J. ENVIRONMENTAL SYSTEMS, Vol. 32(2) 109-123, 2005-2006

GROUNDWATER VULNERABILITY ASSESSMENT USING SOIL AND HYDROGEOLOGICAL DATA IN THE PETROLIFEROUS NIGER DELTA, SOUTHERN NIGERIA

ANIEKAN EDET
University of Calabar, Nigeria

ABSTRACT

This work documents the vulnerability of coastal aquifers located in the Niger Delta region (Nigeria) using soil and hydrogeological data. The parameters used include depth to water levels (SWL), cation exchange capacity (CEC), organic matter content (OMC), aquifer media character (AMC), recharge (R), and soil type (ST; based on the percentages of sand, silt, and clay). The results show that the most vulnerable areas are located in the southern part of the study area due mainly to seawater. The parameters used are cheap to be obtained and the the method can be applied in other coastal areas with similar conditions.

INTRODUCTION

Groundwater resource is a valuable source of drinking water, but may pose a serious health hazard if contaminated (Bekesi, 1998). This contamination can be through a wide variety of human activities because of the bad practices of waste disposal methods in the area from both domestic and industrial sources. In addition, the interaction between the surface water and groundwater bodies increase the salinity of groundwater. These factors combine to make the groundwater unsuitable for drinking and domestic purposes. Therefore, an assessment of the risks posed to groundwater by the factors mentioned above can be achieved by

doi: 10.2190/ES.32.2.c
http://baywood.com

site-specific studies, which in many cases would involve soil and hydrogeological investigations. In the Niger Delta region, the factors thought to control groundwater vulnerability include: soil, properties, recharge, depth to water level, and aquifer media character. This is because the majority of the aquifers are shallow, consist of coarse alluvial material, and have high transmissivity and recharge. The work involved in this article is one part of a large scale study whose aim is to provide methodology for assessing groundwater vulnerability as a management tool for protecting groundwater in the Niger Delta.

The assessment of groundwater vulnerability is a useful tool for groundwater management and protection (Al-Adamat, Foster, & Baban, 2003; Gianneli, Ibe, Nwankwor, & Onyekuru, 2001). 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 (Foster, 1987), DRASTIC point count system (Aller, Bennet, Lehr, Petty, & Hackett, 1987), AVI rating system (Van Stempvoort, Evert, & Wassenaar, 1993), SINTACS methods (Civita, 1994), ISIS method (Civita & De Regibus, 1995). These methods generally consider geology, hydrogeology, soil, topography, and recharge. The present work consists of soil characteristics, geology, static water level, and recharge. This guided the production of a groundwater vulnerability map for the Niger Delta.

STUDY AREA DESCRIPTION

The Niger Delta is situated in the southern part of Nigeria (Figure 1). It covers about 6400 km^2 of southern Nigeria. Most of the boreholes in the area are shallow with more than 50% being less than 30m depth (Edet, 2008).

The mean annual temperature varies from 21 to 32°C with average precipitation of 2500 mm. The area has a tropical climate with two distinct seasons, wet (April to October) and dry (November to March). The mean annual rainfall exceeds 3500 mm along the coast and gradually decreases to a little above 2000mm inland (Akpokoje 1987).

The Niger Delta region is underlain by two geologic formations of groundwater significance. These are the Deltaic and Benin Formations (Assez, 1989; Short & Stauble, 1976).

1. *Deltaic Formation:* The Deltaic plains occupy most of the area of the present delta and stretches narrowly eastwards along the coastline. The sediments consist of coarse to medium grained unconsolidated sands forming lenticular beds with intercalations of peaty matter and lenses of soft silt, clay, and shale. Gravelly beds, up to 10 m thick, have been reported (Assez, 1989). These beds dip at varying angles toward the sea, forming units of what represents a series of old deltas.
2. *Benin Formation:* The Benin Formation is composed of gravels and sands with shale and clay intercalations. This intercalation gives rise to a multi-aquifer

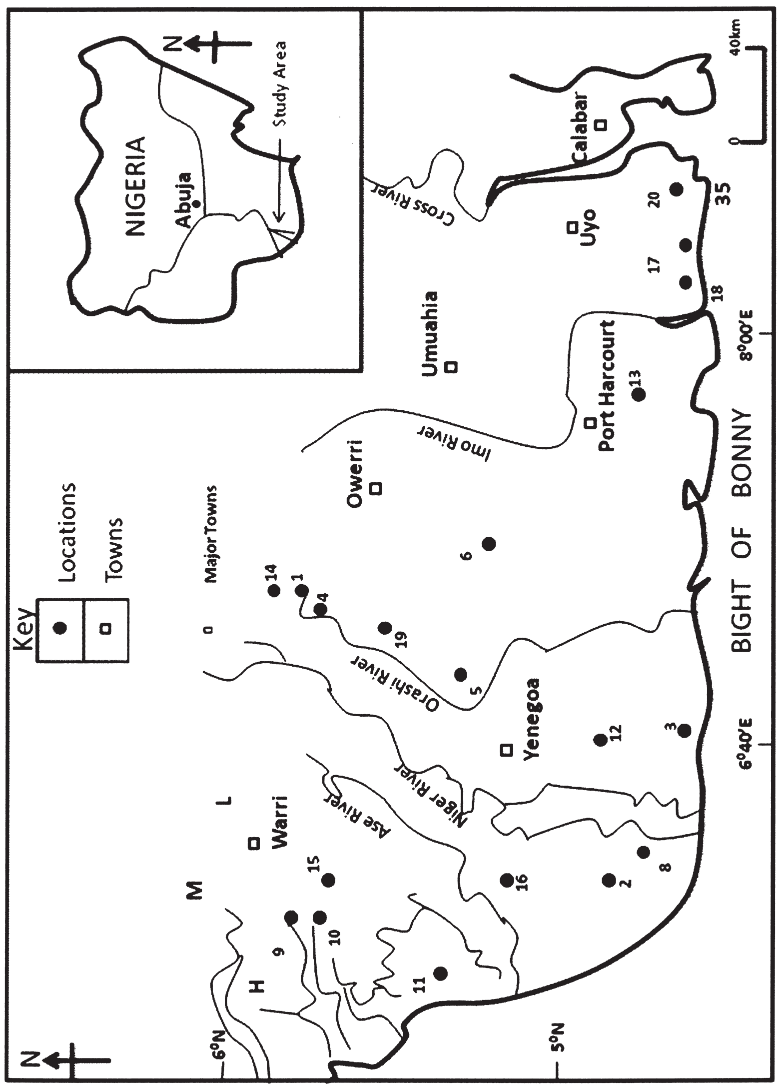

Figure 1. Map of Niger Delta showing sample locations.

system and making the formation one of the prolific aquifers in the Niger Delta. This formation outcrops in the north east of the coastal belt and dips at a low angle in the southwest. The sediments consist generally of lenticular unconsolidated, dominantly sandy formations. Pebble beds occur in places and have given rise to high yielding boreholes. Lenticular clay and shale occur particularly in the eastern areas where they confine small but moderately high yielding aquifers. Generally, lateritic beds characterize a greater part of the Niger Delta and these seem to mark the erosional surfaces of the offset beds of the delta. A generalized geologic section based on field data acquisition (Edet, 2008) is presented in Figure 2.

Regionally, the Niger Delta is underlain by both unconfined and confined aquifers.

1. *Unconfined aquifers:* In the Deltaic Formation, the water table in the Niger Delta area is very close to the ground surface, ranging from 0.0-9.0 m below ground level. The aquifers in this area obtain steady recharge through direct precipitation and major rivers. Very limited water table fluctuation is expected in these areas where there is heavy rainfall nearly all the year round. According to Offodile (1992), the Deltaic Plains have specific capacities in the range 6,750 and 13,530 l/hr/m. Within the Benin Formation, the sediments are more permeable than those of the Deltaic Formation. The depth to water table ranges between 3 and 15 m below ground surface. A few values for seasonal fluctuations obtained from the area indicate seasonal differences of between 2.1 and 3.6 m. The Benin Formation, due to its more arenaceous character, discharges significantly more water than the Deltaic sediments. Moreover, with little runoff and other losses within the Benin Formation, much of the water goes into storage. This is reflected in the specific capacity data which ranges between 6,000 and 58,500 l/hr/m (Offodile, 1992).
2. *Confined aquifers:* Confined aquifers occur within both the Deltaic and Benin Formations. These formations are characterized by moderately high yielding artesian flows. Data on drilled boreholes in the southern parts of the Niger Delta area, especially along the coastline, give pressure water. In some areas the aquifers are confined by a shale or clay bed with thicknesses in the range 19.8 to 36.0 m. Lithologic data show that the aquifers cannot be said to be completely confined. It indicates a definite hydrologic connection between the confined aquifers along the coastline and the unconfined aquifers of the Benin Formation to the north, inland. The aquifers increase in thickness toward the mainland, while the confining clays thin out, exposing the water charged medium to direct recharge, through rainfall, in the hinterland. The specific capacity for this formation varies between 3750 and 13500 l/hr/m. In the area underlain by the Benin Formation,

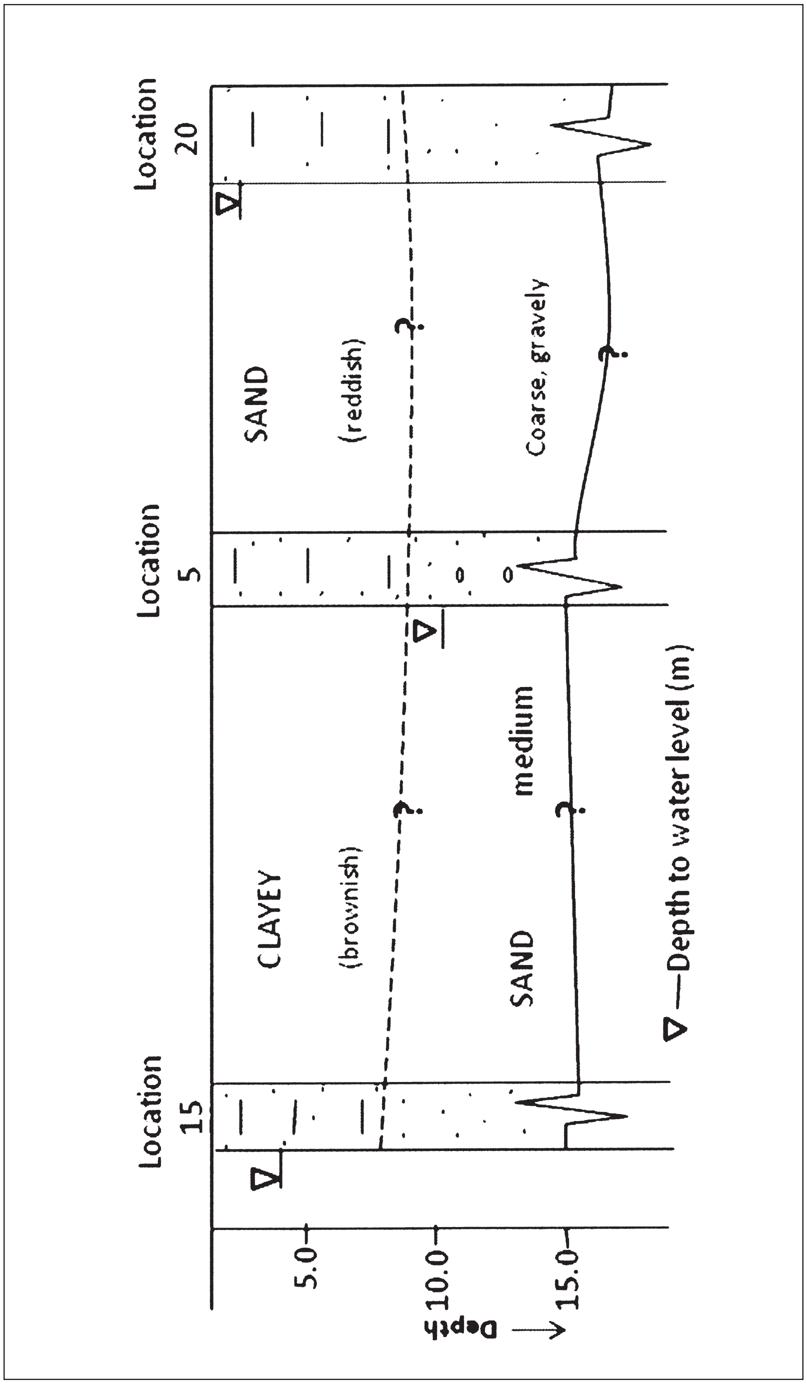

Figure 2. Regional subsurface lithology of the Niger Delta (after Edet, 2008).

the confined aquifers occur in the south-eastern parts of the Niger Delta. The aquifer was confined by several shale and clay beds. The specific capacity for this formation varies of 6000 and 7500 l/hr/m. The recorded free flow yield is in the range of 4320 and 21000 l/hr (Adelana, Olasehinde, Bale, Vrbha, Edet, & Goni, 2008).

METHODOLOGY

A total of 20 soil samples were taken from the study area. Sampling at each location was done using the graduated Dutch-type tabular auger (Netherland model) and conical soil-sampling trowel. The soil samples from different sample stations and soil depth levels were, on each occasion, collected in polythene bags and labeled accordingly.

In the laboratory, the samples were air dried, crushed, and passed through 2 mm diameter sieves for analysis. Particle size fractions were determined by the Boyoucos hydrometer method (Boyoucos, 1951) using sodium hexametaphosphate as dispersing agent. The depths to groundwater levels were measured from existing boreholes and wells during the field survey using a water level recorder (Type KLT-Du). The recharge to groundwater were considered to be 20% of the total precipitation.

Data on three indicators of pollution (Cl, NO_3, THC) for the area were obtained from Edet (2008). Generally, the concentrations of Cl and NO_3, represent the influence of seawater and human activities respectively, while the total hydrocarbon content (THC) indicate contamination of groundwater from oil and gas industries through improper waste disposal, spills, leakages from broken pipelines, and storage facilities (Table 1). The values were compared with the rating to establish if there was any relationship or not with the vulnerability of the groundwater.

In assessing the vulnerability of the area, the depth to water levels (SWL), cation exchange capacity (CEC), organic matter content (OMC), Aquifer media character (AMC), recharge (R), and soil type (ST; based on the percentages of sand, silt and clay).

The parameters were assigned weights on the basis of importance. The most important parameter has 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 interval (Table 2).

Depth to Water Level

The depth to water level determines the migration distance that a contaminant will travel before reaching the aquifer. Therefore, the contaminant will take a relatively longer time to reach deep water compared to a shallow water table. The water level in the area ranged between 0.18 and 5.7 (mean 1.71 m; see Table 3. Depth to water level was assigned a weight of 5.

Table 1. Chemical Data for the Study Area[a]

Sample No.	Cl	THC	NO_3
1	82.70	150.00	0.53
2	1072.20	575.00	0.11
3	970.30	10.00	3.50
4	88.80	3.00	0.80
5	43.00	8.30	0.30
6	115.30	175.00	1.30
7	76.7	25	0.10
8	397.80	33.50	2.90
9	172.70	433.50	0.10
10	604.70	150.00	0.10
11	110.80	25.00	1.20
12	230.60	570.00	0.50
13	310.90	10.80	0.70
14	24.30	127.50	0.20
15	10.90	0.17	0.80
16	33.10	9.21	0.70
17	68.1	0.375	0.09
18	35.1	0.333	0.15
19		0.34	1.45
20	35.5	0.75	5.682

[a]Edet (2008).

The following classes were used for rating: high (depth < 0.5 m), moderate (depth 0.5-1.0 m) and low (>1.0 m).

Cation Exchange Capacity (CEC) and Organic Matter Content (OMC)

Sorption of contaminants into soil particles is an important process in vulnerability assessment (Bekesi, 1998; Bekesi & McConchie, 2000). This is because sorption decreases the concentration of contaminants; in the liquid phase unit, the sorption capacity of soil is saturated. These authors have shown that in estimating soil sorption capacity, the partition coefficient of a medium is

Table 2. Weights and Ratings Assigned to Each Parameter

Parameter	Weight	Rating 1 Low	2 Moderate	3 High
Static water level, SWL (m)	5	> 1.0	0.5-1.0	< 0.5
Cation exchange capacity, CEC (meq/100 g)	4	< 5.0	5.0-10.0	> 10.0
Aquifer media characteristics	3	Clay-Silt	Silt-Fine Sand	M-C Sand-Gravel
Recharge (mm)	2	< 300	300-500	> 500
Soil type	1	Clay	Silt	Sand

M-C (Medium-Coarse)

considered to be a function of its organic matter content (OMC) and cation exchange capacity (CEC).

$$K_p = f(f_{oc}, \text{CEC}),$$

Where f_{oc} is organic matter content and CEC is cation exchange capacity. Increasing OMC and/or CEC increases potential for accumulation of the contaminants onto solid surfaces. The OMC varies between 0.12 and 28.2% (mean 6.4%). The CEC in the study area varies between 3.02 and 176.50 meq/100 g (mean 31.58 meq/100 g).

The weight of 4 was assigned for both CEC and OMC. The following classes were used for CEC: high (> 10.00 meq/100 g), moderate (5.00-10.00 meq/100 g), and low (< 5.00 meq/100 g). For the OMC, the ratings were: high (> 5.00%), moderate (2.50-5.00%), and low (< 2.50%).

Aquifer Media Characteristics

The geology controls the migration of contaminants into the aquifer in addition to influencing the quality of groundwater through filtration, sorption, cation exchange, and other processes (Soller & Berg, 1992b). Since the geology controls the movement and quality of groundwater, the texture is of utmost importance in the assessment of groundwater vulnerability. Hence, the pathway of a contaminant depends on the permeability, and the thicker the sequence, the higher the dilution effect, the lower is the contamination risk. The aquifer media characteristics vary from clay/silt through silt/fine sand to medium-coarse sand/gravel (Table 3). Aquifer media character was assigned a weight of 3, while

Table 3. Input Data Used for the Present Study

						Soil type			
Sample no.	SWL m	OC %	CEC meq/100 g	Aquifer media	Recharge mm	Sand %	Silt %	Clay %	Soil class
1	2.6	4.1	8.5	Silty Clay	280	94	1	5	S
2	0.48	4.4	7.6	Clayey Sand	700	96	2	2	S
3	1.3	3.4	9.7	Sand	800	53	18	29	SL
4	5.7	3.6	4.4	Clayey Sand	200	91	5	4	S
5	0.3	1.9	5.6	Silty Clay	360	47	16	37	C
6	1.7	2.5	8.9	Clayey Sand	400	94	1	5	S
7	3.7	3.4	9.7	Silty Clay	250	53	18	29	SCL
8	0.18	3.0	11.7	Silty Clay	560	59	27	14	SL
9	0.41	3.8	8.8	Sand	600	94	2	4	S
10	0.47	5.2	24.5	Silty Clay	700	76	21	3	SL
11	0.51	4.6	12.4	Clayey Sand	540	95	1	4	S
12	1.5	3.2	12.0	Clayey Sand	340	55	25	20	SL
13	1.4	1.5	5.5	Sand	520	92	2	6	S
14	4	3.7	10.9	Clayey Sand	260	70	18	12	SL
15	3.2	1.2	6.0	Sand	360	57	24	19	SL
16	1.32	3.1	12.3	Clayey Sand	400	64	20	16	SL
17	1.05	24.9	144.7	Sand	420	60	15	25	SCL
18	0.65	24.2	148.9	Sand	380	34	19	47	C
19	2	28.2	176.5	Clayey Sand	220	33	15	52	C
20	1.60	0.1	3.0	Sand	700	98	1	1	S

the ratings were as follows: high (medium-coarse sand to gravel), moderate (fine sand-silt), and low (clay-silt).

Recharge

The primary source of recharge is precipitation which infiltrates through the surface of the ground and percolates to the water table. This recharge water is available to transport a contaminant vertically to the water table and horizontally within the aquifer. In addition, the quantity of water available for dispersion and dilution in the vadose zone and in the saturated zone is controlled by this parameter. Therefore, the greater the recharge, the greater will be the potential for pollution (Aller, Bennet, Lehr, Petty, & Hackett, 1987). Net recharge indicates the amount of water per unit area of land which penetrates the ground surface and reaches the water table. For the present work, net recharge was taken as 20% of precipitation. The net recharge for the area varied from 200-800 mm. A weight of 2 was assigned to recharge. The ratings are: high (> 500 mm), moderate (300-500mm), and low (< 300 mm).

Soil Type

Soil is commonly considered the upper weathered zone of the earth which averages 1.00 m or less (Aller et al., 1987). Soil has a significant impact on the amount of recharge which can infiltrate into the ground and, hence, the ability of a contaminant to move vertically into the vadose zone. Moreover, where the soil zone is fairly thick, the attenuation process of filtration, biodegradation, sorption, and volatilization may be quite significant. In general, the pollution potential of the soil is largely affected by the amount of sand, silt, and clay. Thus, the smaller the grain size, the less pollution potential of the area. In the study area, the sand varied from 33.00-97.90% (mean 70.75%), the silt from 1.00-27.00% (mean 12.55%), and clay between 1.05 and 52.00% (mean 16.70%). These values indicate that the soil types vary from sand (S) through sandy loam (SL) and sandy clay loam (SCL). The soil type was assigned a rating of 1 with ratings as low (clay), moderate (silt), and high (sand).

Computation of Vulnerability Index

The vulnerability index (VI) for each cell was computed as:

$$VI = SWL_W\ SWL_R + CEC_W\ CEC_R + OMC_W\ OMC_R + AMC_W\ AMC_R + R_W\ R_R + ST_W\ ST_R,$$

where W and R represents the weight and ratings of the parameters.

The computed index values are divided into three classes as presented in Table 4.

Table 4. Vulnerability Level

Class	Vulnerability index	Vulnerability level
I	< 35	Low
II	35-40	Moderate
III	> 40	High

Table 5. Computed Ratings for the Study Area

Sample location	Rating						Total rating
	SWL	OC	CEC	Aquifer media	Recharge	Soil type	
1	5	8	8	7.5	2	3	33.5
2	15	8	8	2.5	6	3	42.5
3	5	8	8	9	6	2.5	38.5
4	5	8	8	4.5	2	3	30.5
5	15	4	8	7.5	4	1	39.5
6	5	8	8	4.5	4	3	32.5
7	5	8	8	7.5	2	1.5	32.0
8	15	8	12	7.5	6	2.5	51.0
9	15	8	8	9	6	3	49.0
10	15	12	12	7.5	6	2.5	55.0
11	10	8	12	4.5	6	3	43.5
12	5	8	12	4.5	4	2.5	36.0
13	5	4	8	9	6	3	35.0
14	5	8	12	4.5	2	2.5	34.0
15	5	4	8	9	4	2.5	32.5
16	5	8	12	4.5	4	2.5	36.0
17	5	12	12	9	4	1.5	43.5
18	10	12	12	9	4	1	48.0
19	5	12	12	4.5	2	1	36.5
20	5	4	4	9	6	3	31.0

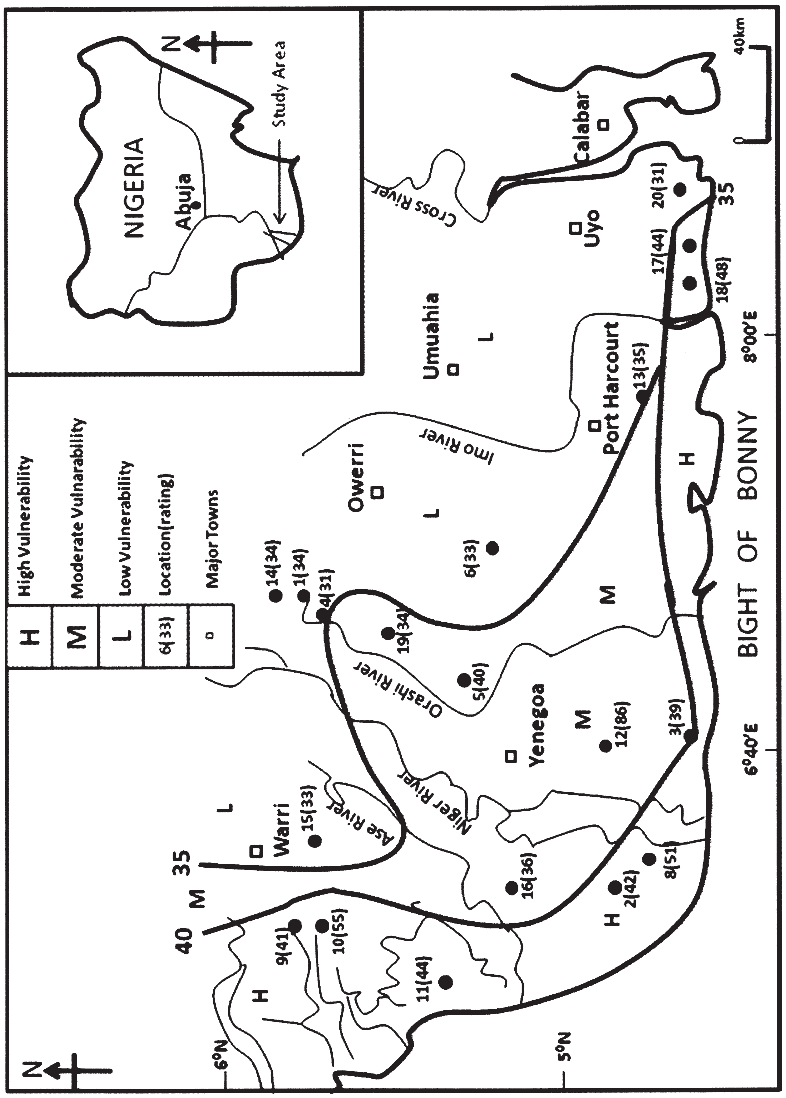

Figure 3. Groundwater vulnerability map for the Niger Delta.

Table 6. Correlation between Input Parameters, Chemical Data, and the Total Rating Values

Parameters	SWL	OC	CEC	Soil type	Recharge	Aquifer media	Cl-	THC	NO_3	Rating
SWL	1.000									
OC	0.163	1.000								
CEC	0.164	0.654	1.000							
Soil type	–0.124	–0.268	–0.289	1.000						
Recharge	0.510	–0.090	–0.056	0.279	1.000					
Aquifer media	–0.017	–0.088	–0.250	–0.339	0.213	1.000				
Cl-	0.373	0.154	–0.054	0.249	0.550	–0.146	1.000			
TNC	0.314	0.118	0.032	0.326	0.165	–0.451	0.402	1.000		
NO_3	–0.174	–0.373	–0.453	0.299	0.410	0.258	0.130	–0.292	1.000	
Rating	0.802	0.573	0.527	–0.206	0.560	0.189	0.355	0.171	–0.185	1.000

RESULTS AND ASSESSMENT

Table 5 contains the derived rating values for each parameter and the computed ratings based on equation above and Table 3.

The groundwater vulnerability map shows areas with high, moderate and low vulnerability (Figure 3). The map shows high vulnerability toward the coast. This indicates that the area is affected by the influence seawater using Cl- compared to hydrocarbon contamination (THC as indicator) and anthropogenic using the concentration of NO_3. Data on Table 6 also show that SWL, OMC, CEC, and recharge are the most important parameters contributing to the vulnerability of groundwater.

CONCLUSION

A method for assessing groundwater vulnerability was applied in the Niger Delta. The groundwater vulnerability was assessed using the depth to water levels (SWL), cation exchange capacity (CEC), organic matter content (OMC), aquifer media character (AMC), recharge (R), and soil type (ST; based on the percentages of sand, silt, and clay). The most vulnerable areas are located in the southern part of the area. Comparison, with chemical data shows that the area is mostly affected by seawater. The most important parameters are SWL, OC, CEC, and recharge. This method is cheap and can be applied in other coastal areas with similar conditions.

REFERENCES

Adelana, S. M. A., Olasehinde, P. I., Bale, R. B., Vrbka, P., Edet, A. E., & Goni, I. B. (2008). An Overview of geology and hydrogeology of Nigeria. In S. Adelana & A. MacDonald (Eds.), *Applied groundwater studies in Africa.* IAH Selected Papers on Hydrogeology, Vol. 13, pp. 171-198.

Akpokoje, E. G. (1987). The engineering geological characteristics and classification of major superficial soils of Niger Delta. *Engineering Geology, 23,* 193-211.

Al-Adamat, R. A. N., Foster, I. D. L., & Baban, S. M. J. (2003). Groundwater vulnerability and risk mapping for the basaltic aquifer of the Azraq basin of Jordan using GIS, remote sensing and DRASTIC. *Applied Geography, 23,* 303-324.

Aller, L., Bennet, T., Lehr, J. H., Petty, R. J., & Hackett, G. (1987). DRASTIC: A standardised system for evaluating groundwater pollution potentials using hydrogeological settings. EPA/600/2-87/035 (455 pp.), U.S. Environmental Protection Agency, Washington, DC.

Assez, L. O. (1989). Review of the stratigraphy, sedimentation and structure of the Niger Delta. In C. A. Kogbe (Ed.), *Geology of Nigeria* (pp. 311-324). Jos: Rock View (Nigeria) Limited.

Bekesi, G. (1998). *The development of an aquifer vulnerability assessment methodology with application to the Manawatu area of New Zealand* (256 pp.). Unpublished Ph.D. thesis, School of Earth Sciences, Victoria University, Wellington, New Zealand.

Bekesi, G., & McConchie, J. (2000). Mapping soil sorption capacity as measure of regional groundwater vulnerability. *Journal of Hydrology (NZ), 39*(1), 1-18.

Bouyoucos, G. H. (1951). Method of determining particle sizes by soil hydrometer. *Agronomy Journal, 43,* 434-438.

Civita, M. (1994). *Vulnerability maps of aquifers subjected to pollution: Theory and practice* (192 pp.). Bologna: Pitagora Editrice (in Italian).

Civita, M., & De Regibus, C. (1995). Sperimentazione di alcune metodologie per la valutazione della vulnerabilita degli aquiferi. *Q Geol Appl Pitagora, Bologna, 3*: 63-71.

Edet, A. (2008). *Hydrogeochemical characteristics of groundwater in parts of the Niger Delta*. 1st Postgraduate Researchers Conference on Meeting Environmental Challenges in the Coastal Regions of Nigeria, September 29-30, 2008, University of Abertay Dundee, United Kingdom.

Foster, S. S. D. (1987). Fundamental concepts in aquifer vulnerability, pollution risk and protection strategy. In W. van Duijvenbooden & H. G. van Waegeningh (Eds)., TNO Committee on Hydrological Research, The Hague. *Vulnerability of soil and groundwater to pollutants, Processing and Information, 38*: 69-86.

Gianneli, C., Voudouris, K., Stamos, A. P., & Soulios, G. (2007). *Proposed method to assess the intrinsic groundwater vulnerability of shallow aquifers: An example from Amytaion Basin, North Greece.* International conference on water pollution in natural porous media at different scales. Assessment of fate, impact and indicators. Barcelona, Spain, pp 1-5.

Ibe, K. M., Nwankwor, G. I., & Onyekuru, S. O. (2001). Assessment of groundwater vulnerability and its application to the development of protection strategy for water supply aquifer in Owerri, Southeastern Nigeria. *Environmental Monitoring and Assessment, 67,* 323-360.

Offodile, M. E. (1992). *An approach to ground water study and development in Nigeria* (247 pp.). Jos: Mecon.

Short, K. C., & Stauble, A. J. (1976). Outline of the geology of the Niger Delta. *Bulletin of the American Association of Petroleum Geology, 54,* 761-779.

Soller, D. R., & Berg, R. C. (1992). A model of assessment of aquifer contamination potential based on regional geologic framework. *Environmental Geology and Water Sciences, 19,* 205-213.

Van Stempvoort, D., Evert, L., & Wassenaar, L. (1993). Aquifer vulnerability index: A GIS compactable method for groundwater vulnerability mapping. *Canadian Water Research Journal, 18,* 25-37.

Direct reprint requests to:

Aniekan Edet
Department of Geology
University of Calabar
P.O. Box 3609
Calabar, Nigeria
e-mail: aniekanedet@yahoo.com