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Hydrochemical Evolution of Urban Impacted Shallow Aquifer of Enugu, Nigeria: A Geospatial Approach

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ABSTRACT

The region under study suffers from a severe lack of groundwater, and the current shallow aquifers are at risk due to rapid population growth and urbanization. This makes Enugu's groundwater particularly valuable, as it is the sole source of water for both domestic and industrial purposes. To meet the increasing demand, a thorough assessment of groundwater quality is necessary, which must be conducted with the aid of geochemical modelling techniques and geographic information systems. The goal of this research is to evaluate the impact of urbanization and hydrogeochemical processes on groundwater evolution and quality, to facilitate better management and protection. By examining hydrochemical properties, rock-water interactions, ion exchange, and water quality indices, the study revealed a geospatial distribution of hydrochemical parameters.Rock weathering, mineral dissolution, ion exchange, and anthropogenic activities such as urbanization and environmental sanitation were the primary factors determining the evolution of the region's water quality. Despite this, the water still meets the WHO standards for drinking water, with only minor treatment potentially required. However, to prevent significant groundwater pollution, management options must be explored to guarantee its long-term viability.

Keywords: Groundwaterquality, Potability, Hydrochemistry, Evolution, Rock–water interaction, Ion exchange, geospatial, Enugu Urban

1.0 Introduction

To plan effectively for municipal, commercial, industrial, agricultural, and drinking water supplies, a hydrochemical study is an essential tool, particularly when dealing with groundwater. The study of hydrochemical evolution provides valuable insights into the suitability of water for its intended use. Through this, it becomes possible to determine changes in water quality due to rock-water interaction or external human influence(Sadashivaiah et al, 2008). When analyzing groundwater, major chemical components such as Na^{+1}, K^{+1}, Ca^{+2}, Mg^{+2}, Cl^{-1}, HCO_3^{-1}, and $SO4^{-2}$ are typically present. These components play crucial roles in assessing and characterizing water quality for different applications. To accurately evaluate subtle variations in water chemistry, a comprehensive understanding of the hydrogeochemical and geospatial conditions that influence groundwater composition is necessary. Hydrogeochemical processes are pivotal in defining groundwater hydrology in an aquifer system. Similarly, hydrochemistry varies geographically and spatially with many complex geological, geochemical, hydrogeological, anthropological, and climatic factors. Frequent spatial and depth water chemistry variations across a range of compositional scales are commonly encountered in many urbanized settings. Likewise, in terms of residence time, temporal variations in response to variable atmospheric activity and changes in aquifer dynamics can be expected.

The potability of groundwater in urban environments is an important issue, complicated by a large number of possible sources of contamination. In rapidly urbanizing and industrializing environments, land use and land cover change with stringent environmental norms. These urban activities have resulted in significant damage to groundwater quality, even at short distances (Jayaprakash et al., 2008; Subba Rao, 2006 and 1997).

The study aimed to assess the hydrogeochemical evolution and water quality of Enugu urban groundwater. The specific objectives are to assess the geochemical status of shallow groundwater and to assess the distribution of water chemical components in the study area and their influencing factors. Use analytical methods and geographic information science (GIS) to determine the underlying (background) groundwater quality of the study area by chemical and environmental speciation, and to construct groundwater quality indicators for the study area.

2.0 Study area

Enugu Urban is located at latitudes 6°20′N and 6°32′N and longitudes 7°26′E and 7°37′E. It is located in Southeastern Nigeria and covers an area of nearly 350 square kilometres. It is located at the eastern foot of a north-south trending cuesta,popularly referred to as Enugu Cuesta (Fig. 1), which represents the main surface and subsurface watershed of two hydrological (drainage) basins (the Cross River and the Anambra River), separating the city to the east and south respectively. The study area is easily accessible by road from all parts of Nigeria. Most of the city of Enugu lies beneath the

Campanian Enugu Shale (Fig. 2), which is the main lithostratigraphic unit in the study area. Outcrops of the Enugu Shale occur on the plains east of the north-south trending cliffs (Eshowbo and Ezeanyim, 1993). The region is characterised by topography which consists of vast plains divided by steep valleys and low hills modified by long exposure to weathering and erosion.

The shales are fractured, jointed, and weather into a black and grey to red lateritic clay cover that covers the shale bedrock. This lateritic overburden is porous and permeable, varying in thickness up to about 20 meters depending on topography. Composite aquifers are formed from weathered laterite regolith overlying fractured shale bedrock. In recent times, the aquifer has become an important source of water supply for residents, with hand-dug wells meeting most of their water needs. Rapid population growth in Enugu City has resulted in increasing infrastructure and housing development, requiring large quantities of potable water for sustainable development. Therefore, an additional water supply system is required.

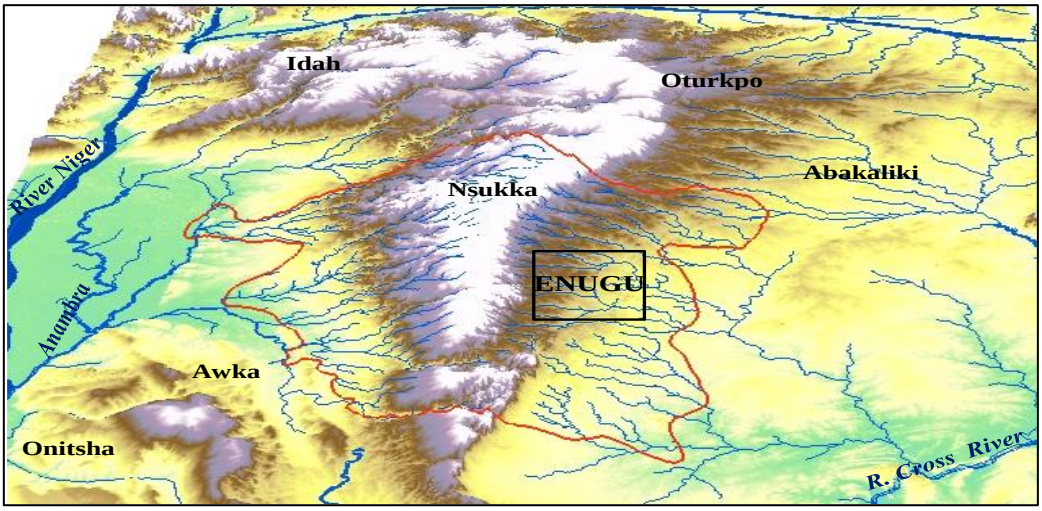

Fig. 1. 3D topographic image of Enugu State (red outline) and its environs depicting the study area (black box outline) relative to north-south Enugu cuesta (modified by Author from SRTM)

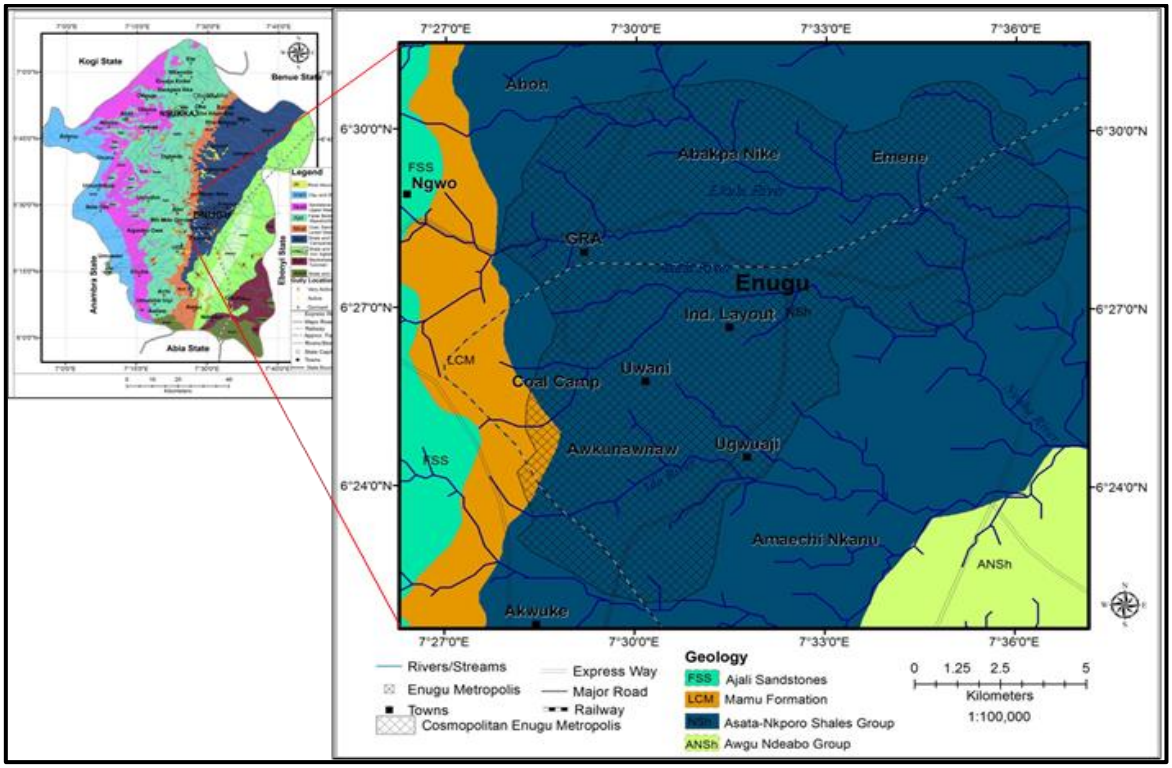

Fig. 2: Geologic map of Enugu Urban and its environs (insert: geologic map of Enugu State modified after Nigeria Geological Survey Agency (NGSA, 2006))

3.0 Materials and Methods

Sixty-six (61) groundwater samples were collected for hydrochemical studies during field operations between June 2017 and March 2018. At each sample well location, two (2) 500 ml plastic sampling containers were used to collect two (2) groundwater samples. One of the water samples designated A, was preserved for hydrochemical analysis of significant anions, including Cl^-, SO_4^{2-}, HCO_3^-, CO_3^{2-}, and NO_3^-. The second sample, designated B, was used to analyze the cations Na^+, K^+, Ca^{2+}, Mg^{2+}, Fe^{2+}, Mn^{2+}, and Pb^{2+} after being acidified with 2 drops of pure nitric acid (HNO3-). Atomic absorption spectroscopy (AAS) was used to analyse the major cations Ca^{2+}, Mg^{2+}, Na+, and K^+ as well as trace metals. Ion chromatography was used to analyse various anions, such as Cl^-, SO_4^-, and NO_3^-.The titration method was used to determine bicarbonate (HCO3-). A portablepH meter was used to determine the pH in the field. The water's total dissolved solids (TDS) and electrical conductivity(EC) were measured in situ using a portable TDS electrode. At the time of sampling, the temperature range varies from 26 to 30oC. To determine the accuracy of cation and anion analysis, the ionic balance error (eqn. 3.1) was calculated. According to Hounslow, 1995 and Freeze and Cherry, 1979, the error should vary between 5-15% for optimal accuracy.

$$Electroneutrality(\%) = \frac{\sum Cations - \sum Anionss}{\sum Cations + \sum Anions} \times 100 \qquad (3.1)$$

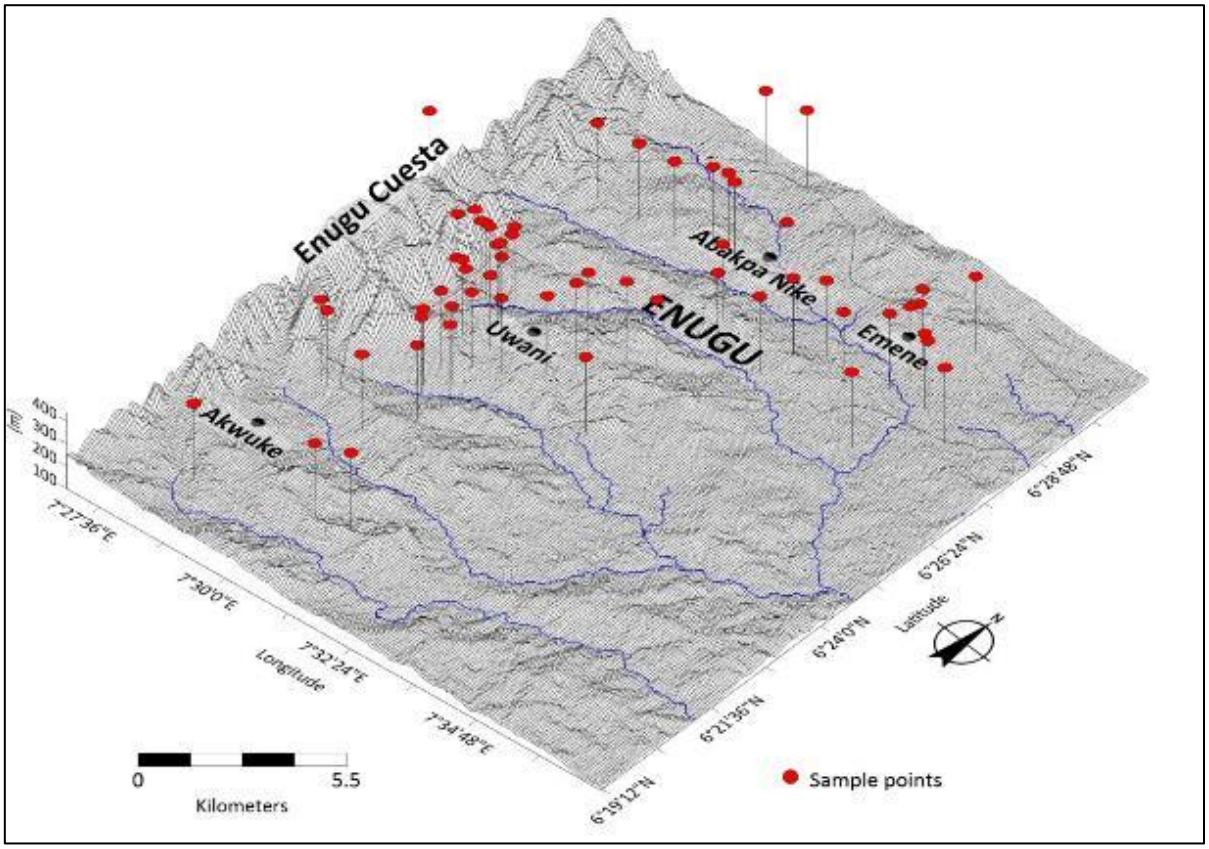

Fig.3. Digital Terrain Model of the study area showing relative geomorphic features and major drainage systems and the sample location

4.0 Results and Discussions

4.1 Groundwater Flow Patterns in the Study Area

The groundwater table configuration of the regolith aquifer of Enugu urban and environs generally tend to replicate the surface topography. Figure 4 shows the static water level (SWL), which refers to the water table elevation in a well, referenced to the mean sea level (MSL), and the groundwater flow pattern of the study area. This indicatesthe groundwater flow pattern showing the equipotential lines (contour lines) and flow direction (arrows). The major groundwater flow direction is eastwards, which coincides with the surface topographic orientation. However, some localised flows were oblique to the main flow towards the surface water. It is also evident that the groundwater is the source of recharge to the river system which acts as the natural discharges in the area. The figure distinctly demonstrates the relationship between recharge, discharge areas and surface topography. The

recharge areas coincide with the areas of topographic highs whereas, the discharges take place naturally downslope and valley, often as base-flow to the river system of the study area. Most of the wells sunk in the recharge areas are always deeper and often short-lived when compared with those in the discharge areas.

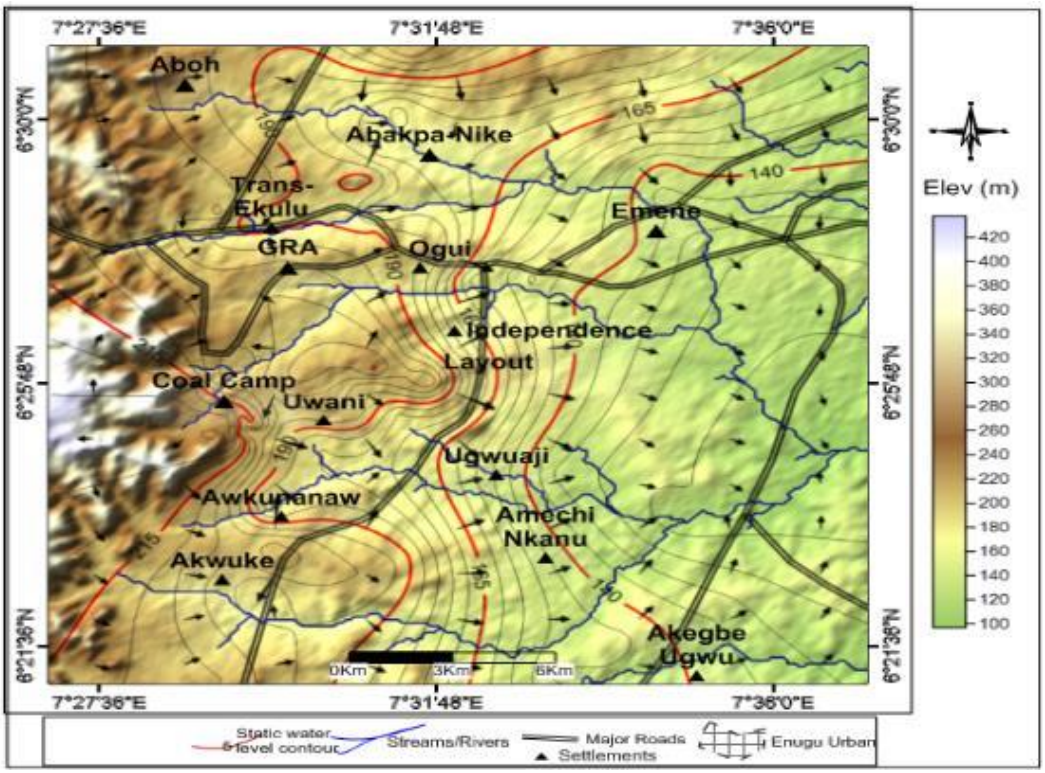

Fig. 4. Static water level map and groundwater flow pattern in Enugu Urban and its environs

4.2 Characterization of groundwater chemistry

The study of groundwater quality involves the description of the occurrence of the various chemical constituents of the groundwater and the relation of these constituents to water use. This finds importance in both groundwater management, sustainability and other uses as it provides insight into the evolution (modification) of the water, groundwater-rock interaction and anthropogenic impact on the groundwater sources.Table 1, summarises the main water quality parameters of the studied groundwater.

Table 1: Descriptive statistics of concentration of Rainy and Dry Season hydrochemical parameters in the study area

Parameters	**Rainy Season**					**Dry Season**				
	Min	**Max**	**Range**	**Mean**	**Stdev**	**Min**	**Max**	**Range**	**Mean**	**Stdev**
pH	3.5	8.9	5.4	6.1	1.4	4.1	8.2	4.1	5.9	0.8
Electrical Conductivity (EC)	6.5	950	943.5	209.3	257.9	31.1	1067	1036	444.3	214.7
Total Dissolved Solids (TDS)	10	500	490	152.9	129.5	17.4	715.6	698.1	248.8	120.2
Total Hardness (as CaCO3)	10	483.3	483.3	63.9	90.3	20	450	430	219.4	121.3
Calcium (Ca2+)	2.4	84.2	81.8	16.4	15	14.9	181.6	166.7	67.8	38.8
Magnesium (Mg2+)	0.2	26.1	25.9	5.3	5.19	0.9	27.9	27	4.5	4.61
Sodium (Na+)	1.2	153.4	152.2	45.3	35.5	1.3	15.5	14.1	4.2	3.5
Potassium (K+)	0.7	54.7	54	11.4	12.8	7.4	53.8	46.4	18.5	10.7
Bicarbonate (HCO3-)	8.2	588.3	580.1	82.9	87	15.2	155.8	140.6	76.7	37.5
Sulphate (SO42-)	1.2	201.7	200.5	36.5	41.6	0.9	62.6	61.7	19.6	15.5
Chloride (Cl-)	0.4	176	175.6	27.6	32.3	7.2	189.9	182.7	69.7	50.4
Nitrate (NO3-)	0.1	60	59.9	11.9	12.1	0.1	12.9	12.8	5.2	4
Manganese (Mn2+)	0.03	29.9	29.9	2.9	4.7	0.1	0.3	0.1	0.2	0
Soluble iron (Fe2+)	0.002	3.1	3.1	0.3	0.5	0.4	1.8	1.4	0.7	0.4
Lead (Pb)	<0.001	5	4.9	0.1	0.8	<0.001	0.8	0.7	0.5	0.2

All the values are in mg/L except Electrical Conductivity (µS/cm), pH

4.2.1 Hydrogen ion concentration (pH)

The pH of the water samples ranges from 3.4 – 8.9 with a mean of 6.09 and a standard deviation of 1.4 during the rainy season. During the dry season, the values range between 4.1 – 8.2, mean of 5.9 and a standard deviation of 0.8 (Table 1). This range of pH values is akin to that measured for the shale aquifer (Nkporo/Enugu Shale) by Nganje, et al (2017) and Onwuka, et al (2004). In Figure 5ab, pH ranges between 3.4 and 6.0 (about 44%) characterize most of the study area in a way that mimics the outline of the urban setup. Pockets of very low pH values between 3.4 and 4.5 were observed in some parts of the urban setup of Abakpa, Trans-Ekulu, Awkunanaw and Emene, characterised by avery dense urban population and anthropogenic activities. pH values between 6.0 and 7.3 (36%) characterized the fringes of the study area most of which are low-density areas and peri-urban.

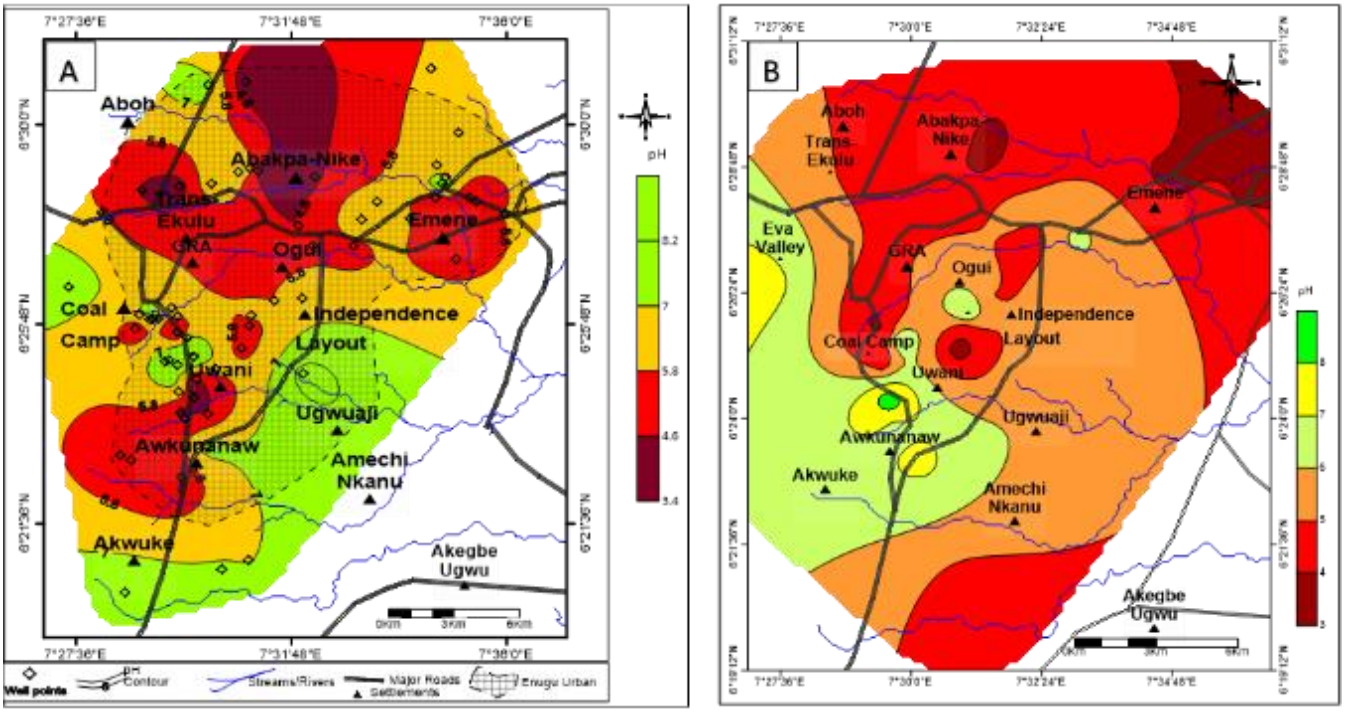

Fig. 5: pH distribution (colour interval) map of the study area (A) Rainy season(B) Dry season

4.2.3 Total Dissolved Solids (TDS) and Electrical Conductivity (EC)

A linearrelationship was observed to exist between TDS and EC in the studied groundwater by a factor of the range 0.55 and 0.75 which is similar to Driscoll, 1989. Figures 6a&b represent the spatial distribution of the measured TDS in the study area. TDS values range between 10mg/l – 500mg/l in both the rainy and dry seasons. The background TDS values for the study area were taken as a range between 10mg/l and 100mg/l. Over 57% of the rainy season and about 90% of the dry season samples exceeded the background values. These samples were mostly observed in some localised areas within the Enugu Urban. TDS ranges between 200mg/l – 490mg/l, and 300mg/l – 500mg/l in both rainy and dry seasons respectively were observed around Abakpa, Trans-Ekulu, Emene, Coal Camp, Uwani – Achara Layout, Garki Awkunawnaw, and Amechi areas. These areas are associated with high anthropogenic activities. Despite the wide range of TDS (10mg/l – 500mg/l), the water still falls within the recommended acceptable limit (500mg/l) by WHO (2011) water quality standards.

4.2.4 Bicarbonate (HCO_3^-)

A wide range of HCO_3^-concentrationswere observed in the study area. Figures 7a&b show the spatial distribution and range of HCO_3- in the study area. The concentration varies from 8.2mg/l to about 300.3mg/l with a mean of 76.38mg/l and a standard deviation of 59.31mg/l in the rainy season. The dry season data similarly show a wide variation in concentration ranging between 6.20mg/l – 218.3mg/l with a mean of 77.6mg/l and a standard deviation of 47.8mg/l. About 56% of the rainy season data and 62% of the dry season data were above the adopted background concentration (50mg/l) for the study area. This could be indicative of exogenic inputs associated with urban activities on the groundwater. The majority of the data exceeding the background concentration were found mostly in the highly active and populated areas including Abakpa, Achara Layout, Uwani, Emene and Coal Camp, and might have been derived probably from leaching of carbonate materials from buildings, cement dust from cement depots.

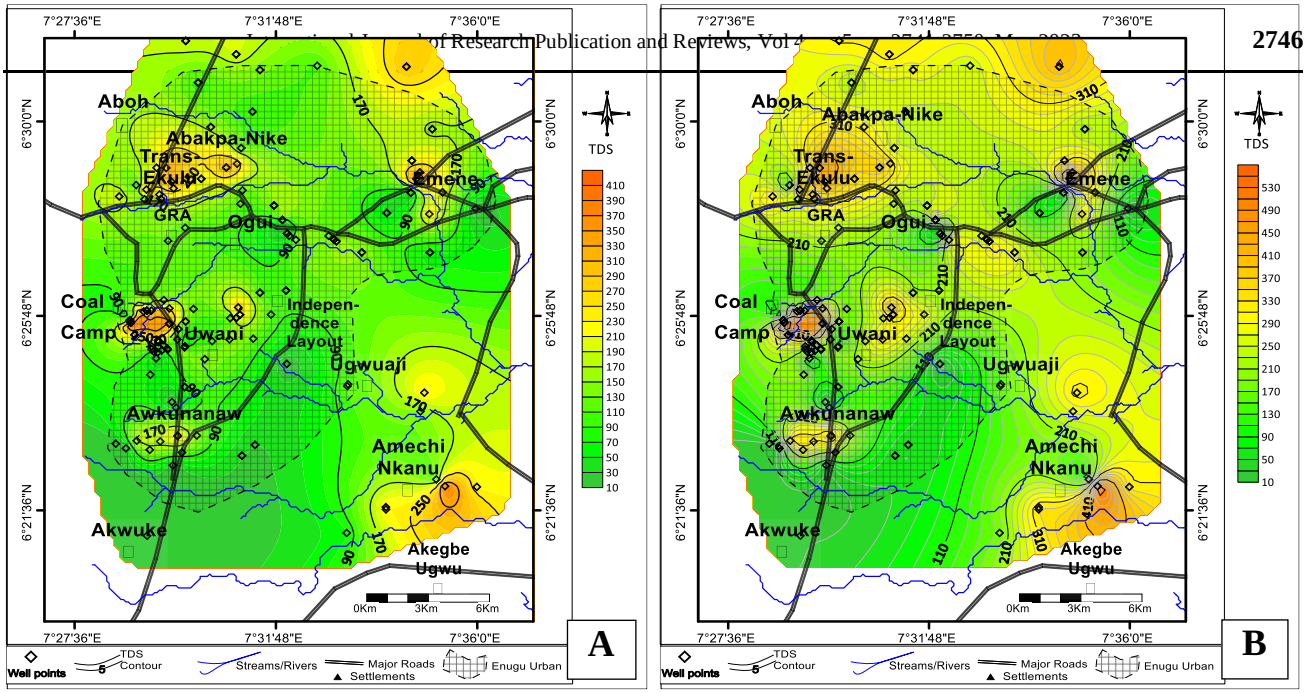

Fig. 6. TDS distribution map of the study area: (A) Rainy season; (B) Dry season

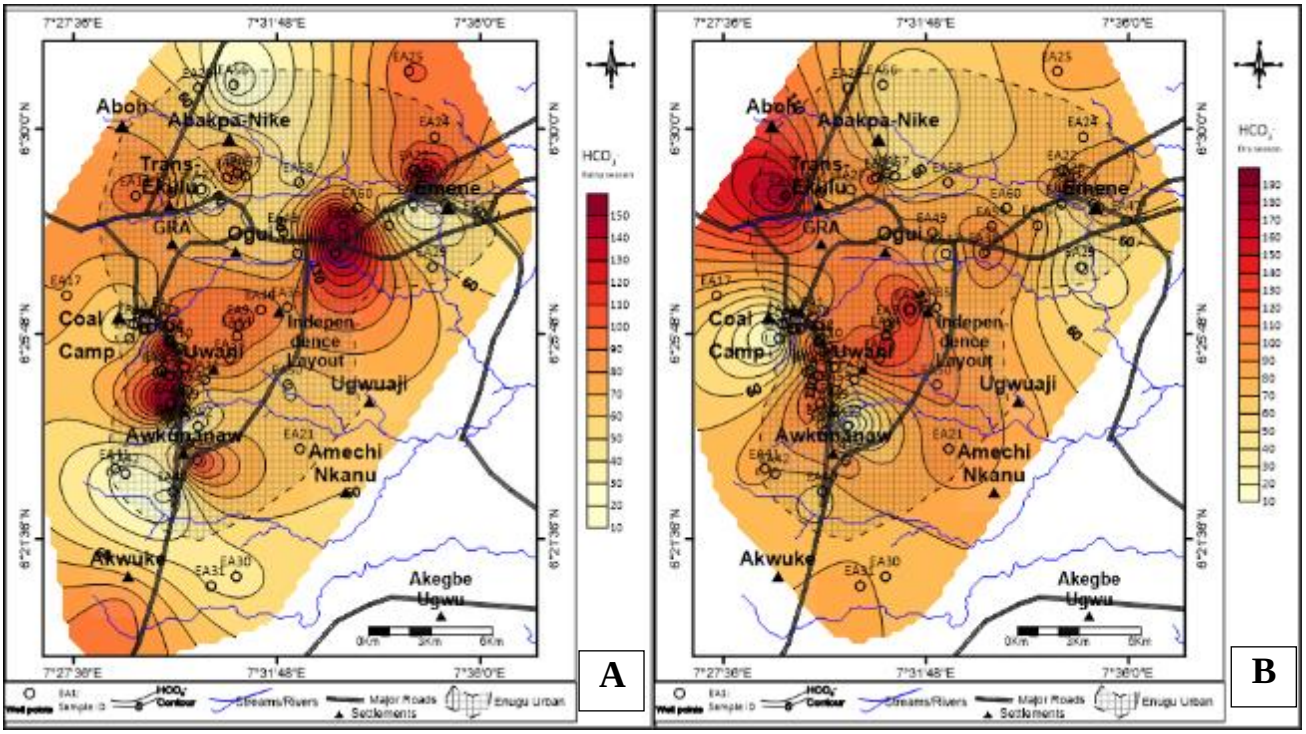

Fig. 7. Bicarbonate (HCO3-) distribution map of the study area (A) Rainy season, (B) Dry season

4.2.5 Sulphate SO_4^{2-} concentration

SO_4^{2-}concentration and distribution are shown in Figures 8a&b. Concentrations range from about 1.2mg/l – 197.8mg/l with a mean of about 33.7mg/l, and standard deviation of 36.26mg/l for the rainy season; and 1.4mg/l – 161.0mg/l with a mean of 31.3mg/l and standard deviation 34.5mg/l for dry season were obtained. There is not much significant difference in the statistical summaries of the concentrations for both seasons. However, the rainy season samples appear to have some isolated higher concentrations over the dry season, and this could be due to some points of transient recharges of the aquifer at the time of sampling during the rains.

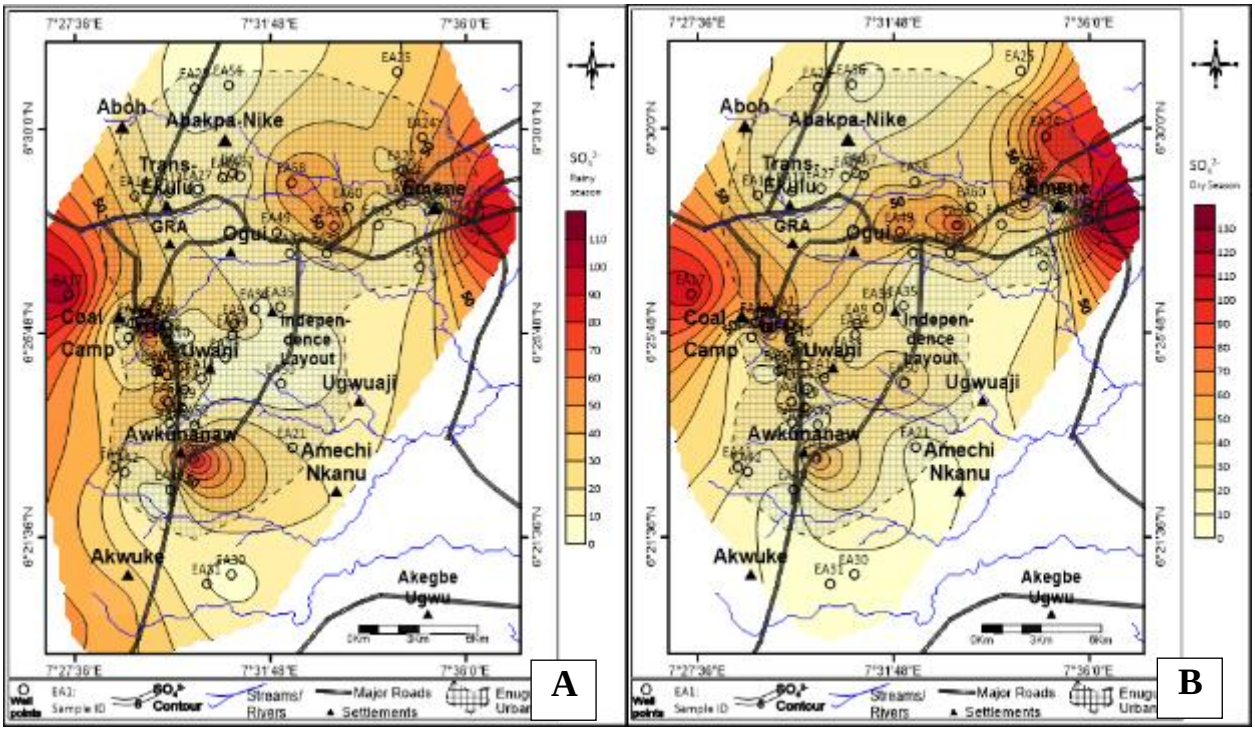

Fig.8 Sulphate ($SO4^{2+}$) distribution map of study area (A) rainy season; (B) dry season

4.2.6 Chloride (Cl^-) Concentration

Figures9a and9b show the spatial distribution of chloride concentration of the two seasons. The result of the analysis shows concentration values range 0.4mg/l – 86.0mg/l with a mean of 25mg/l, and standard deviation of 27.0mg/l; and1.5mg/l – 132.8mg/l with a mean of 37.0mg/l and standard deviation 31.7mg/l respectively for the two seasons. There is a somewhat significant difference in the concentration in both seasons, as evident in the difference in the mean values. Similarly, about 57.4% of the rainy season and80% of the dry season data plotted above 10mg/l were adopted as the background concentration.

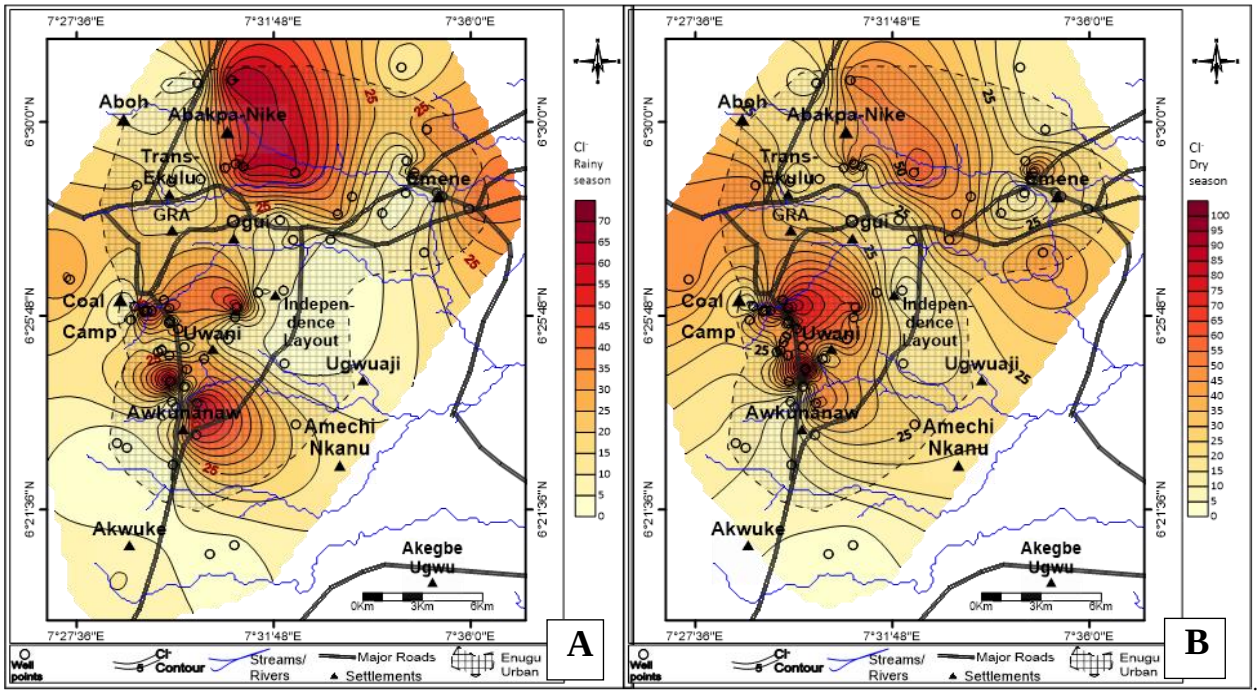

Fig. 9. Chloride ion (Cl^-) distribution map of the study area (A) rainy season, (B) dry season

4.2.7 Sodium Na^+ Concentration Distribution

The range of the Na^+ concentration in the groundwater is between 1mg/l and 155mg/l with a mean of 45.1mg/l, and standard deviation of 36.11mg/l during the rainy season; and 10.3mg/l and 210.3mg/l, with a mean of 63.1mg/l, and standard deviation 36.13in the dry season (Table 1, Fig 10). The observed concentration variations in the study area seem to be due to anthropogenic activities resulting from differences in the urban culture. Isolated high-concentration clusters are identifiable within areas of very high population density and slum activities. About 31 of 61 (50.8%) samples had concentration values exceeding the adopted background concentration (20mg/l) during the rainy season. The dry season result, however, showed a more extensive coalescing of the observed high-concentrationcluster zones, with about 45 (73.8%) samples having concentrations exceeding 20mg/l. Generally, the ranges of concentration for both seasons are within the World Health Organisation's (WHO) permissible limits.

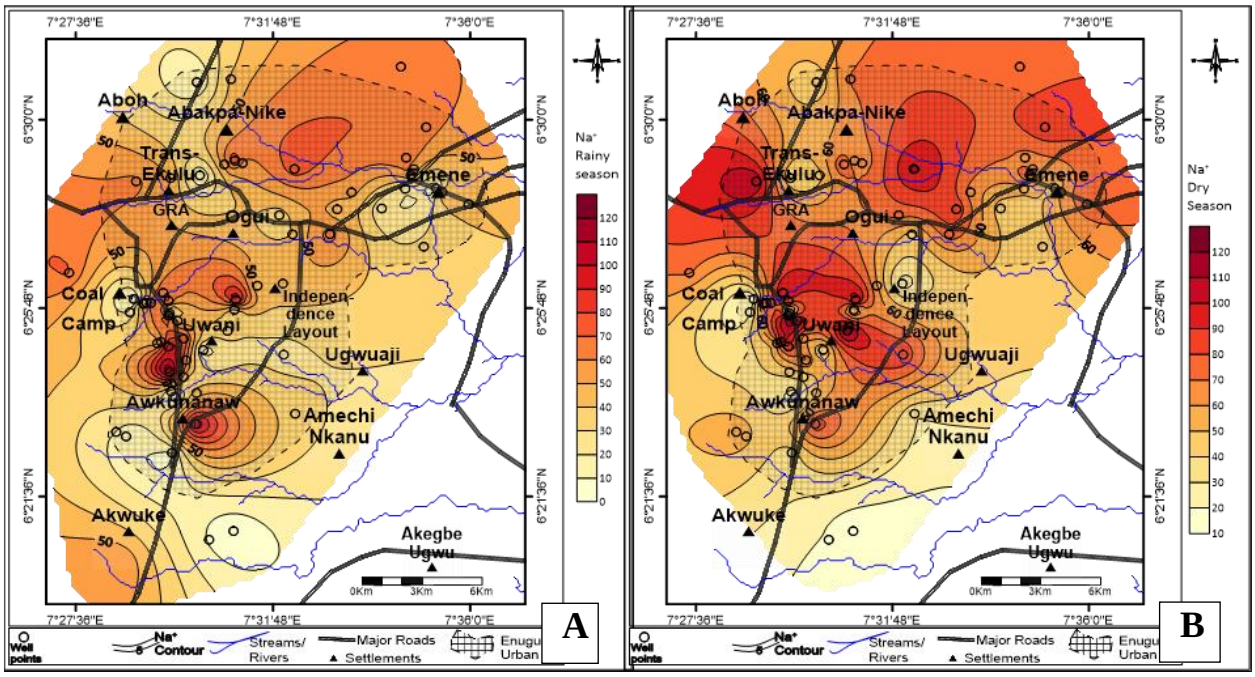

Fig. 10. Sodium (Na^+) distribution map of the study area (A) rainy season, (B) dry season

4.2.8 Calcium Ca^{2+} Concentration Distribution

The valuesof Ca^{2+} in this study vary from 2.4 – 84.17 mg/l with a mean of 16.39mg/l and a standard deviation of 15.01mg/l during the rains (Fig 11a). The dry season (Fig 11b) concentration varied widely between 14.9 – 181.6mg/l with a mean of 67mg/l and a standard deviation of 38.8mg/l. The distribution and trend of the concentration seem to mimic the urban setup of the study area. Few clusters zone of Ca^{2+}, though low concentration, coincides with some major centres associated with different urban activities.The adopted background concentration of Ca^{2+} in this study is taken to be about 10mg/l. This background concentration is indicative of generally low calcium content in the groundwater. Most of the values are below the W.H.O. (2006) recommended limit of 75 mg/l for drinking water except for two samples from around the Emene Industrial Layout.

4.2.9 Total Hardness

The degreeof hardness of the groundwater was determined using the classification by Chadetrik and Arabinda (2011); Durfor and Becker (1964). About 38 of the 61 rainy season samples (or 62%) were soft, 16 samples were moderately hard; 5 samples were hard; and 2 samples were very hard. Similarly, for the dry season samples, about 67% were soft; 25% were moderate hard; 3% were hard and 5% were very hard (Table 2).

Table 2: Degree of total hardness for the analysed groundwater of Enugu (after Durfor and Becker, 1964)

Hardness as CaCO3 (mg/l)	**Water class**	**Rainy Season**		**Dry Season**	
		No. samples	% sample	No. samples	% sample
0 – 60	Soft	38	62	41	67
61 – 120	Moderate hard	16	26	15	25
121 – 180	Hard	5	8	2	3
>181	Very hard	2	3	3	5

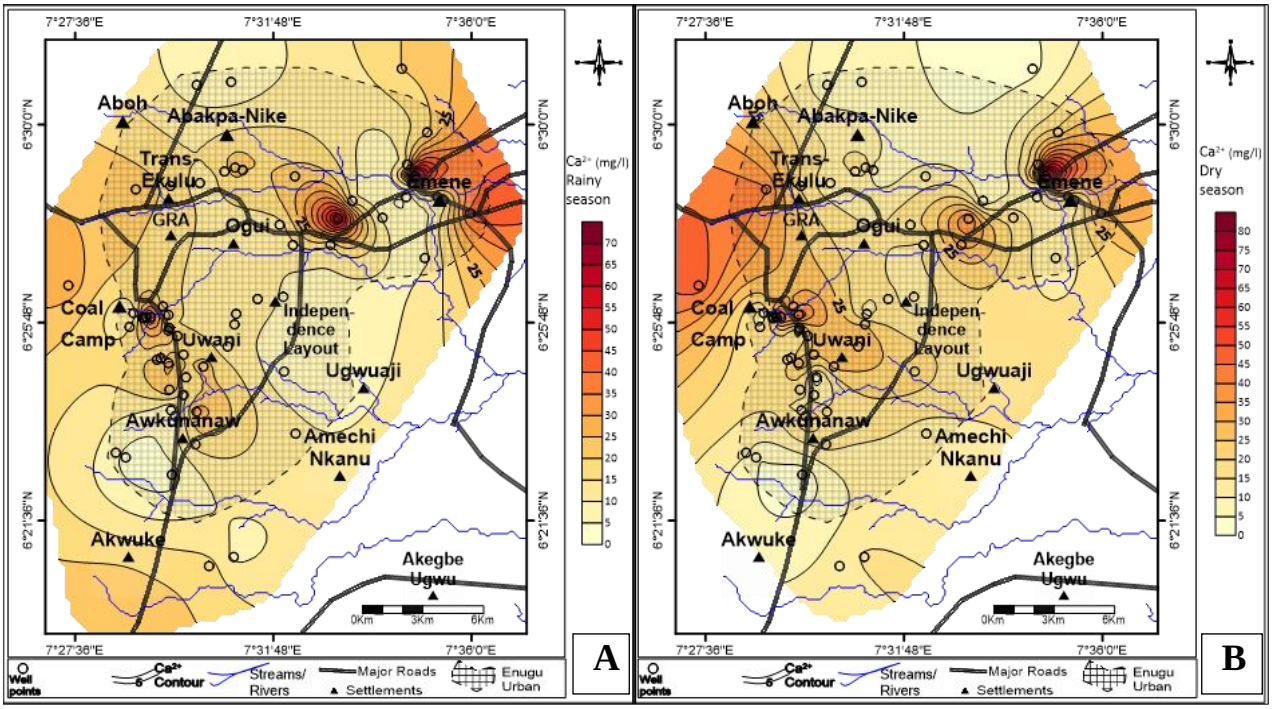

Fig. 11. Calcium distribution map of the study area (A) Rainy season (B) Dry season

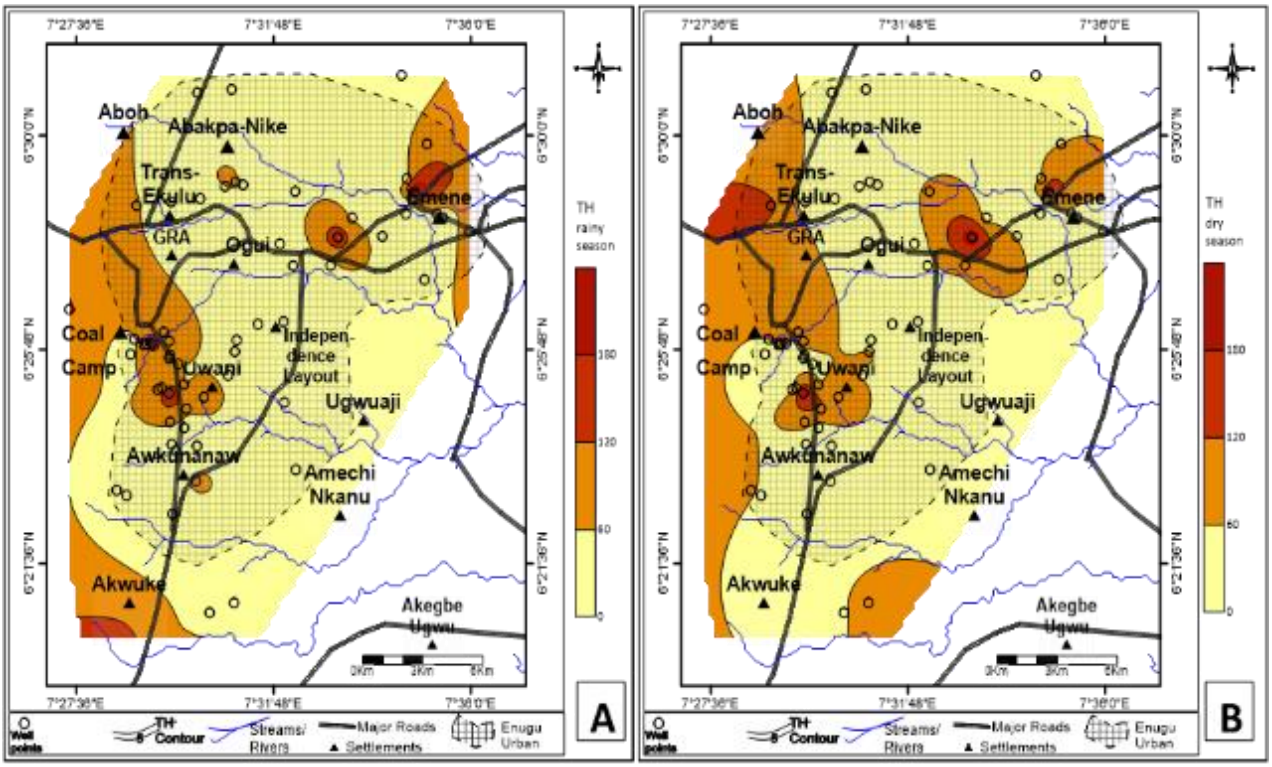

Fig. 12. Hardness as CaCO3 distribution map of the study area: A. Rainy season; B. Dry season

5. Conclusion

The studied groundwater occurs within the Enugu Shales and its weathered regolith composite. The recharge areas coincide with the areas of topographic highs whereas discharges take place naturally downslope and, in the valleys, often as baseflow to the river system of the study area. The concentration of the hydrochemical parameters shows significant geospatial distributions which reflects the urban enviro-metropolitan setup of the area. Results of hydrochemical analyses show the order of abundance of the major ions as Na > K > Ca >Mg and HCO3 > Cl > SO4 > NO3. Hydrochemical

facies of the groundwater samples have been classified into a variety of groundwater types as Na-Ca-HCO_3, Na-Cl-HCO_3, Ca–Mg-HCO_3, Na-Cl, Na-HCO_3 and Ca–Mg-Cl-SO_4 types, with the Na-HCO3 type been most dominant, followed by Na-Cl type. It is indicated that the water types are affected by dissolution process dominated by ion exchange. The relationship of statistically defined clusters of samples to geographic location shows direct interference of the urban activities on the geochemical evolution of groundwater cluster distribution.

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