 2.30 | 4 |
| State Housing | 82 | 501.047 | 8019.895 | 2 | 50.1 | Gravely sand | 1495 | - | 45 | 3.61 | 89.70 | 1.30 | 5 |
| State Housing | 83 | 4059.9 | 8020.069 | 2 | 54 | Gravely sand | 2240 | $1.50 \times 10^{-04}$ | 50 | 2.90 | 120.20 | 5.30 | 6 |
| Atimbo | 84 | 4059.439 | 8020.026 | 2 | 30 | Medium sand | 2581 | $1.60 \times 10^{-05}$ | 45 | 4.60 | 246 | 6.50 | 7 |
| Edim Otop | 85 | 4058.695 | 8019.754 | 2 | 23.6 | Coarse sand | 2810 | $2.10 \times 10^{-03}$ | 55 | 3.55 | 75.50 | 0.98 | 3 |
| Fed. Girls | 86 | 4058.302 | 8019.571 | 2 | 47.1 | Coarse sand | 5730 | $3.00 \times 10^{-03}$ | 50 | 3.45 | 243 | 2.40 | 4 |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| UNICAL | 87 | 4056.734 | 8020.895 | 3 | 28.7 | Fine sand | 113.4 | 2595 | - | 48 | 4.40 | 48 | 2.50 | 0 |
| Anantigha | 46 | 4055.831 | 8020.274 | 3 | 2.3 | Coarse sand | 28.5 | 2930 | 2.00 x $10^{-02}$ | 45 | 7.50 | 300 | 2.60 | 0 |
| UNICAL | 71 | 4050.105 | 8033.001 | 3 | 28 | Fine sand | 258 | 840 | 1.50 x $10^{-04}$ | 50 | 5.50 | 148 | 3.40 | 0 |
| UNICAL | 72 | 4053.821 | 8024.599 | 3 | 47.9 | Fine sand | 51.6 | 950 | - | 4.5 | 2.95 | 150.00 | 3.30 | 1 |
| Goldie | 73 | 4055.915 | 8025.383 | 3 | 40 | Coarse sand | 93.2 | 560 | 1.80 x $10^{-03}$ | 60 | 4.01 | 202.50 | 6.20 | 2 |
| Eyo Ita | 77 | 4054.601 | 8022.501 | 3 | 20.8 | Medium sand | 191.2 | 2412 | - | 65 | 2.50 | 90.40 | 1.50 | 3 |
| Ikang | AK1 | 4052.465 | 8035.45 | 3 | 5.6 | Clayey sand | 29.7 | 1180 | 2.10 x $10^{-04}$ | 70 | 6.25 | 245 | 2.10 | 12 |
| Ikot Edem Edo | 3 | 4050.056 | 8040.605 | 2 | 27.8 | Coarse sand | 18.1 | 2248 | 2.00 x $10^{-03}$ | 48 | 4.90 | 230 | 5.40 | 30 |
| Ikot Oyom | 7 | 4052.064 | 8045.401 | 2 | 28.9 | Fine sand | 17.3 | 3310 | 9.20 x $10^{-02}$ | 50 | 4.60 | 230 | 8.50 | 7 |
| Ikot Mbakara | 9 | 4059.045 | 8015.729 | 2 | 28.2 | Coarse sand | 10.5 | 2248.7 | 2.10 x $10^{-03}$ | 55 | 8.50 | 250 | 1.00 | 4 |
| Akwa Obio Inwang | 10 | 5006.376 | 8008.845 | 3 | 31.6 | Coarse sand | 344 | 629.5 | 3.00 x $10^{-03}$ | 65 | 5.21 | 220 | 2.00 | 50 |
| Ikot Ekpo | 11 | 5004.52 | 8009.257 | 3 | 20.5 | Silty clay | 9.02 | 1156 | 2.20 x $10^{-03}$ | 50 | 3.65 | 290 | 1.50 | 30 |
| Creek Town | OD 2 | 5010.486 | 8011.279 | 3 | 15 | Silty clay | 770.2 | 4388.2 | - | 40 | 10.25 | 200 | 3.00 | 5 |
| Obom Itiat | OD12 | 5006.385 | 8009.125 | 1 | 2.6 | Silty clay | 158.4 | 3416 | 4.93 x $10^{-05}$ | 45 | 3.50 | 120.20 | 2.40 | 6 |
| Atan Eki | OD13 | 5011.681 | 8009.784 | 1 | 14.2 | Silty clay | 6.8 | 4.39 | 9.20 x $10^{-05}$ | 30 | 3.00 | 75.50 | 4.50 | 7 |
| Inu Akpa | OD14 | 5004.132 | 8020.423 | 1 | 28.2 | Silty clay | 568.3 | 1881.1 | - | 45 | 3.25 | 45.0 | 1.40 | 1 |
| Okuri Ikan | OD15 | 4056.734 | 8020.895 | 1 | 52.6 | Silty clay | 60.9 | 200.7 | - | 35 | 3.50 | 55.21 | 1.20 | 2 |
| Maximum | | | | | 70.1 | | 770.2 | 5730 | 4.93 x $10^{-03}$ | 70 | 11.21 | 300 | 8.5 | 50 |
| Minimum | | | | | 2.3 | | 6.7 | 1.6 | 0.000016 | 4.5 | 0.43 | 48 | 0.05 | 0 |
| Mean | | | | | 37.9 | | 165.3 | 1638.7 | 0.0024 | 43.5 | 10.25 | 110.5 | 2.9 | 6 |

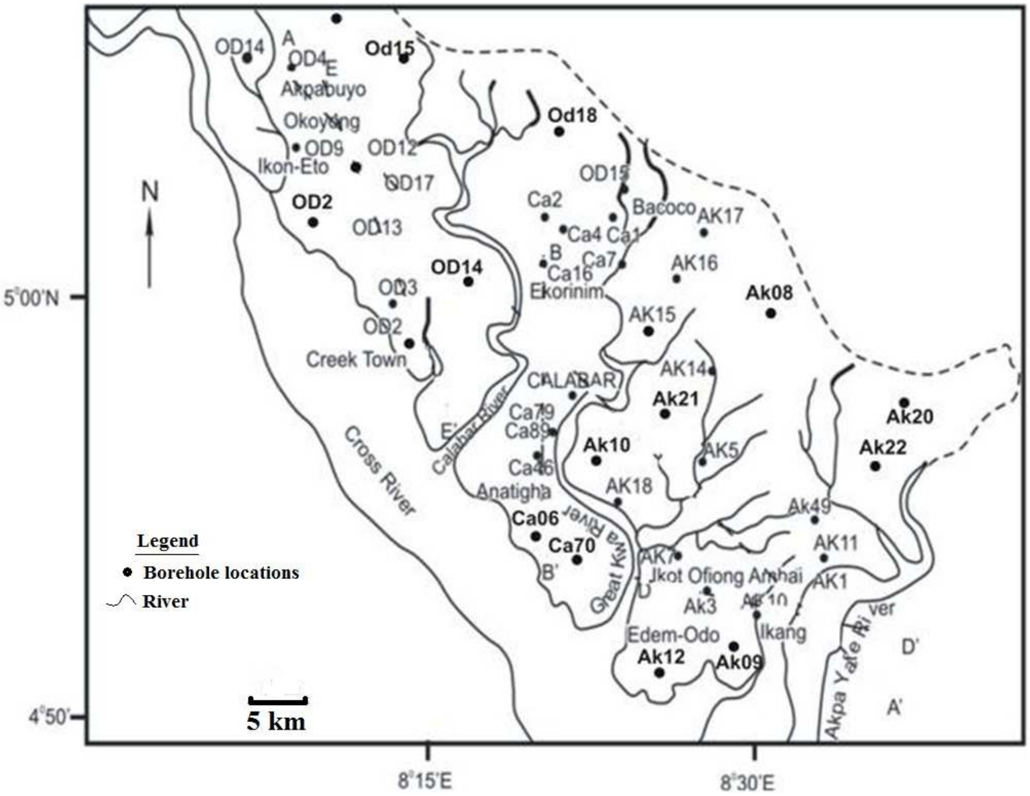

Fig. 2. Sample location map of the study area

## 2.1 Litho-facies (L) and Aquifer Thickness (b)

The litho-facies (L) and thickness (b) which determine the hydro-geologic properties (porosity and permeability) were the most significant parameters. They were assigned weights of 5 and 4 respectively. They control texture and the migration of contaminants into the aquifer in addition to influencing the quality of groundwater through filtration, sorption, cation exchange and other processes [16,17]. The litho-facies vary from clay silt through fine sand to medium-coarse sand. The following classes were used for L: high (coarse sand), medium (fine sand) and low (clay-silt). For the thickness (b), the rating was: high (<20 m), medium (20-50 m) and low >50 m (Table 2).

## 2.2 Depth to Static Water Level (SWL)

The depth to water level is also a very important parameter that determines the migration distance that a contaminant will travel before reaching the aquifer. It takes the contaminant a relatively longer time to reach deep water compared to a shallow water table [6]. Depth to static water level was assigned a weight of 5 because the nearer the SWL to the ground surface the higher is the contamination risk of the aquifer [2,6]. The water level in the area ranged between 2.3 m and 69.0 m (Table 1). The following classes were used for rating: high (depth < 10 m), moderate depth (10 – 30 m) and low (>30 m) as indicated in Table 2.

## 2.3 Transmissivity (T) and Storativity (S)

Transmissivity is a product of permeability and thickness of the aquifer. Hence the pathway of a contaminant depends on the permeability of the soil medium. The thicker the sequence, the higher the dilution effect and the lower is the contamination risk. The transmissivity varies from 175 $m^2/d$ to 5730 $m^2/d$ and was assigned a weight of 3, while the ratings were as follows; high (>2000 $m^2/d$), moderate (500 – 2000 $m^2/d$), and low (<500 $m^2/d$), (Table 2). Storativity is the quantity of water an aquifer releases from or takes into storage per unit area of aquifer per unit change in hydraulic head. However, storativity S was given a weight of 1 in this study because certain factors like lithology and stress history show that T affects movements of contaminants in an aquifer more than S in tight formation [18]. In this work S ranges from $1.0X10^{-5}$ to $2.0X10^{-2}$. A rating of high (shallow unconfined aquifer) is assigned to S $>2.0X10^{-2}$ and low for (deeper confined aquifer) $S<1.0X10^{-5}$

## 2.4 Total Dissolved Solids (TDS)

Total dissolved solids indicate the amount of contaminants available in a given volume of solvent. The degree of pollution of an aquifer depends on the amount of solute dissolved in a given volume of water per unit area of aquifer. The TDS ranged from 1.4 mg/l to 300 mg/l. The weight of 2 was assigned for TDS since dissolved solutes are usually picked up during groundwater interaction with geological materials (water – rock interaction) and infiltrated leachates from the surface, which interacts with groundwater flow and its ratings are shown in Table 2.

## 2.5 Biochemical Indicators (*E-coli*, $NO_3^-$, $Cl^-$)

In addition to TDS, the *E-coli*, $NO_3^-$ and chloride $Cl^-$ are also pollution indicators representing the biochemical quality of water in an aquifer were given a weight of 1 each. 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). The corresponding ratings for *E-coli*, $NO_3^-$ and $Cl^-$ are indicated in Table 2.

## 2.6 Computation of Ground Water Pollution Potential Index (GWPPI)

The groundwater pollution potential index (GWPPI) was then computed by taking the sum of the products of weights with rating over all the (9) parameters as:

$$GWPPI\ (=R) = L_w.L_r + b_w.b_r + SWL_w.SWL_r + T_w.T_r + S_w.S_r + TDS_w.TDS_r + NO_{3w}.NO_{3r} + Cl_w.Cl_r + E_w.E_r.$$

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

The computed (GWPPI=R) values for the 39 locations ranges between 27 and 56 (see Table 4) are conveniently divided into three classes for qualitative assessment of groundwater pollution level (Table 3). From Table 3, $R\geq40$ is considered to be high, $30\leq R<40$ medium, and $R<30$ low in pollution potential.

**Table 2. Weight and ratings assigned to each parameter**

| s/n | Parameter | Weight(w) | Rating(r) | | |
|---|---|---|---|---|---|
| | | | **1 low** | **2 moderate** | **3 High** |
| 1 | Lithosfacies/aquifer media(L) | 5 | Clay silt | fine sand | Coarse sand |
| 2 | Aquifer thickness(b) | 4 | >50 | 20-50 | <20 |
| 3 | Static water level (SWL) | 5 | >30 | 10-30 | <10 |
| 4 | Transmisivity (T) | 3 | <500 | 500-2000 | >2000 |
| 5 | Storativity (S) | 1 | $<1.0X10^{-5}$ | $1.0X10^{-5}$-$2.0X10^{-2}$ | $>2.0X10^{-2}$ |
| 6 | TDS mg/l | 2 | <500 | 500-1000 | >1000 |
| 7 | $NO_3^-$ mg/l | 1 | <10 | 10-20 | >20 |
| 8 | $Cl^-$ mg/l | 1 | <20 | 20-40 | >40 |
| 9 | *E- coli* /100 ml | 1 | <2 | 2-10 | >10 |

**Table 3. Groundwater pollution level**

| Class | (GWPPI = R) | Groundwater Pollution level |
|---|---|---|
| A | > 40 | High |
| B | 30 – 40 | Medium |
| C | < 30 | Low |

## 3. RESULTS AND DISCUSSION

The results of GWPPI as applied to the entire area of study are presented in (Table 4) and as a GWPPI map (Fig. 3). The results indicate that the study area can be demarcated into smaller hydrogeologic zones (1, 2 and 3) suitable for detailed pollution studies.

### 3.1 GWPPI Vulnerability Map

The groundwater vulnerability map (Fig. 3) shows that the coastal areas (zone 3) with GWPPI>40 are highly vulnerable to groundwater contamination. In the northern part (zone 1) of the study area, the GWPPI is less than 30 indicating areas of low vulnerability while the central (zone 2) with (30≤GWPPI<40) shows area of medium potential for groundwater contamination. Thus, groundwater contamination zone lies entirely in the south (zone 3) and some parts of central (zone 2) with GWPPI ≥30. This southern zone is the most highly vulnerable to surface and near surface contamination [10]. This work is also in good agreement with the work of [6], 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. The correlation matrix (Table 5) of parameters indicates that the most important parameters which contribute to groundwater pollution in the unconfined coastal aquifer of the study area are: static water level (SWL), coliform bacteria (*E-coli*) and $NO_3^-$.

Table 5 further shows positive correlation coefficient (r=0.642) for *E-coli* versus $NO_3$- and negative correlation coefficient (r=-0.624) for *E-coli* versus SWL. This implies that the coastal area is affected by the influence of anthropogenic (human) activities rather than geogenic factors based on the concentration of $NO_3^-$ (0.43-10.25 mg/l) and *E-coli* (1-50 counts/100 ml) in ground water.

### 3.2 Sources of Contamination

In the area of study, bad practices of waste disposal from both domestic and industrial sources are common. Human excretion and other waste are disposed of in either ill-maintained landfills with contaminant leaching effluents apparently occurring below the landfills or dumped into creeks and rivers. These practices contribute significantly to the high *E-coli* counts (Table 1) of (1-50 counts/100 ml) above the World Health Organisation (WHO 2001) standard (< 1 count/100 ml), thereby making groundwater unsuitable for drinking and domestic purposes. Moreover, aquifer

**Table 4. Computed groundwater pollution potential index (GWPPI) for some localities within the study area**

| Sample location | Zone | Local geology | L | SWL | B | T | S | TDS | $NO_3^-$ | $Cl^-$ | *E-coli* | GWPPI | Pollution level |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ca 1 | 1 | Sandy | 5 | 5 | 8 | 3 | 1 | 2 | 1 | 1 | 1 | 27 | Low |
| Ca 7 | | clay/silt | 15 | 5 | 8 | 3 | 1 | 2 | 1 | 1 | 2 | 38 | Medium |
| Ca 10 | North | gravel | 15 | 5 | 8 | 3 | 1 | 2 | 1 | 1 | 1 | 37 | Medium |
| OD 15 | | interbeds | 5 | 5 | 8 | 3 | 1 | 2 | 1 | 1 | 2 | 28 | Low |
| OD 12 | | | 5 | 10 | 8 | 3 | 2 | 2 | 1 | 1 | 2 | 34 | Medium |
| Ca 2 | | | 5 | 5 | 8 | 3 | 2 | 2 | 1 | 1 | 1 | 28 | Low |
| Ca 74 | 2 | Fine | 10 | 5 | 8 | 9 | 2 | 2 | 1 | 1 | 2 | 40 | High |
| Ca 78 | | sand | 15 | 5 | 8 | 6 | 2 | 2 | 1 | 1 | 2 | 42 | High |
| AK 9 | Central | sand | 15 | 10 | 5 | 9 | 2 | 2 | 1 | 1 | 2 | 47 | High |
| Ca 76 | | clay | 15 | 5 | 5 | 6 | 2 | 2 | 1 | 1 | 2 | 39 | Medium |
| Ca 84 | | | 10 | 10 | 8 | 9 | 1 | 2 | 1 | 1 | 2 | 44 | High |
| Ca 86 | | | 10 | 10 | 8 | 9 | 2 | 2 | 1 | 1 | 2 | 45 | Medium |
| Ca 83 | | | 10 | 5 | 8 | 9 | 1 | 2 | 1 | 1 | 2 | 39 | Medium |
| Ca 46 | 3 | Coarse | 15 | 15 | 8 | 9 | 2 | 2 | 1 | 1 | 3 | 56 | High |
| Ca 87 | | sand | 10 | 10 | 8 | 9 | 1 | 2 | 1 | 1 | 2 | 44 | High |
| Ca 26 | South | gravel | 15 | 5 | 8 | 6 | 1 | 2 | 2 | 1 | 3 | 43 | High |
| AK 1 | | clay | 5 | 15 | 8 | 6 | 1 | 2 | 1 | 1 | 3 | 42 | High |
| AK 3 | | | 15 | 10 | 8 | 9 | 1 | 2 | 1 | 1 | 2 | 49 | High |
| AK 7 | | | 5 | 10 | 8 | 9 | 1 | 2 | 1 | 1 | 2 | 39 | Medium |
| OD 2 | | | 5 | 15 | 8 | 9 | 1 | 2 | 2 | 1 | 2 | 45 | High |

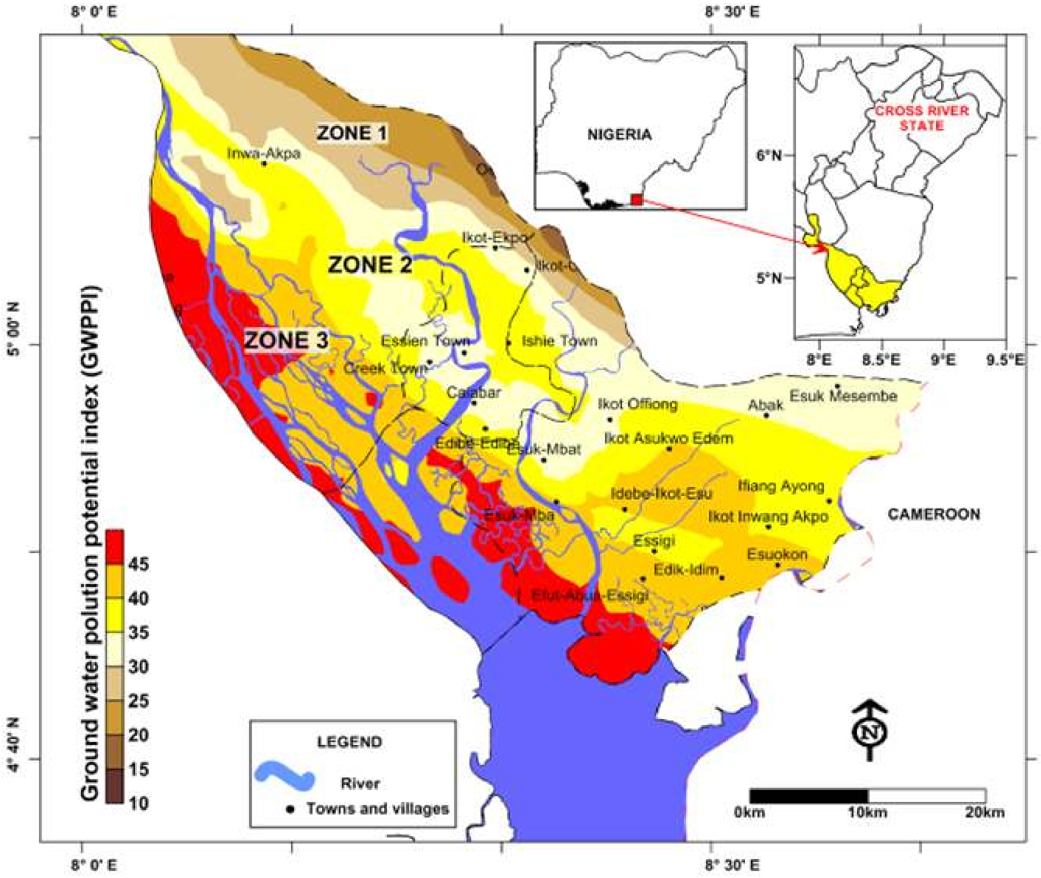

**Fig. 3. Ground Water Pollution Potential Index (GWPPI) map of the study area**

contamination in the area could also be attributed to the inflows of contaminated surface water resulting from poor construction of boreholes and nearness of the Static Water Level (SWL) to the surface in areas where the porous and permeable rocks/soils overlie the water table [19]. Such bacterialogical contamination is expected in coastal zone (3) where the static water level SWL occurs at shallow depths less than 2 m in most places (Table 1). Indeed some pit toilets in this zone strike water at very shallow depths (0.5 m - 1.5 m). The pit toilets may now act as potential sources of contaminant effluents to nearby hand dug wells and shallow boreholes located close to the coastline.

These poor disposal methods pose immediate pollution dangers to those using such bacteriologically contaminated water for drinking purposes. Users risk such water borne diseases like typhoid, dysentery and cholera which incidentally are on the increase in these areas with attendants high infant mortality rates [7]. This observation confirms the work of [20] who concluded that hazards from microbial pollution of water to health in the tropics were on a higher scale than from chemical pollutants.

## 4. CONCLUSION

The GWPPI was developed and applied in the Calabar area, South-eastern Nigeria. The vulnerability of the study area to groundwater pollution was assessed using the depth to Static Water Level (SWL), Litho-facies (L), aquifer thickness (b), transmissivity (T), storativity (S) and bio-chemical pollution indicators (*E-coli*, TDS, $NO_3^-$, $Cl^-$).

The GWPPI has enable the demarcation of the Coastal Plain Sands of Calabar area into smaller hydro-geologic zones (1, 2, 3) suitable for detailed pollution studies. The most vulnerable areas are located in the southern part (zone 3) of the study area.

The pollution 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* (1-50 counts/100 ml) above the World Health Organization (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.

The significant correlation existing between some GWPPI parameters indicates that SWL, *E-coli* and $NO_3^-$ are the most important parameters that contribute to ground water pollution in the area. The GWPPI model can be applied to other sedimentary basins with similar conditions.

## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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