FUPRE Journal of Scientific and Industrial Research
Vol.2, (1), 2018
ISSN: 2579-184 (Print) ISSN: 2578-1129 (Online)

Hydrochemistry of Water Resources in Parts of Enugu, South Eastern, Nigeria

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Abstract

Evaluation of the hydrochemical status of water resources in selected parts of Enugu (precisely, Independence Layout, Uwani, Ugwuaji, Emene, Trans Ekulu, Abakpa, Coal Camp and Asata Localities), Nigeria was conducted. This was purposed to assess the suitability of the resources for irrigation and domestic consumption as well as delineating their attributive hydrochemical facies. Water samples collected from sixteen (16) hand dug wells were analyzed for various physiochemical parameters using standard in-situ and laboratory procedures. The analysis showed the following peak values; Temperature- 31^0C, pH- 6.3, Na – 38mg/l, K – 200mg/l, Ca- 34.3mg/l, Mg- 6.3mg/l, Cl- – 105mg/l, HCO_3 – 17.2mg/l, CO_3 – 12.8mg/l, SO_4^{2-}- 63.01mg/l, NO_3^- - 6.21mg/l, Fe- 0.27mg/l, Mn – 0.39mg/l, BOD -560mg/l, COD- 1176mg/l, Electrical Conductivity -253ϰs/cm, TDS- 140mg/l, TPH- 2410.59mg/l. Interpretations revealed a strong-weakly acidic groundwater presumably reflecting the effect of pyrite weathering, mine drainage and precipitation charged by chloride ions. Groundwater characterization revealed the dominance of Na-Cl facies with sub-ordinate mixed facies and Na-SO_4 facies. Except for local occurrences of unacceptably high levels of Magnesium (Mg), Hardness, Manganese (Mn), BOD, COD and TPH in addition to pH, all other parameters were compatible with the World Health Organization and Nigerian standards for drinking water (NSDWQ).Although, the water is suitable for irrigation, it would require treatment to restore the pH and the other deficiencies to acceptable standards for drinking.

Keywords: Groundwater, Hydrochemical Facies, Physiochemical Parameters, Weathering, Pyrite.

1.0 Introduction

The city of Enugu in South-Eastern Nigeria has witnessed a significant population growth on account of urbanization. It is one of the fastest growing cities in Nigeria having a population of about 750000 (Utom*et al.,* 2012). This rapid growth in population density coupled with intermittent groundwater supply shortages in the area has placed a huge dependence in surface water. The area is characterized by numerous surface waters, hand-dug wells and shallow unconfined aquifers which are vulnerable to contamination especially in vicinities that were notable for coal mining activities. Acidic mine drainage poses a major environmental hazard to fresh water resources worldwide and has enhanced levels of heavy metals and reduced the pH of such waters due to the weathering of sulphide minerals. Contamination occasioned by acid mine drainage in Enugu has been reported by several researchers (Egboka 1985, Nganje *et al.*, 2011, Utom*et al.*, 2012; 2013). Water supplies are also prone to contamination from domestic waste, as evident by the presence of various dumpsites in the area. Furthermore, the recent encouragement to farmers to produce more food has resulted in extensive use of fertilizers thus the consequent eutrophication of lakes. Therefore the need to evaluate the potability and hydrochemical status of water resource in parts of the area should not be undermined, hence the rationale for this research.

1.1 Physiography, Drainage and Climate

Enugu area is characterized by escarpment landforms often with incised valleys and Canyons with a lot of irregularities in surface water flow pattern and sporadic flow reversals (Akudinobi and Egboka 1996). The landscape of the area is broadly undulating with topographic heights ranging from 150m to 350m (Figure 1).

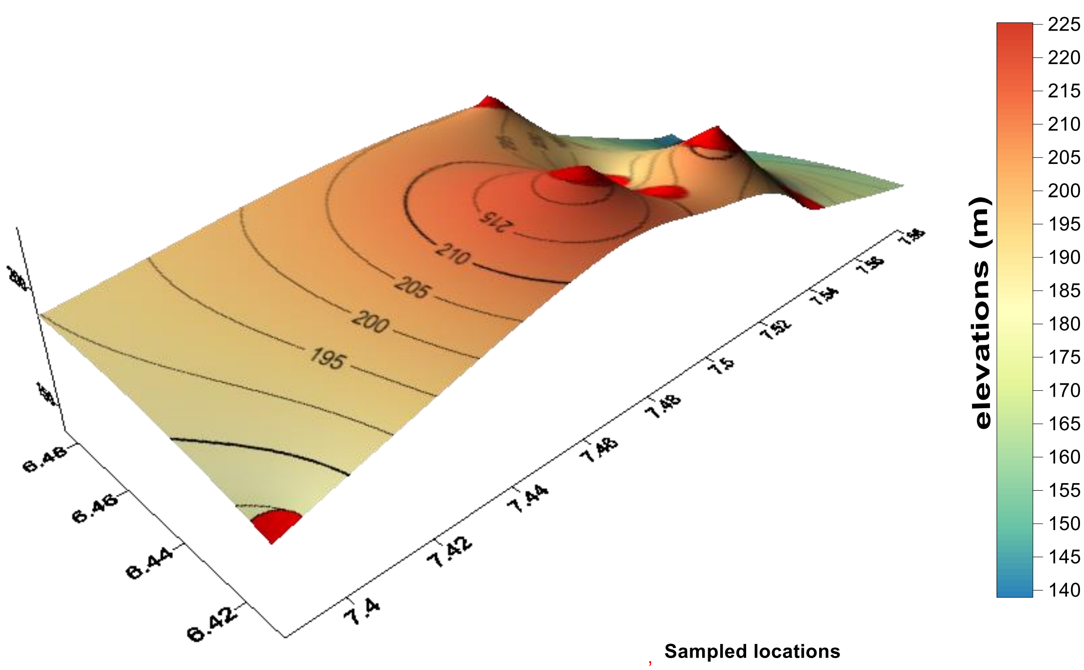

Figure 1: Topographic Model of The Study area

The North-South trending Enugu-Awgu escarpment constitutes a linear barrier to surface water causing a major surface and subsurface water divide with Enugu city at the foot scarp. On the scarp, slope failures, landslides, soil and gully erosion and slump features are common. Major rivers that drain the area include the Ajali, Iyoko, Atafu, Asoli, Iva, Ekulu, and Nyaba rivers. Structural control on some of the rivers resulted in a partly trellis to partly dendritic drainage pattern in the area (Utom*et al.*, 2013).Water resource is limited due to spatio-Temporal variation of precipitation (Utom*et al.*, 2013). The climate is tropical and dominated by the dry and rainy seasons. The rainy season spans from April to October while the dry season runs from November to March. The mean annual rainfall is 1750mm and mean daily temperatures range from 22 to 32^{0}C (Onwuka*et al.,* 2004).

1.2 Geology and Hydrogeology

The study area lies within the Anambra Basin, at the southwestern extremity of the Benue Trough of Nigeria and its underlain by two conformable geologic formations (Figure 2) which are Enugu shale (Campanian) and the Coaliferous Mamu Formation (Lower Maastrichtian).The Enugu Shale consists of mudstone, sandy shale with sandstone intercalations, and underlies plains east of the escarpment (Egboka 1985, Reijers 1996). The shales are fractured and weathered to blackish and grayish laterites which serve as cap over the fresh bedrock and may attain thickness of 20m (Onwuka*et al.*, 2004). The fractured shale constitute the only known aquifer in the Metropolis (Ezeh 2011, Omonona *et al.*, 2014). The aquifer is thin, shallow but extensively unconfined with depth to water table less than 20meters and it is extensively exploited by hand-dug wells within the study area. The coaliferous Mamu Formation contains sandstone, shale, mudstone and sandy shale with coal seams mined since 1915.The upper sections of the Mamu Formation constitute the partial recharging zones for the deeper-seated confined aquifers (Akudinobi and Egboka, 1996). The formation is also aquiferous, contributing about 70% of acid mine drainage water into the coal mines which are highly-fractured, jointed and faulted (Egboka and Uma, 1985).The geology of the

Anambra Basin has been described in various works such as (Reyment, 1965; Nwajide 1977; Akudinobi and Egboka, 1996; Egboka and Uma, 1985; Agagu and Ekweozor, 1982).

2.0 Methodology

2.1 Groundwater Sampling/In-situ Analysis.

Groundwater samples were collected from Sixteen (16) existing wells (Figure 3). The co-ordinates and elevations of the sampling points or wells were established using the .

hand-held GARMIN 12 model GPS. Water samples were collected in sterilized, 1.5 liter plastic bottles with tight fitting plastic caps. The bottle lid was replaced immediately after the sampling to minimize the escape of dissolved gases and oxygen contamination

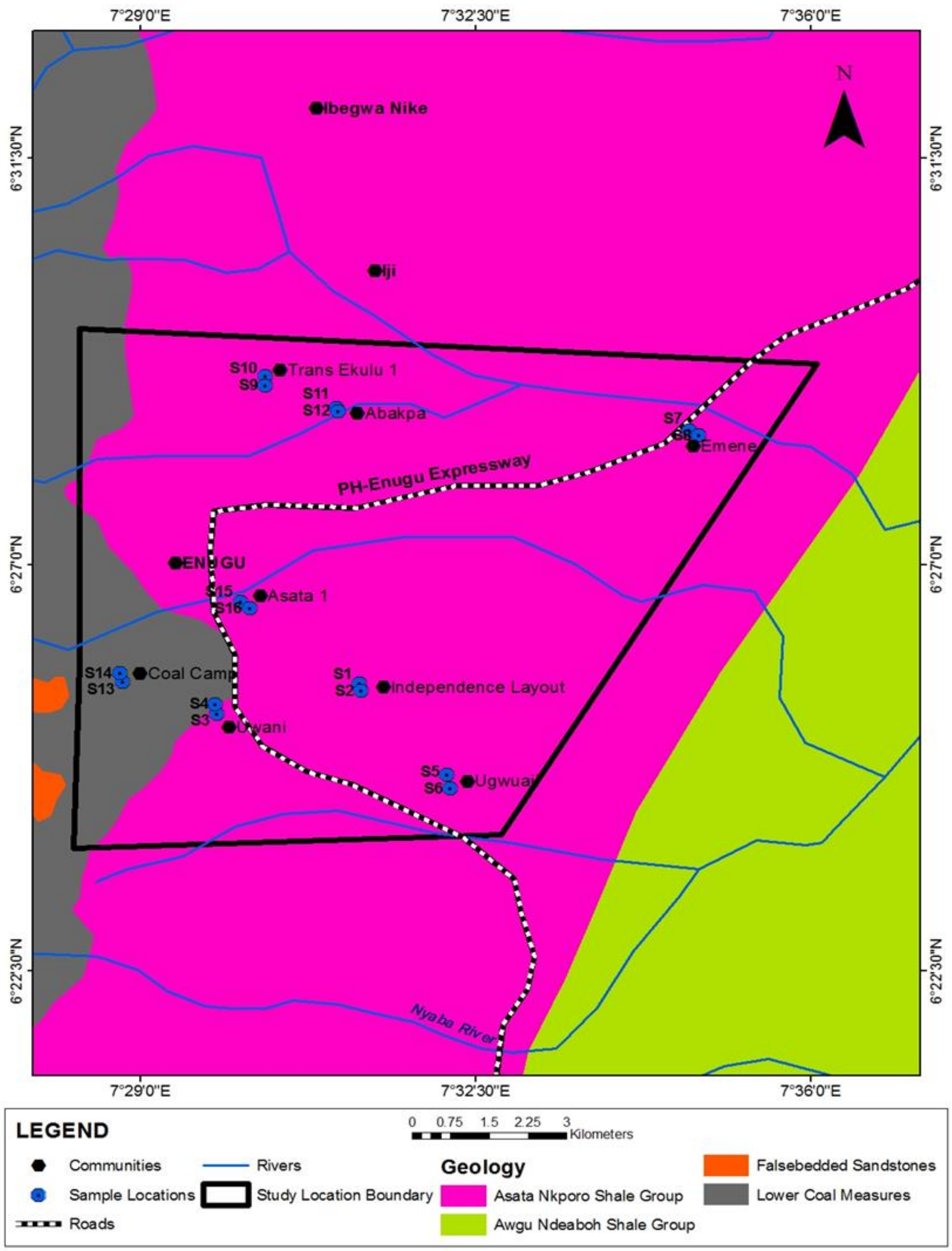

Figure 2: Geologic Map of the Study Area.

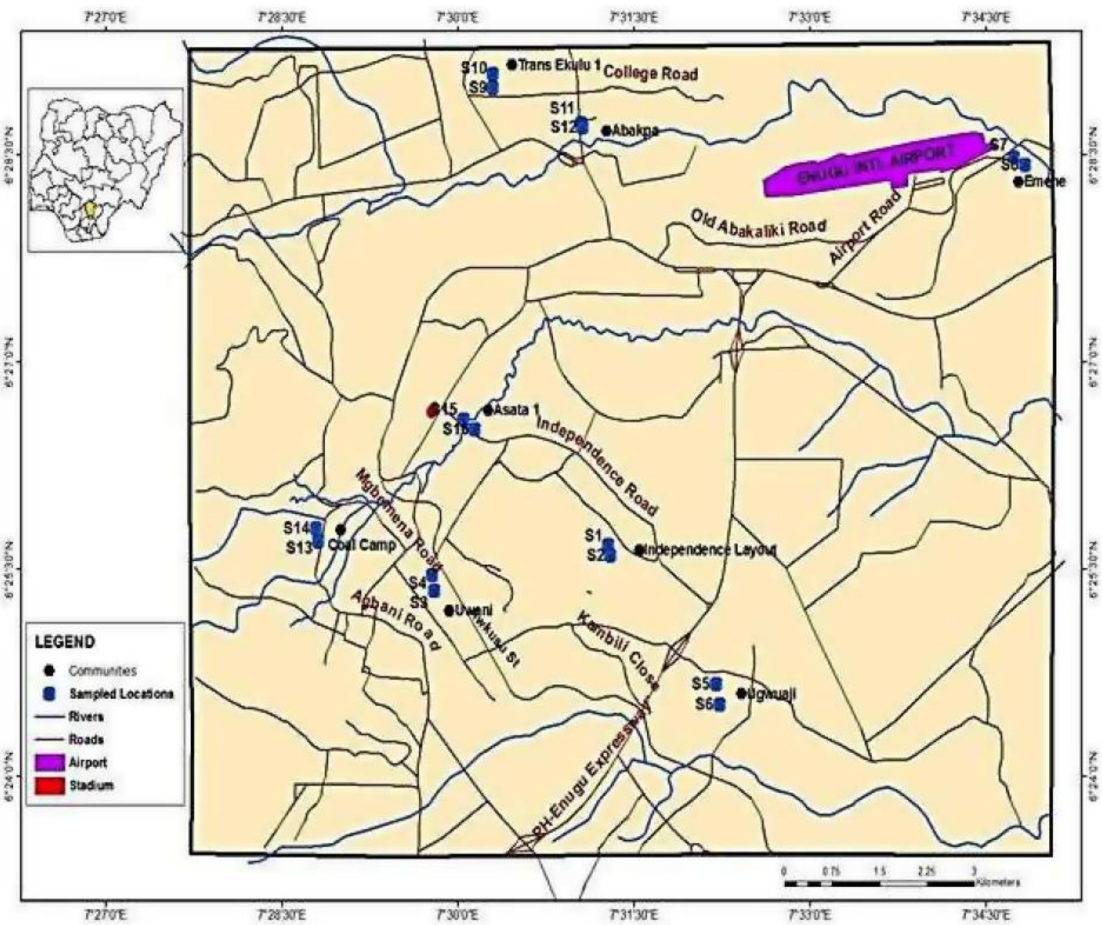

Figure 3: Map of the study area showing the sampled locations

Sensitive parameters such as temperature, Conductivity and pH were measured in-situ before samples were labeled, stored in an ice packed cooler and taken to the laboratory for further physiochemical analyses within 24 hours. Temperature was measured with a mercury-filled Celsius thermometer, Electrical Conductivity were estimated with Oakton Conductivity meter and PH was estimated using the ATI-Orion PH meter.

2.2 Physiochemical Analysis of Groundwater

Standard water analysis techniques stipulated by Association of Official Analytical Chemists (AOAC, 1980) (Table 1) were employed to determine the level of concentration of anions and cations in the water. Concentration of Na^+ and K^+ were determined with a flame Emission analyser. Ca^{2+} and Mg^{2+} were determined by EDTA Titrimetry. Cl^-, HCO_3 and CO_3^{2-} were also measured by appropriate titrimetric methods. NO_3^- was measured by Colorimetry while SO_4^{2-} was determined by precipitation using $BaCl_2$ and measurement of absorbency with a spectrophotometer. The concentration of heavy metals (such as Iron and Manganese) were estimated using AAS (Atomic Absorption spectrophotometer; Model SP2900 Pye-Unicam) while the Biochemical Oxygen Demand (BOD) and the Chemical Oxygen Demand (BOD) were determined using the modified Winkler and $KMnO_4$ methods respectively

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3.0 Results and Discussion

3.1 Sodium (Na)

Sodium in water is sourced from sea, rainwater or feldspar weathering (Albite) and leaching of clay minerals into groundwater system. As a result of the detrimental effects on soil permeability and plant, sodium is considered a major factor governing the choice of water for irrigation (Hem, 1986). Suitability of water for this purpose is based on the Sodium Adsorption Ratio (SAR).This was calculated for each of the sample based on the formula provided by the U.S Salinity Laboratory (1954) as follows;

$$SAR = \frac{(Na^+)}{\sqrt{\frac{1}{2}[(Ca^{2+} + Mg^{2+})]}} \quad (1)$$

Table 1: Result of Hydrochemical analysis of groundwater samples from the study area

S/N	SAMPLE IDENTITY	QUALITY STANDARD	Temp (^oC)	pH	Na (mg/l)	K (mg/l)	Ca (mg/l)	Mg (mg/l)	Cl^- (mg/l)	HCO_3^- (mg/l)	CO_3^- (mg/l)	SO_4^{2-} (mg/l)	NO_3^- (mg/l)	Fe (mg/l)	Mn (mg/l)	BOD mg/l	COD (mg/l)	EC (лs/cm)	TDS (mg/l)	HARDNESS ($CaCO_3$)	TPH (mg/l)
		WHO (2011)	NS	6.5-8.5	200	NS	NS	0.200	250	NS	NS	250	50	0.300	0.300	NS	NS	500	600	200	
		NSDWQ (2007)	NS	6.5-8.5	200	NS	75	0.200	250	NS	NS	100	50	0.300	0.200	NS	NS	NS	500	500	
1	Independence layout 1		29.000	4.610	9.838	5.002	3.401	3.079	28.000	17.200	1.600	13.780	4.410	0.256	0.271	9.600	32.000	89.000	40.000	5.440	-
2	Independence layout 2		29.000	4.600	10.010	4.850	2.980	3.081	27.500	16.800	2.100	12.790	3.800	0.270	0.269	10.100	34.000	85.000	40.000	6.260	-
3	Uwani 1		29.500	4.580	12.08	1.956	2.937	0.755	36.00	8.800	1.600	6.890	3.530	0.065	0.027	9.600	24.000	68.000	40.00	4.700	-
4	Uwani 2		29.300	4.560	11.80	2.100	3.003	0.756	34.00	9.421	2.330	8.010	4.310	0.071	0.028	9.600	25.000	66.000	40.00	7.000	-
5	Ugwuaji 1		29.700	6.310	33.04	2.407	2.949	6.341	4.000	0.000	11.200	48.220	0.880	0.075	0.000	28.00	102.00	120.00	80.00	33.030	-
6	Ugwuaji 2		29.700	6.320	32.08	3.210	3.321	6.340	5.000	0.000	12.100	46.220	1.020	0.069	0.000	29.10	101.00	118.00	80.00	40.180	-
7	Emene 1		30.500	4.120	9.496	9.130	3.115	3.415	32.00	3.200	1.600	7.580	4.150	0.203	0.117	6.400	16.000	123.00	80.00	4.980	-
8	Emene 2		30.000	4.140	10.30	8.760	2.891	3.418	30.00	2.754	2.010	8.400	3.980	0.204	0.120	5.870	16.000	124.00	80.00	5.810	-
9	Trans Ekulu 1		29.000	3.890	13.53	2.830	0.567	1.051	36.00	7.200	1.600	6.890	3.530	0.124	0.000	22.40	196.00	71.000	40.00	0.910	-
10	Trans Ekulu 2		29.500	3.900	14.20	3.120	1.173	1.051	35.00	6.700	2.200	8.200	4.120	0.124	0.000	23.10	196.00	73.000	40.00	2.580	-
11	Abakpa 1		31.000	6.160	34.64	18.595	33.450	5.983	84.00	0.000	12.800	61.310	3.710	0.119	0.396	23.04	232.00	251.00	140.0	428.160	-
12	Abakpa 2		31.000	6.200	36.01	20.011	34.321	5.981	82.00	0.000	14.000	63.010	4.010	0.121	0.391	22.03	233.00	253.00	140.0	480.490	-
13	Coal Camp 1		29.500	4.040	38.10	0.324	3.191	3.722	104.0	15.200	1.600	20.670	5.290	0.092	0.088	9.600	36.000	199.00	120.0	5.110	-
14	Coal Camp 2		29.500	4.020	37.890	1.020	2.765	3.721	105.000	16.000	2.200	21.340	6.210	0.101	0.088	10.200	34.000	195.000	120.000	6.080	-
15	Asata 1 (Jacob's well)		31.000	4.440	3.519	2.896	1.573	1.517	16.000	5.600	1.040	13.780	6.180	0.201	0.010	560.000	1,176.000	47.000	20.000	1.640	2,410.590
16	Asata 2 (Mmili-ani)		31.000	4.510	1.995	2.637	1.368	1.195	20.000	9.200	0.800	12.400	3.440	0.099	0.000	22.400	92.000	41.000	20.000	1.090	-

NS - Not stated

The results of the calculated SAR values from the analyzed groundwater sample in the study area are shown in Table 2. The SAR values of groundwater in study area occur below 10 which indicate the water is good for Irrigation.

Table 2: SAR Values for the Sampled Wells in the Study Area

S/N	Well / Sample Location	SAR value (meq/l)
1	Independence layout 1	3.4
2	Independence layout 2	1.63
3	Uwani 1	2.73
4	Uwani 2	2.71
5	Ugwuaji 1	7.22
6	Ugwuaji 2	3.99
7	Emene 1	3.18
8	Emene 2	3.73
9	Trans Ekulu 1	4.13
10	Trans Ekulu 2	3.86
11	Abakpa 1	2.08
12	Abakpa 2	2.38
13	Coal Camp 1	5.75
14	Coal Camp 2	5.87
15	Asata 1 (Jacob's well)	0.81
16	Asata 2 (Mmili-ani)	0.51

3.2 Potassium (K)

The potassium concentration in samples ranges from 0.3mg/l – 18.6mg/l. This falls within the WHO (2011) permissible range for drinking water. The presence of potassium in the water samples can be attributed to the weathering of clays

3.3 Hardness

Hardness value for ground water in the study area ranges from 0.91mg/l to 480mg/l (Table 3). These values when compared with WHO (2011) and NSWDQ (2007) desired hardness levels of 200mg/l and 200mg/l respectively, show that the water at Abakpa area is hard unlike the other areas.

Further comparison of these results with the hardness classification scheme for groundwater in Table 3, indicates a generally soft water except for localized hard water in Abakpa. Hardness in water is caused by calcium and magnesium. Total carbonate hardness exceeding 300mg/l implies such water is encrusting (Offodile 2002) and could cause blockage to distribution.

Table 3: Hardness Classification of Water

HARDNESS (mg/l as $CaCO_3$)	CLASSIFICATION
0 – 75	Soft
75 – 150	Moderately hard
150 – 300	Hard
Over 300	Very Hard

(Source: American Public Health Association (ALPHA) 2003)

3.4 Calcium (Ca)

The result of the analysis shows a calcium concentration range of 0.6mg/l to 34.3mg/l (Table 1). WHO (2011) Standards has no guideline for calcium concentration. Weathering of clay minerals could be the source of calcium in the waters.

3.5 Magnesium (Mg)

Magnesium concentration from the result ranges from 0.8mg/l to 6.3mg/l. as NSDWQ (2007) gave a limit of 0.2mg/l while the WHO (2011) gave no guideline for magnesium. Based on the NSDWQ (2007), the water is not suitable for domestic use.

3.6 Chloride (Cl^-)

The result of the analysis shows a concentration range of 4.0mg/l to 105.0mg/l for chloride. This range falls within the WHO (2011) and NSDWQ (2007) potable water limit of 250mg/l and it implies that the groundwater in the study area is suitable for drinking. The weathering of the rocks and industrial waste probably from the mine are traceable sources of chloride in the area.

3.7 Bicarbonate (HCO_3^-) and Carbonate (CO_3^{2-})

The result of analysis shows a concentration range of 0 – 17.2mg/l and 0.8mg/l – 14.0mg/l for bicarbonate and carbonate respectively. There is no stipulated limit for the parameters by the WHO (2011) and NSDQW (2007).

3.8 Sulphate (SO_4^{2-})

Sulphate concentration of ground water in the study area is low varying from 6.8mg/l to 63.0mg/l (Table 1). This agrees with the WHO (2011) desirable limit of 250mg/l, hence the water is suitable for domestic use with respect to this parameter. According to Udom*et al.* (1999), higher concentration of sulphate adds bitter taste to water and can produce laxative effects when combined with magnesium or sodium. It can be inferred that weathering of pyrite inherent in coal mine locations in area may have resulted in the sulphate contamination of the groundwater and this concentration have reduced compared with previous works of Egboka and Uma (1985) due to the suspension of the coal mining activities in the area.

3.9 Nitrate (NO_3^-)

Nitrate concentration of ground water in the study area varies from 1.0mg/l to 6.2mg/l (Table1). According to WHO (2011) and NSDWQ (2007), the permissible limit of nitrate in drinking water should not exceed 50mg/l (Table 1). The results show low nitrate values implying that ground water in the area is safe for drinking. Nitrate content in the ground water could sourced from fertilizer application, sewage and decomposition of plants.

3.10 Iron (Fe)

Iron concentration in the study area is in the range of 0.1mg/l to 0.3mg/l (Table 1). This falls within the maximum permissible limit of 0.3mg/l by WHO (2011) and NSDWQ (2007). High iron concentration in boreholes may clog the screen openings and hence increases the chances of borehole failure. The concentration of iron in water could be attributed to dissolution/weathering of ferromagnesian minerals from rock. It may also have been leached out of pyrite into the groundwater system.

3.11 Manganese (Mn)

Manganese concentration ranges from 0 to 0.4mg/l. At levels exceeding 0.1 mg/l, manganese in water supplies causes an undesirable taste in beverages and stains sanitary ware and laundry (WHO 2011). The presence of manganese in drinking water, like that of iron, may lead to the accumulation of deposits in the distribution system and causes neurological disorder (NSDWQ, 2007). The result shows relatively high concentration of Manganese at Abakpa area (Table 1).

3.12 BOD and COD

BOD values range from 5.9mg/l to 560.0mg/l and COD values of 16.0mg/l to 1,176.0 mg/l. WHO (2011) and (NSDWQ, 2007) recommends no health-based guideline value for these parameters.

3.13 Electrical Conductivity

Electrical Conductivity values range from 47ϰs/cm to 233ϰs/cm in the water (Table1). The permissible limit for this parameter in drinking water is 500ϰs/cm (WHO, 2011). The values show that the water is not saline, hence suitable for both drinking and irrigation purpose. Conductivity values up to 2000ϰs/cm are permissible for irrigation (Wilcox, 1955).

3.14 pH and Temperature

Groundwater pH in the study area ranges from 3.89 – 6.32 at a temperature range of $29.0^{o}C$ – $31.0^{o}C$ (Table 1). This implies the water is strongly- weakly acidic at these temperatures. WHO (2011) did not state any limit for this temperature. However at temperature higher than $15^{0}C$, there is prevalence of micro-organisms and parameters such as odours and taste, and hastened chemical reactions. Comparison of the pH values with the WHO (2011) and NSDWQ (2007) limits shows the water is not potable with respect to pH. Hence there is need for pH adjustment to potable standards which can achieved through base-exchange method with dolomite.

3.15 Total Dissolved Solids (TDS)

Result of the shows a range of 20.0mg/l to 140.0mg/l (Table1). This is also compatible WHO (2011) and NSDWQ (2007) permissible limits of 600mg/l and 500mg/l respectively. Therefore, with regards to TDS values, the water in the study area is good for drinking.

3.16 Total Petroleum Hydrocarbon (TPH)

The analysis for this parameter was necessitated by the presence of free phase floating hydrocarbon on groundwater at sampling point 15 (commonly known as Jacob`s well) in Asata. The analysis gave a TPH value of 2,410.59mg/l with predominantly C_8–C_{12} hydrocarbon type which exceeded the Nigerian standard (NSDWQ 2007) and the DPR-EGASPIN (2002) permissible limits of 0.007mg/l and

0.6mg/l respectively. There is no guideline for this parameter in WHO (2011) as taste and odour of petroleum hydrocarbon will be detectable at concentrations below those of health concern. The exceedance with respect to the Nigerian and EGASPIN standards implies the water in the area is contaminated with regards to TPH. Hunt (1979) stated that gasoline consist of hydrocarbon varying from C_5 to C_{10} while kerosene fraction of crude oil varies from C_{11} to C_{13}. Hence, this hydrocarbon contamination could be attributed to seepage of gasoline / kerosene from an underground tank, filling station and/or lubricants from nearby automobile workshops.

3.17 HydrochemicalFacies / Class of Water

The abundance of major ions in the groundwater is reflected by the following sequence;

Na>Ca>K>Mg and Cl>SO_4>HCO_3>NO_3.

Results of hydrochemical analysis (Table 1.0) were used to classify groundwater based on the predominance of major cations and anions (in meq/l) using the Piper's Trilinear Plot (Figure 4).

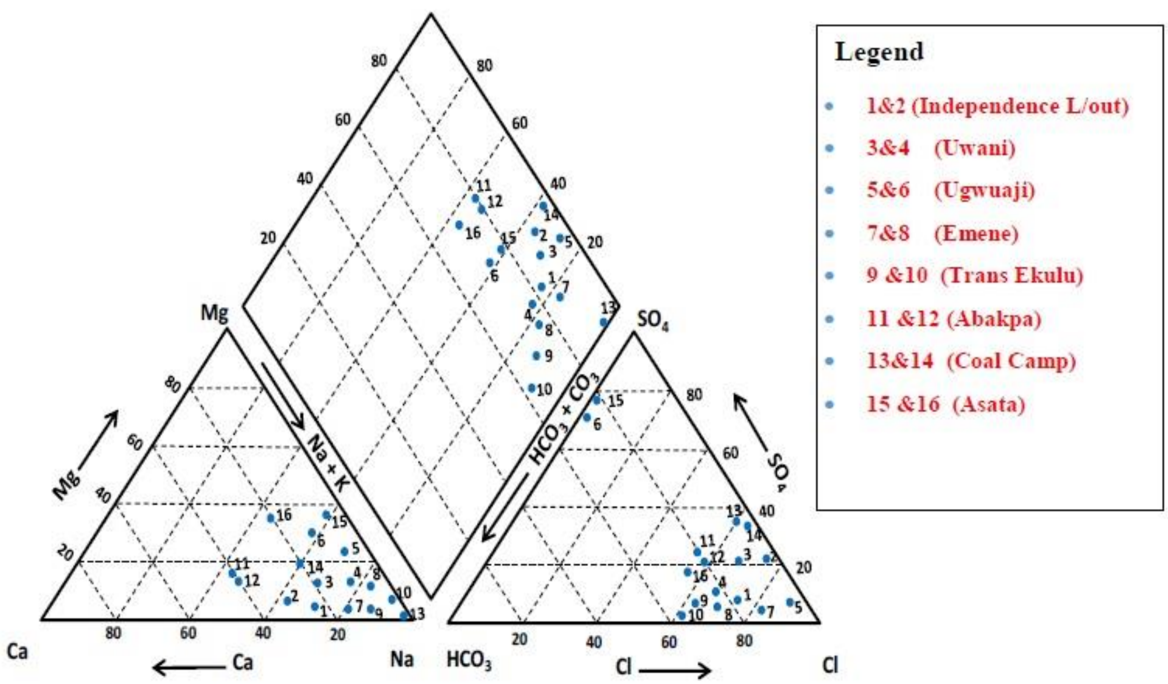

Figure 4: Piper trilinear plot showing the hydochemicalfacies in the study area.

The plot shows the water is predominantly characterized by sodium-chloride (Na-Cl) facies with subordinate mixed water facies (Na-Ca-Cl/Ca-Na-Cl) and sodium-sulphate (Na-SO_4) facies. Sodium-chloride facies constitute 75% of the total ground samples while the mixed water and Na-SO4 facies account for 12.5% respectively. The hydrochemicalfacies are reflections of the interplay of geochemical processes between mineral in subsurface rocks and the groundwater. Major processes/factors which could have dictated the water types include seepage of mine water (mine drainage), pyrite/silicate weathering, ion exchange and natural water recharge. The dominance of Na-Clfacies (Figure 4) is a reflection of these processes most probably the weathering of silicates (Albite) coupled with infiltration of rainwater charged with sodium and chloride ions. The sub-ordinate $NaSO_4$ water could be traceable to pyrite / silicate weathering as well as seepage of mine water into the groundwater especially in coal mine vicinities.

Figure 5 illustrates stiff plots used to compare the concentration of the major anions and cations in water samples from different locations. The cations are plotted on the left axis while the anions on the right axis. A greater shift from the vertical axis represents a greater ionic concentration.

The cation and anion concentrations are linked to form an asymmetric polygon, where the size is a relative indication of the dissolved-solids concentration. From the plot, it is observed that Na+K and Mg constitute the dominant cations while HCO_3+ CO_3 and Cl the dominant anions, which further confirms the facies types delineated from the Piper plot.

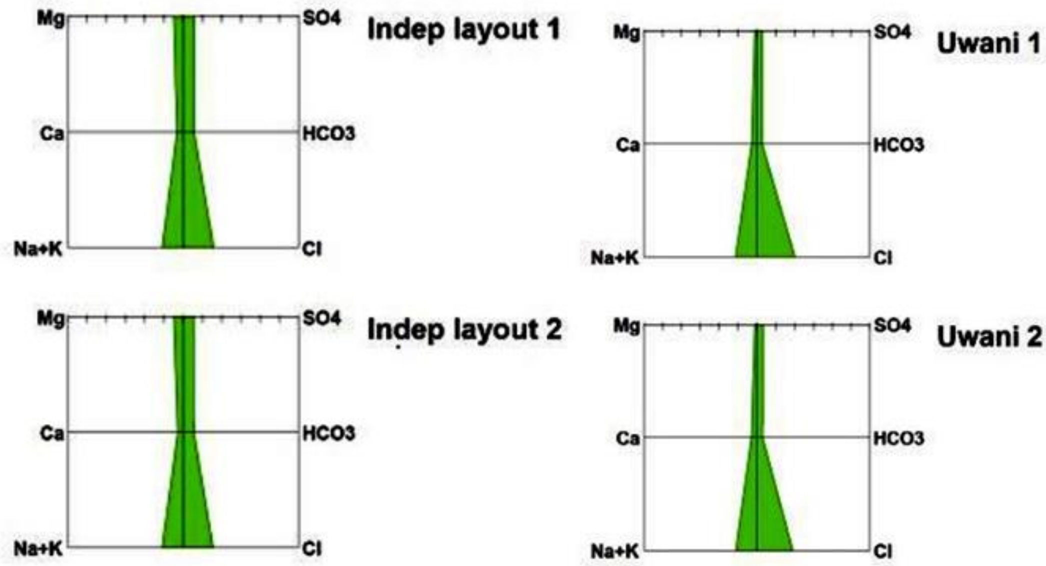

Figure 5a: Stiff diagrams showing the dominant ions in the sample location (independent layout, Uwani)

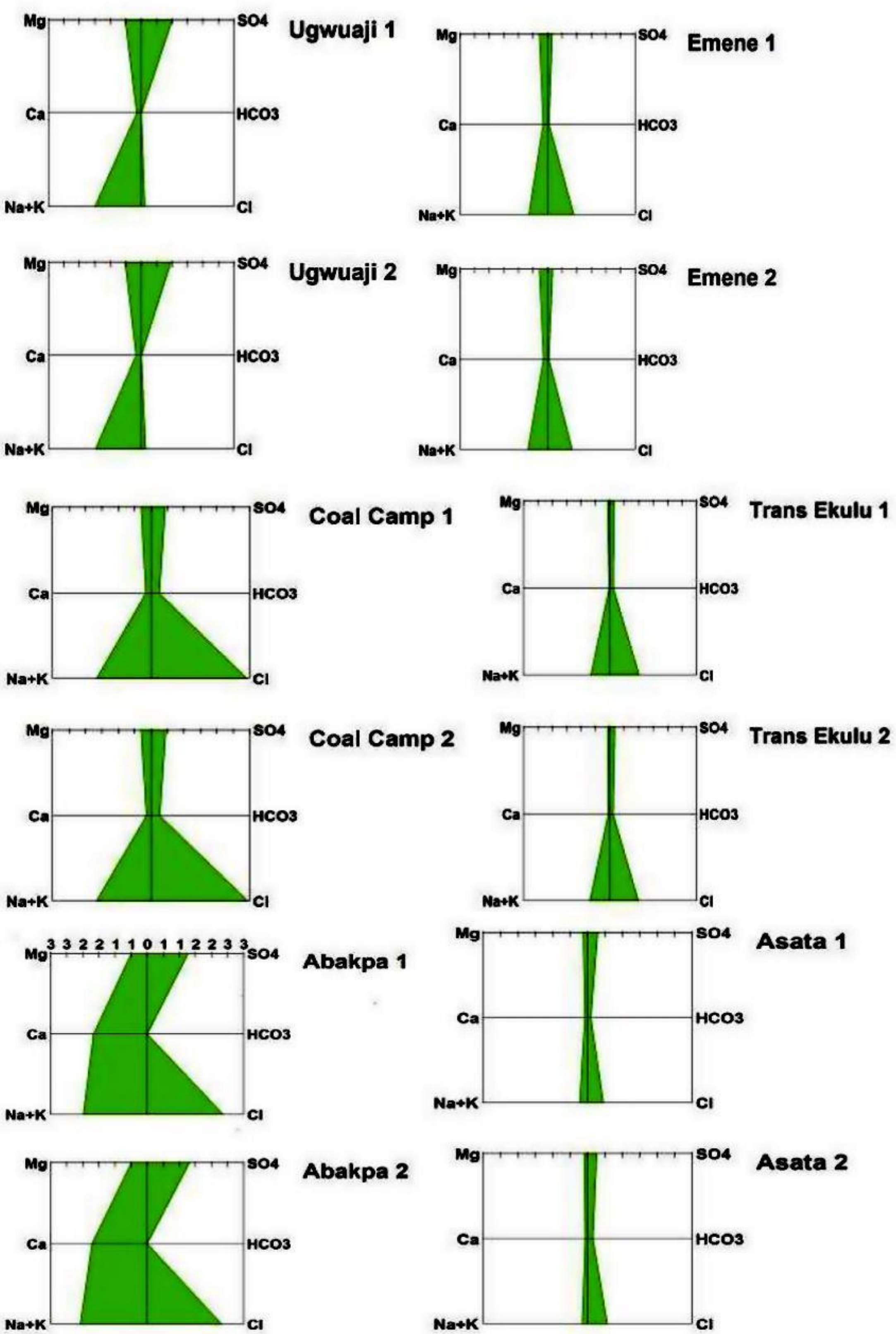

Figure 5b: Stiff diagrams showing the dominant ions in the sample locations (Ugwuaji, Emene, Coal camp, Trans Ekuli, Abakpa and Asata)

4.0 Conclusion

An evaluation of the hydrochemical status of the water resource in parts of Enugu shows the areas have a low-pH (4.00-6.80) water dominantly characterized by Na-Clfacies with subordinate Mixed (Na-Ca-Cl/Ca-Na-Cl) facies and Na-SO_4 facies. Except for local occurrences of unacceptably high levels of Magnesium (Mg), Hardness, Manganese (Mn), BOD, COD and TPH in addition to pH, all other parameters are compatible with the WHO (2011) and Nigeria standards for drinking water (NSDWQ 2007). Although, the water is suitable for irrigation but would require treatment to restore the pH and the other deficiencies to acceptable standards for drinking.

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Acknowledgement

We appreciate the Scholarly advice and immense contributions of Prof. G.J. Udom, and Dr. A.C. Tse, both of the Department of Geology, University of Port Harcourt. Special thanks to Mr. Ben Anowo of Ministry of Water Resources, Enugu whose contributions cannot be over looked.