

# Assessment of Groundwater Vulnerability using Vulnerability Index (Static Water Level, Cation Exchange Capacity, Organic Contents, Nitrate and Chloride) (SCONC) in Part of Mamfe Embayment South Eastern Nigeria

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## Abstract

The following form the focus of the research work: Determine the physical parameters like conductivity, color, dissolved oxygen, pH and temperature, chemical and biological parameters. Using static water level, cation exchange capacity, organic contents, nitrate and chloride to evaluate the vulnerability of the aquifers in the study area. Eighty-eight water samples were collected from 22 locations across the periods of dry (January), dry-wet (March), wet (June), wet-dry (September), to highlight the influence of micro-climatic conditions between January to September 2015 on groundwater vulnerability. In this study, the relationship between various elements has been studied using correlation analysis, cluster analysis, factor analysis and vulnerability index (using the Static water level, Cation Exchange Capacity, Organic Contents, Nitrate and Chloride). Vulnerability index reveals that intrusive and Eze-Aku Formation are more vulnerable than Asu-River Group. The data also show that the aquifer in the study area are not vulnerable to nitrate, organic content and CEC but are rather vulnerable to fecal coliform due to water from runoff that infiltrates into the aquifer from the vadose zone during precipitation in the area.

**Keywords:** Cross river state, groundwater, Mamfe embayment, Nigeria, vulnerability index (SCONC)

## INTRODUCTION

In Cross River State, the Mamfe Embayment is the least studied in terms of groundwater quality/potentials.

The area has high potentials, where a lot geochemical study was carried out with drilling. Despite this, nothing has been done on the quality including the vulnerability of the aquifer to surface contamination. In assessing the



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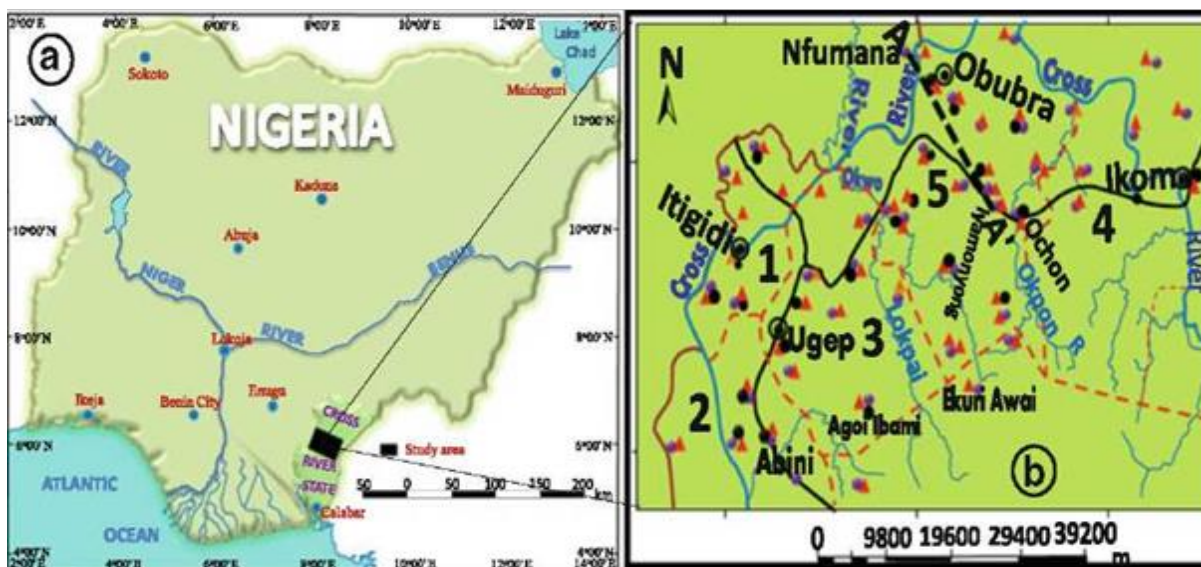


Fig. 1: Map of the studied area showing samples locations/drainage pattern

quality of groundwater in a heterogeneous area like the study area, it is imperative to understand the geochemical circulation of groundwater bearing in mind the different lithologic units. Ground-water vulnerability to contamination was defined by the National Research Council (1993) as the tendency or likelihood for contaminants to reach a specified position in the ground-water system after introduction at some location above the uppermost aquifer based on whether the assessment was contaminant specific, if so, is "specific vulnerability," if the contaminant is general, "intrinsic vulnerability," is apply. Ground-water vulnerability is a function not only of the properties of the ground-water-flow system (intrinsic susceptibility) but also of the proximity of contaminant sources, characteristics of the contaminant and other factors that could potentially increase loads of specified contaminants to the aquifer and (or) their eventual delivery to a ground-water resource (Vowinkel *et al.*, 1996). The geochemical properties of groundwater also depend on the chemistry of water in the recharge area as well as the different geochemical processes that are occurring in the subsurface. These geochemical processes are responsible for the seasonal and spatial variations in groundwater chemistry (Matthess, 1982). Generally, groundwater at the discharge zones tend to have higher mineral concentration compared to that at the recharge zones due to the longer residence time and prolonged contact with the aquifer matrix (Freeze and Cherry, 1979). Further, the weathering of primary and secondary minerals also contributes to cations and silica in the system (Jacks, 1973; Bartarya, 1993). The vulnerability potential of an aquifer to groundwater contamination is to a large extent a function of the susceptibility of its

recharge area to infiltration. Areas that are replenished at a high rate are generally more vulnerable to contaminant than those replenished at a slower rate. Groundwater pollution is caused by a variety of substances originating from many different activities. Most of the contaminants that commonly cause concern originate above ground, often as the result of human activities. After release at the land surface, the contaminant may infiltrate downward through the soil, vadose zone and saturated zone finally, reaching the aquifer. Soil overlying the water table provides the primary protection against groundwater pollution, because, sediment and other insoluble forms of contamination become trapped within the soil pores. Some chemical are absorbed or react chemically with various soil constituents, thereby preventing or slowing the migration of these pollutants into the ground waters. In addition plants and soil microorganism use some potential pollutants such as nitrogen, as nutrients for growth, thereby depleting the amount that reaches the groundwater (Hearne *et al.*, 1992).

**Study area:** The study area lies between latitudes  $5^{\circ}15'$  and  $6^{\circ}15'N$  and longitudes  $7^{\circ}45'$  and  $8^{\circ}45'E$  (Fig. 1). It is located within the sub-equatorial climatic region of Nigeria with a total annual rainfall of more than 300 to 400 cm. The temperature ranges from 25 to  $28^{\circ}C$ . The area experiences two seasons, these are the wet season which lasts from April to September with a peak in June and July while the dry seasons lasts from October to March (Iloje, 1991). The elevation of the study area ranges from 14 to 170 m above sea level. The relief is characterized by undulations running in an undefined direction and variably demarcating the very lowland

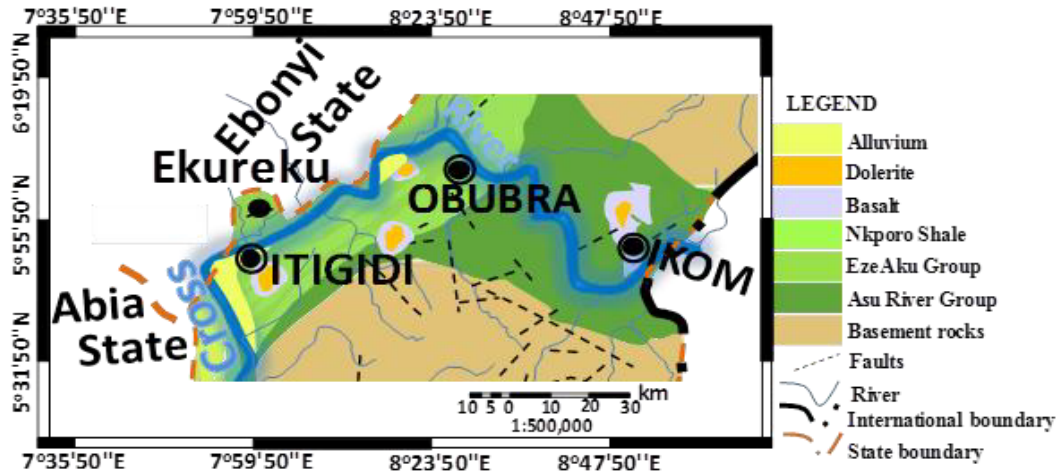


Fig. 2: Geologic map of the study area

areas from moderate relief landmarks. The occurrence of the low plains is occasionally broken by inselbergs of granite, basalts in the southern portion of the study area. In the sediment-filled portions, the low plains are occasionally broken by flat-topped hills of sandstone ridges and igneous intrusive with highly ferrogitized sandstones with gravels resulting from uplifts. The area is drained by the Cross River with major tributaries like Udip, Ukong, Lakpoi, Okwo and Okpon rivers (Fig. 1). These rivers form a network of a dendritic drainage system. The minor rivers and or streams that feed these major ones are, however, perennial and trace their origin from the Enugu escarpment and the Cameroon highlands.

**Geology:** The study area is underlain by two major lithologic units: Crystalline basement and Cretaceous sediments. The crystalline basement rocks occupy the extreme south of the study area. Also, there are intermediate rocks scattered in patches around Obubra, Iyamayong, Iyamitet, Ikom, Nkpani and Usumutong (Fig. 2). The Cretaceous sediments cover about 90% of the study area. Asu River Group is the basal and oldest recorded sediment in the study area. It is dominated by bluish-gray/black to olivine brown shale and sandy shale, fine-grained micaceous calcareous sandstone and siltstone with limestone lenses. The shale is often carbonaceous and pyritic which indicates that the sediments were deposited under a poorly oxygenated shallow water environment of restricted circulation, an indication of low energy environment (Petters *et al.*, 1987).

**Hydrogeology:** In basement provinces, groundwater occurrence depends exclusively on discontinuities like fractures, joints, fissures and weathered lithozones. The fissures of crystalline rocks are limited to shallow depths

and water movement is lateral in the direction of the gradient downwards to the drainage area. Fracturing and fissuring is a common phenomenon in basalts because of the tectonic chilling effects on them, which develops fractures. About 60% of groundwater is habited in weathered-fresh bedrock transition with aquifer yields of 0.2-3.5 L/sec. (CRBDA (Cross River Basin Development Authority), 1982). According to Petters (1989) recharge to the weathered zones and joints system is greatly retarded in significantly lateritic cover areas. This is attributed to the high content of the impermeable clay in the laterite. CRBDA (Cross River Basin Development Authority) (1982) put the yield for this province (weathered zones) at 84.4-345.6 m<sup>3</sup>/day. Static Water Level (SWL) is between 4.6-19.8 m in Obubra and 12.2-21.4 m for part of Ikom in the study area. Boreholes depths range between 25-47 m in the study area. Shale-sandstone or shale/siltstone province is the largest hydrogeological province in the study area, occupying about 80% of the study area. This area cuts across locations like Obubra, Apiapum, Nko, Ekori, Ugep, Ochom and Agara Ekureku. It constitutes the geologic Asu River Group and Eze-Aku formation. These sediments are slightly folded, tilted and at times broken by faults. Fractures, fissures and joints commonly occur in sandstones and sandstone affiliated sediments, but are commonly restricted to shallow depths of 20-50 m. Permeability of the study area is influenced by the nature and texture of the sediment type, constituting the study area. For example permeability is moderate in porous, fissured and fractured sandstone/Shale but very low in impervious shale and siltstones. Shale/siltstones province record very low aquifer yield of 0.05-0.5 L/sec, while some sub-area record up to 2.02 L/sec (CRBDA, 1982).

## MATERIALS AND METHODS

**Sampling:** Water samples were collected from various locations within the study area (Table 1). The groundwater samples were collected to cover (4)

microclimatic condition (Table 2) using pre-washed two-liter polythene plastic bottles for chemical and biological analysis while 250 mL polythene plastic was used to collect samples for heavy metals. The samples

Table 1: Sample location and type of sample

Location name	Latitude	Longitude	Northing	Easting	Geology (lithology)	Type of sample
Ikrom	5°56.805	8°43.343	657160	469113	Basalt	Gw,
Ikrom	5°57.123	8°43.260	657747	468960	Basalt	Gw, soil
Ochon stream	5°55.759	8°26.659	655257	438334	Sandstone	SW
Ochon	5°55.656	8°26.567	655066	438165	Sandstone/shale	Gw
Edondon	5°51.922	8°25.608	648185	436385	Sandstone	Gw, soil
Iyamoyong	5°57.950	8°21.164	659304	428200	Basalt/shale	Gw
Iyamitet	5°52.889	8°20.130	649981	426280	Shale/siltstone	Gw
Obubra	6°04.092	8°20.379	670623	426766	Basalt/shale	Gw, soil
Apiapum	5°59.806	8°16.985	662734	420493	shale/siltstone	Gw
Ofudua	5°58.539	8°15.508	660402	417769	Siltstone/shale	Gw
Ababene	5°57.208	8°15.654	657949	418035	Silt/sandstone	Gw
Onyadama	5°56.281	8°14.492	656245	415889	Silt/sandstone	Gw, soil
Nko	5°52.281	8°11.238	648883	409875	Silt/sandstone	Gw, soil
Ekpenti	5°53.287	8°07.356	650747	402714	Silt/sandstone	Gw
Ekori	5°52.381	8°07.165	649078	402361	Silt/sandstone	Gw
Ugep	5°48.252	8°04.736	641476	397864	Silt/sandstone	Gw, soil
Ebom	5°50.803	8°58.194	646197	385799	Sandstone	Gw
Usumutong	5°49.847	8°01.074	644430	391113	Basalt/sandstone	Gw
Adim	5°43.796	8°02.494	633272	393715	Shale/siltstone	Gw, soil
Agwugune	5°40.929	8°00.719	627997	390428	Shale/siltstone	Gw
Abini	5°41.325	8°03.860	628711	396209	Siltstone	Gw
Igbo Ekureku (Agbara)	5°59.283	8°01.266	661813	391497	Sandstone	Gw

Gw: Groundwater; sw: surface water

Table 2: The groundwater water samples were collected to cover 4 microclimatic conditions

Microclimatic type	Abbreviation	Months	Avg. rainfall (mm)	Avg. temperature (°C)
Dry	D	Jan-March	4.07	33
Dry-wet	DW	April-June	13.84	30.93
Wet	W	July-September	19.94	27.90
Wet-dry	WD	September-Dec	6	30.53

Avg.: Average

Table 3: Statistical summary of the groundwater analysis for the different sampling period

Parameters	Dry				Dry-wet			
	Min.	Max.	Mean	S.D.	Min.	Max.	Mean	S.D.
SWL (m)	0.00	14.00	4.70	3.16	0.00	14.00	4.18	3.33
Temperature (°C)	27.80	32.20	28.80	0.93	27.80	32.00	29.34	1.15
Conductivity (µsm/cm)	27.40	529.00	191.73	124.57	53.00	1141.00	310.00	296.32
pH	6.00	9.10	7.33	0.73	5.30	9.10	7.34	1.03
Color (Pt-Co)	0.00	51.00	6.86	15.05	0.00	825.00	76.18	210.46
DO (mg/L)	0.20	5.00	2.42	1.16	0.00	6.60	5.22	1.33
BOD (mg/L)	0.00	2.40	0.25	0.67	0.00	2.80	1.13	0.78
Total hardness	18.00	2456.00	369.64	569.40	84.00	2188.00	653.82	554.59
Alkalinity (ppm)	77.00	1090.00	364.77	316.95	40.00	870.00	216.82	222.74
Na <sup>+</sup> (mg/L)	27.60	386.20	130.59	113.15	9.20	73.60	34.92	21.42
K <sup>+</sup> (mg/L)	0.90	12.10	4.04	3.52	0.30	2.30	1.07	0.66
Ca <sup>2+</sup> (mg/L)	5.60	199.60	82.85	63.43	14.40	347.90	125.25	93.22
Mg <sup>2+</sup> (mg/L)	3.40	533.00	77.50	116.17	5.80	337.90	83.97	93.57
NH <sub>4</sub> <sup>+</sup> (mg/L)	0.09	1044.00	0.74	1.18	0.01	260.20	0.95	1.16
HCO <sub>3</sub> <sup>-</sup> (mg/L)	92.40	1308.00	437.73	380.30	48.00	1044.00	260.20	267.30
Cl <sup>-</sup> (mg/L)	42.60	603.50	201.90	175.40	14.20	113.60	53.90	33.06
SO <sub>4</sub> <sup>2-</sup> (mg/L)	0.00	0.68	0.09	0.17	0.00	0.46	0.09	0.14
NO <sub>2</sub> <sup>-</sup> (mg/L)	0.00	8.00	0.23	0.43	0.00	0.90	0.07	0.19
NO <sub>3</sub> <sup>-</sup> (mg/L)	0.40	3.20	2.31	0.95	2.00	3.20	2.78	0.30
PO <sub>4</sub> <sup>3-</sup> (mg/L)	0.05	0.80	0.22	0.21	0.04	1.85	0.26	0.39
Total Fe (mg/L)	0.00	0.64	0.048	0.13	0.00	2.40	0.17	0.51
Total Mn (mg/L)	0.00	24.00	5.06	6.38	0.04	11.40	2.47	3.69
Zn (mg/L)	0.00	0.00	0.00	0.00	0.00	0.09	0.0071	0.03
THB (x10 <sup>3</sup> cfu/mL)	0.11	13.00	1.26	2.75	0.14	25.47	3.26	5.48



Table 3 : Continue

Parameters	Wet				Wet-dry			
	Min.	Max.	Mean	S.D.	Min.	Max.	Mean	S.D.
Faecal coli (/100 mL)	0.00	20.00	1.25	0.50	0.00	16.00	3.30	4.64
Total coli (/100 mL)	0.00	15.00	5.56	3.97	0.00	134.00	14.93	33.55
SWL (m)	0.00	13.20	2.97	3.27	0	7	2.74	2.00
Temperature (°C)	24.00	31.00	27.84	1.79	26.5	30	28.26	1.10
Conductivity (µsm/cm)	33.00	1139.00	343.82	295.66	29	897	352.45	258.80
pH	4.10	7.50	5.93	0.92	5.3	8.4	7.37	0.73
Color (Pt-Co)	0.00	304.00	23.09	67.26	0	187	35.05	54.20
DO (mg/L)	0.00	5.60	3.83	1.31	1.2	5.2	3.57	1.10
BOD (mg/L)	0.00	0.80	0.04	0.29	0	2.4	0.25	0.60
Total hardness	12.00	1258.00	417.54	357.69	12	318	105.82	78.70
Alkalinity (ppm)	30.00	730.00	168.18	164.91	40	550	199.55	140.30
Na <sup>+</sup> (mg/L)	13.80	73.60	29.83	18.63	13.8	69	30.95	16.40
K <sup>+</sup> (mg/L)	0.40	2.30	0.92	0.56	0.4	2.1	0.96	0.51
Ca <sup>2+</sup> (mg/L)	2.40	65.70	26.81	19.32	3.2	48.1	47.76	25.30
Mg <sup>2+</sup> (mg/L)	7.30	272.40	88.15	77.50	0	48.1	13.52	14.50
NH <sub>4</sub> <sup>+</sup> (mg/L)	0.03	267.30	0.77	1.22	0	36	1.42	2.20
HCO <sub>3</sub> <sup>-</sup> (mg/L)	36.00	876.00	201.82	197.90	48	660	239.45	168.30
Cl <sup>-</sup> (mg/L)	21.30	114.00	45.83	28.38	21.3	107	47.76	25.30
SO <sub>4</sub> <sup>2-</sup> (mg/L)	0.00	0.33	0.08	0.10	0	0.32	0.07	0.09
NO <sub>2</sub> <sup>-</sup> (mg/L)	0.00	1.40	0.10	0.30	0	1.4	0.12	0.30
NO <sub>3</sub> <sup>-</sup> (mg/L)	0.40	2.70	1.97	0.77	0.32	4.8	2.61	1.22
PO <sub>4</sub> <sup>3-</sup> (mg/L)	0.00	2.41	0.42	0.60	0.03	0.83	0.26	0.26
Total Fe (mg/L)	0.00	0.52	0.07	0.12	0	1.1	0.09	0.23
Total Mn (mg/L)	0.21	12.70	5.93	4.36	0.1	11.9	3.56	3.42
Zn (mg/L)	0.00	0.14	0.01	0.15	0	0	0.00	0.00
THB (x10 <sup>3</sup> cfu/mL)	0.00	6.10	1.48	1.86	0	21.1	2.85	4.50
Faecal coli (/100 mL)	0.00	3.00	0.81	0.91	0	4	1.70	1.06
Total coli (/100 mL)	0.00	20.00	5.09	5.94	0	31	9.15	9.80

Min.: Minimum; Max.: Maximum; S.D.: Standard deviation

for heavy metals analysis were acidified to pH of 2 using nitric acid. The Physical parameters (Color, oxygen, pH, conductivity and temperature) were determined in the field using standard field equipment.

## RESULTS

**Laboratory analysis:** The groundwater samples were analyzed using standard methods. The statistical summary of the groundwater analysis for the different sampling period are given in Table 3 while Table 4 to 6 contain the mean values for the three lithologies.

Table 7 is the results of Soil Analysis in the study area while Table 8 are the factors and their ratings in vulnerability index of (SCONC).

## DISCUSSION

**Variation with formation:** Static water level varies from 0 to 14 m with the lowest mean value of 1.56 m in Eze-Aku Formation and the highest mean value of 6.47 m in the intrusive. Temperature range from 24 to 32.2°C with the lowest mean value of 28.29°C in intrusive and highest mean value of 28.76°C in Eze-Aku Formation. The high temperature may be attributed to the physiographic condition of the area. Conductivity range from 27.4 to 1141 µs/cm with the lowest mean value of 185.34 µs/cm in intrusive and the highest mean value of 417.46 µs/cm in Eze-Aku Formation. pH varies from 4.1 to 9.1 with the lowest mean value of 6.86 in Asu-river

group and the highest mean value of 7.25 in the intrusive. The low pH may be attributed to subsurface runoff and organic waste while the high pH may be due to a decrease in the dissolved solute. Color varies from 0 (Pt-Co) to 127 (Pt-Co) with the lowest mean of 25.50 (Pt-Co) in intrusive and the highest mean value of 39.5 (Pt-Co) in Asu River Group. Udom *et al.* (1998) attributed the high value of color to iron contamination in water. DO (Dissolved Oxygen) range from 0 to 6.6 mg/L with the lowest mean value of 3.15 mg/L in Eze-Aku Formation and the highest mean value of 4.31 mg/L in intrusive. BOD values range from 0.7 to 24 mg/L with the lowest mean value of 0.34 mg/L in Asu-River group and a high of 0.48 mg/L in Eze-Aku Formation. Total hardness varies from 12 to 2456 mg/L with the lowest mean value of 280.83 mg/L in intrusive and the highest mean value of 530.29 mg/L in Eze-Aku Formation. Alkalinity and total hardness are usually nearly equal in concentration (when they are both reported in mg/L CaCO<sub>3</sub> (calcium carbonate)), because they form from the same minerals (Spurlock, 2005). Alkalinity varies from 30 to 1090 mg/L with the lowest mean value of 164.13 mg/L in intrusive and the highest mean value of 343.86 mg/L in Eze-Aku Formation. Sodium (Na<sup>+</sup>) varies from a low of 9.2 mg/L to a high of 386.2 mg/L with the lowest mean value of 30.19 mg/L in intrusive and the highest mean value of 73.60 mg/L in Eze-Aku Formation. Higher concentrations of Sodium usually indicate contamination by septic systems, road salt, fertilizer, animal waste or other wastes. Potassium (K<sup>+</sup>)

Table 4: Mean values of parameters in intrusive

Parameters	Dry	Dry-wet	Wet	Wet-dry
s.w.l (m)	8.17	7.67	6.10	3.93
Temp. (°C)	29.17	28.67	27.08	28.23
Conductivity (µsm/cm)	124.60	221.60	165.33	229.83
pH	7.45	8.12	6.15	7.30
Color (Pt-Co)	0.00	18.17	52.00	33.00
DO (mg/L)	2.67	5.68	4.78	4.10
BOD (mg/L)	0.00	0.95	0.23	0.22
Total hardness	207.67	507.33	312.67	95.67
Alkalinity (ppm)	169.83	178.33	118.33	190.00
Na <sup>+</sup> (mg/L)	60.95	23.77	16.87	19.17
k <sup>+</sup> (mg/L)	1.87	0.73	0.52	0.60
Ca <sup>2+</sup> (mg/L)	61.57	78.55	17.63	14.82
Mg <sup>2+</sup> (mg/L)	44.75	75.57	65.23	14.25
NH <sub>4</sub> <sup>+</sup> (mg/L)	0.17	0.48	0.33	0.63
HCO <sub>3</sub> <sup>-</sup>	203.80	214.00	142.00	228.00
Cl <sup>-</sup> (mg/L)	94.12	36.68	26.03	29.58
SO <sub>4</sub> <sup>2-</sup> (mg/L)	0.00	0.00	0.02	0.02
NO <sub>2</sub> <sup>-</sup> (mg/L)	0.04	0.01	0.02	0.03
NO <sub>3</sub> <sup>-</sup> (mg/L)	2.03	2.93	1.78	1.98
PO <sub>4</sub> <sup>3-</sup> (mg/L)	0.37	0.26	0.16	0.17
Total Fe (mg/L)	0.01	0.09	0.08	0.05
Total Mn (mg/L)	0.00	0.03	3.36	0.82
Zn (mg/L)	0.00	0.02	0.00	0.00
THB (×10 <sup>3</sup> cfu/mL)	2.54	1.31	1.30	1.95
Faecal coli (/100 mL)	0.00	1.00	0.67	2.00
Total coli (/100 mL)	2.50	3.40	3.17	5.25

Table 5: Mean values of parameters in Asu-river group

Parameters	Dry	Dry wet	Wet	Wet-dry
s.w.l (m)	4.73	4.29	3.19	3.54
Temp. (°C)	28.73	29.64	27.82	28.14
Conductivity (µsm/cm)	192.46	285.81	337.56	321.78
pH	7.33	6.91	5.87	7.32
Color (Pt-Co)	8.33	74.78	14.44	60.44
BOD (mg/L)	0.33	0.96	0.02	0.06
DO (mg/L)	2.56	5.20	4.12	3.60
Total hardness	486.89	413.78	397.11	84.67
Alkalinity (ppm)	396.44	122.22	132.22	162.22
Na <sup>+</sup> (mg/L)	142.11	36.29	33.04	32.20
k <sup>+</sup> (mg/L)	4.38	1.12	1.02	0.99
Ca <sup>2+</sup> (mg/L)	91.56	84.42	23.33	20.12
Mg <sup>2+</sup> (mg/L)	99.24	52.11	82.30	8.78
NH <sub>4</sub> <sup>+</sup> (mg/L)	0.58	0.85	0.83	1.80
HCO <sub>3</sub> <sup>-</sup>	396.44	146.67	158.67	194.67
Cl <sup>-</sup> (mg/L)	219.33	56.01	50.49	49.70
SO <sub>4</sub> <sup>2-</sup> (mg/L)	0.10	0.06	0.08	0.06
NO <sub>2</sub> <sup>-</sup> (mg/L)	0.16	0.14	0.05	0.08
NO <sub>3</sub> <sup>-</sup> (mg/L)	2.13	2.89	2.11	2.53
PO <sub>4</sub> <sup>3-</sup> (mg/L)	0.13	0.16	0.28	0.20
Total Fe (mg/L)	0.03	0.07	0.05	0.05
Total Mn (mg/L)	6.91	3.05	6.72	3.42
Zn (mg/L)	0.00	0.00	0.00	0.00
THB (×10 <sup>3</sup> cfu/mL)	0.68	2.14	1.29	4.00
Faecal coli (/100 mL)	1.00	2.25	0.67	1.75
Total coli (/100 mL)	5.00	9.80	5.00	9.11

Table 6: Mean values of parameters in Eze-aku formation

Parameter	Dry	Dry-wet	Wet	Wet-dry
s.w.l (m)	2.59	1.94	0.78	0.91
Temp. (°C)	28.57	29.53	28.50	28.43
Conductivity (µsm/cm)	248.34	419.63	504.86	497.00
pH	7.21	7.21	5.81	7.50
Color (Pt-Co)	11.86	127.71	9.43	4.14
DO (mg/L)	2.03	4.86	2.63	3.07
BOD (mg/L)	0.00	1.50	-0.11	0.53
Total hardness	357.71	1088.00	533.71	141.71
Alkalinity (ppm)	491.14	371.43	257.14	255.71

Table 6: Continue

Parameter	Dry	Dry-wet	Wet	Wet-dry
Na <sup>+</sup> (mg/L)	175.47	42.71	36.80	39.43
k <sup>+</sup> (mg/L)	5.46	1.30	1.14	1.23
Ca <sup>2+</sup> (mg/L)	89.91	217.79	39.16	26.13
Mg <sup>2+</sup> (mg/L)	77.63	132.13	115.30	19.00
NH <sub>4</sub> <sup>+</sup> (mg/L)	1.43	1.48	1.08	1.60
HCO <sub>3</sub> <sup>-</sup>	589.37	445.71	308.57	306.86
Cl <sup>-</sup> (mg/L)	271.86	65.93	56.80	60.86
SO <sub>4</sub> <sup>2-</sup> (mg/L)	0.17	0.19	0.14	0.11
NO <sub>2</sub> <sup>-</sup> (mg/L)	0.47	0.02	0.23	0.26
NO <sub>3</sub> <sup>-</sup> (mg/L)	2.79	2.51	1.96	3.14
PO <sub>4</sub> <sup>3-</sup> (mg/L)	0.22	0.40	0.82	0.41
Total Fe (mg/L)	0.11	0.36	0.10	0.20
Total Mn (mg/L)	7.01	3.83	7.13	6.07
Zn (mg/L)	0.00	0.00	0.00	0.00
THB (×10 <sup>3</sup> cfu/mL)	0.90	6.38	1.89	2.31
Faecal coli (/100 mL)	2.00	5.50	1.14	1.60
Total coli (/100 mL)	15.00	31.60	6.86	11.43

Table 7: The result of soil analysis in the study area

Locations	a	b	c	d	e	f	g	Mean	S.D.
Sand (g/kg)	516	546	796	866	836	816	826	743	135.80
Silt (g/kg)	237	147	177	127	87	177	147	157	43.40
Clay (g/kg)	244	304	27	7	77	7	27	99	113.90
Texture	SCL	SCL	LS	LS	LS	LS	LS		
pH	5.01	4.82	4.51	4.92	4.81	4.62	5.03	4.81	0.18
OC%	1.58	2.21	1.06	0.92	0.81	1.01	1.20	1.25	0.45
Org. M %	2.72	3.81	1.82	1.58	1.39	1.74	2.06	2.16	0.78
N%	1.00	1.03	0.09	0.85	1.13	1.11	1.21	0.92	0.35
P (mg/kg)	14.00	12.00	9.00	5.00	8.00	6.00	11.00	9.28	3.01
K (cmol/kg)	0.33	0.24	0.19	0.08	0.22	0.14	0.21	0.20	0.07
Ca (cmol/kg)	2.41	2.02	1.20	1.20	0.90	1.50	0.70	1.42	0.56
Mg (cmol/kg)	2.30	1.80	0.33	0.58	0.20	0.21	0.54	0.85	0.78
Na (cmol/kg)	0.10	0.09	0.11	0.06	0.10	0.05	0.10	0.08	0.02
H+Al (cmol/kg)	1.60	1.72	1.01	1.21	1.31	0.91	0.98	1.25	0.29
ECEC (cmol/kg)	6.74	5.87	2.84	3.13	2.73	2.81	2.53	3.81	1.60
BS%	76.28	70.70	64.43	61.34	52.01	67.61	61.26	64.80	7.78

a, b: Intrusive; c, d, e: Asu river group; f, g: Eze-Aku formation; SCL: Sandy clay loamy; LS: Loamy sand; S.D.: Standard deviation

Table 8: Factors and their ratings in vulnerability index of (sconce)

Factor	Weight (w)	Range of rating	Parameter range
Static water table	5	1-5	0-14
CEC	4	1-5	0-10
OC	3	1-5	0-2.5
NO <sub>3</sub> <sup>-</sup>	2	1-5	10-650
Cl <sup>-</sup>	1	1-5	0-10

range from 0.3 to 12.1 mg/L with the lowest mean value of 0.93 mg/L in intrusive and the highest mean value of 2.28 mg/L in Eze-Aku Formation. Calcium (Ca<sup>2+</sup>) range from 2.4 to 347.9 mg/L with the lowest mean value of 43.14 mg/L in intrusive and the highest mean value of 93.25 mg/L in Eze-Aku Formation. Magnesium (Mg<sup>2+</sup>) varies from 0 to 534 mg/L with the lowest mean value of 49.95 mg/L in intrusive and the highest mean value of 86.02 mg in Eze-Aku Formation. Most concentrations are higher than the WHO values of 100 mg/L for Calcium and 50 mg/L for Magnesium. As water moves through soil and rock, it dissolves very small amounts of minerals and holds them in solution. Calcium and magnesium dissolved in water are the two most common minerals that make water "hard." The degree of hardness becomes greater as the calcium and magnesium content increases and is related to the concentration of multivalent cations dissolved in the water. Ammonium (NH<sub>4</sub><sup>+</sup>) range from 0.01 to 10.7 mg/L with the lowest

mean value of 0.40 mg/L in intrusive and the highest mean value of 1.39 mg/L in Eze-Aku Formation. Bicarbonate (HCO<sub>3</sub><sup>-</sup>) range from 36 to 1308 mg/L with the lowest mean value of 196.95 mg/L in intrusive and the highest mean value of 412.63 mg/L in Eze-Aku Formation. Chloride (Cl<sup>-</sup>) varies from 14.2 to 603.5 mg/L with the lowest mean value of 46.60 mg/L in intrusive and the highest mean value of 113.86 mg/L in Eze-Aku Formation. The high concentration may be due to contamination by septic systems, road salt, fertilizer, animal waste, landfills, or other wastes. Chlorides are salts resulting from the combination of the gas chlorine with a metal. Some common chlorides include sodium chloride (NaCl) and magnesium chloride (MgCl<sub>2</sub>). Chlorine alone as Cl<sub>2</sub> is highly toxic and it is often used as a disinfectant. In combination with a metal such as sodium it becomes essential for life. Small amounts of chlorides are required for normal cell functions in plant and animal life. Chlorides are not usually harmful to people; however, the sodium part of table salt has been linked to heart and kidney disease. Sodium chloride may impart a salty taste at 250 mg/L; however, calcium or magnesium chlorides are not usually detected by taste until levels of 1000 mg/L are reached. The amount of chlorine that reacts with the other chemicals plus the amount required to achieve disinfection is the chlorine

demand of the water. Chlorides may get into surface water from several sources including: rocks containing chlorides; agricultural runoff; wastewater from industries; oil well wastes; effluent wastewater from wastewater treatment plants and; road salting. Chlorides can corrode metals and affect the taste of food products. Therefore, water that is used in industry or processed for any use has a recommended maximum chloride level. Chlorides can contaminate freshwater streams and lakes. Fish and aquatic communities cannot survive in high levels of chlorides (Farrar, 1997). Nitrate ( $\text{NO}_3^-$ ) range from 0.4 to 4.8 mg/L with the lowest mean value of 2.18 mg/L in intrusive and the highest mean value of 2.60 mg/L in Eze-Aku Formation. Sulphate ( $\text{SO}_4^{2-}$ ) range from 0 to 0.68 mg/L with the lowest mean value of 0.01 mg/L in intrusive and the highest mean value of 0.15 mg/L in Eze-Aku Formation. Nitrate ( $\text{NO}_3^-$ ) is a common inorganic form of nitrogen. Chemically, it is an anion with a single negative charge, consisting of one atom of nitrogen and three atoms of oxygen. Because it is an anion, it is soluble in water. Plants normally use nitrate as their source of the nitrogen needed by all living things and so nitrate is considered a nutrient for plants. Excessive concentrations of nitrate in lakes and streams greater than about 5 mg/L (measured as nitrogen), depending on the water body, can cause excessive growth of algae and other plants, leading to accelerated eutrophication or "aging" of lakes and occasional loss of dissolved oxygen. If nitrate-nitrogen exceeds 10 mg/L in drinking water, it can cause a condition called methemoglobinemia or "blue baby syndrome" in infants (Fan *et al.*, 1987). Some studies has indicated a possible connection between elevated nitrate concentrations and cancer (US Geological Survey, 2004). Nitrite ( $\text{NO}_2^-$ ) varies from 0 to 1.5 mg/L with the lowest mean value of 0.02 mg/L in intrusive and the highest mean value of 0.24 mg/L in Eze-Aku Formation. High concentration of nitrite may be due to waste. Phosphate ( $\text{PO}_4^{3-}$ ) varies from 0.03 to 2.41 mg/L with the lowest mean value of 0.19 mg/L in Asu-River group and the highest mean value of 0.46 mg/L in Eze-Aku Formation. Sulphate ( $\text{SO}_4^{2-}$ ) and Phosphate ( $\text{PO}_4^{3-}$ ) are within WHO (2001) standard values, Phosphates are not toxic to people or animals unless they are present in very high levels. Digestive problems could occur from extremely high levels of phosphate (D'Angelo *et al.*, 2001). Total Iron (mg/L) range from 0 to 2.4 mg/L with the lowest mean value of 0.05 mg/L in Asu-River group and the highest mean level of 0.19 mg/L in Eze-Aku Formation. Zinc (Zn) varies from 0 to 0.14 mg/L with the lowest mean value of 0 mg/L in Asu-River group and the highest mean value of 0.02 mg/L in intrusive. Iron (Fe), Total Manganese (mg/L) values were higher than the WHO (2001) values, while Zinc (Zn) was below WHO value. Dissolved ferrous iron gives water a disagreeable taste. When the iron combines with tea, coffee and other beverages, it produces an inky, black appearance and a harsh, unacceptable taste. Manganese is too reactive a

metal to be found in elemental form in nature but its ore, the black dioxide pyrolusite, is widely distributed. The high concentration of metals in groundwater may be attributed to biodegradation of organic wastes which may lead to the release of these metals which are in turn leached into the water by the process of desorption. Total Manganese (mg/L) range from 0 to 24 mg/L with the lowest mean concentration of 1.05 mg/L in intrusive and the highest mean concentration of 6.01 mg/L in Eze-Aku Formation, most other element follow the same pattern exception of  $\text{PO}_4^{3-}$ , Fe and Zn which had their low concentration in Asu-River group and high concentration in Eze-Aku Formation. Total Heterotrophic Bacteria (THB) range from 0 to 25.47 cfu/mL with the lowest mean value of 1.78 cfu/mL in intrusive and the highest mean value of 2.87 cfu/mL in Eze-Aku Formation. The presence of fecal coliform in drinking water is evidence that human or animal waste has been or is present. This may be cause for concern because many diseases can be spread through fecal transmission. Escherichia coli, is a specific type of fecal coliform, the coliform group that lives in the intestines of humans and other warm-blooded animals and in their waste. Human illnesses such as typhoid, dysentery, cholera, hepatitis and giardiasis have been linked to drinking water contaminated by human waste (Brunett *et al.*, 1997). Faecal coliform varies from 0 to 16 cfu/mL with the lowest mean value of 0.92 cfu/mL in intrusive and the highest mean value of 2.56 cfu/mL in Eze-Aku Formation. Total Coliform bacteria are live organisms and they can multiply rapidly or die off quickly, depending upon water temperature and other variables like Chlorine and Iodine which kills bacteria, including disease-causing organisms and the nuisance organism, iron bacteria. This naturally occurring bacterium does not cause disease, but does form a reddish brown slime that coats the inside of pipes, fouls pumps and clogs waters (Dorsch *et al.*, 1984). Coliform range from 2 to 134 cfu/mL with the lowest mean value of 3.58 cfu/mL in intrusive and the highest mean value of 16.22 cfu/mL in Eze-Aku Formation.

**Vulnerability modeling:** A commonly used model in assessing groundwater vulnerability is the DRASTIC model (Aller *et al.*, 1985; Deichert and Hamlet, 1992; Aller *et al.*, 1987; Kim and Hamm, 1999). The parameters of DRASTIC are weighted according to their relative importance in determining the ability of a pollutant to reach an aquifer.

In this study, Static water level, Cation Exchange capacity, Organic content, Nitrate and Chlorine (SCONC) are used to determine the vulnerability of the different Formation. SCONC index was calculated using the following formulae:

$$\text{SCONC index} = S_r S_w + C_r C_w + O_r O_w + N_r N_w + C_r C_w$$



Table 9: Vulnerability indices of SCONC = Index in the different formations

Values	Intrusive	Asu-river group	Eze-Aku formation
	(2) 43	(5) 43	(9) 46
	(7) 53	(13) 34	(10) 49
	(18) 52	(15) 39	(11) 43
		(16) 46	(12) 43
		(19) 37	(17) 47
		(20) 34	
		(21) 40	
Min.	43	34	43
Max.	53	46	49
Mean	49.30	39	45.60
S.D.	5.51	4.47	2.61

Min.: Minimum; Max.: Maximum; S.D.: Standard deviation

where,

r = Rating for the area being evaluated (1-5)

w = Importance weight for the factor (1-5)

Factor ratings are derived from data on each factor while importance weights are found in a generic DRASTIC table that lists weights for factors having greater applicability (Aller *et al.*, 1987). The Sconc index was further divided into 4 categories: low, moderate, high and very high. Low (10-20), moderate (20-40), high (40-60), very high >60. From Table 9, Asu-River group is moderately vulnerable while Intrusive and Eze-Aku Formation is said to be highly vulnerable to pollution and this may be due to fracture in the intrusive which allows free flow of water into the water table while that of Eze-Aku Formation may be due to shallow depth of the water table to the surface.

## CONCLUSION

Baseline data on hydro geochemical studies and vulnerability assessment of sandstone-shale-intrusive aquifers which previously had not been documented have been assembled and analyzed in this study. The present levels of physicochemical parameters, biological, heavy metal have been used to assess the vulnerability of sandstone-shale-intrusive aquifer in the study area. In physiochemical parameters, more than 70% of the parameters are below the W.H.O standard value for drinking and domestic purposes. More than 65% of biological parameters are below W.H.O standard while the other percentage of more than 25% is higher than W.H.O standard and was noticed to increase during a wet and wet-dry period and reduces during a dry period which shows an increase due to infiltration. It was also noticed to increase from Asu River group to Eze-Aku Formation. More than 40% of the heavy metal was higher than the W.H.O standard values. The data obtained show that contamination or increase in parameters follows the flow direction of groundwater. It was also observed that the Eze-Aku Formation was more vulnerable to coliform than the Asu-River Group followed by the Intrusive. The data also show that the

formations were more vulnerable in the wet period in some area than dry period while in some area the wet period reduces the vulnerability due to dilution from runoff and this is evidence that the vulnerability of the study area is control by infiltration and runoff. And these go further to show that the aquifer in the study area is mostly recharged by precipitation. The data also show that the aquifers in the study area are not vulnerable to nitrate but are rather vulnerable to fecal coliform due to water from runoff that infiltrates into the aquifer from the vadose zone during precipitation in the area. The result of vulnerability of the formations using SCONC index (Table 9) shows a moderate vulnerability of Asu-River group while Intrusive and Eze-Aku Formation is said to be highly vulnerable to pollution and this may be due to fracture in the intrusive which allows free flow of water into the water table while that of Eze-Aku Formation may be due to shallow depth of the water table to the surface.

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