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Major and trace element compositions in groundwater of Awe area, parts of the middle beneue trough-Northcentral Nigeria

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ABSTRACT

A Hydrogeochemical study was carried out in Awe town and environs. The aim of the research was to determine the major, trace, and rare earth elements content of the waters and their suitability for domestic, agricultural, and industrial uses. Fifteen water sources from hand dug wells, a spring, pond, and boreholes were collected and analyzed. Inductively Coupled Plasma Mass Spectrophotometer was used to analyze the major cations trace elements and rare earth elements. Ion Chromatography was used to detect the anions and bicarbonate by titration method. In an attempt to determine the species of the trace elements in the waters, modeling was carried out using the WATEQ4F. Generally, both the trace and the rare earth elements appear to be low in all the water sources and metal species obtain in the area indicate a dominantly reducing environment. Probable reasons for the low content of the trace elements may be the insolubility of their minerals, complexation, adsorption to clays, and some oxides which has immobilized them. Chlorine/Bromine ratios indicate source of saline water (Cl/Br = 1,961) in the free flowing artesian borehole at Old Awe town to be evaporitic in origin. Four groundwater facies types were obtained in the study area; $Ca+Mg-HCO_3$, $Na+K-HCO_3$, NaCl, and $Mg-SO_4$. Physico-chemical parameter, trace elements, and their species determined in the area indicate that except for the acidity of the water, over 80% of water sources are fresh and soft and therefore good for general domestic uses. Percentage sodium, Sodium Absorbtion Ratios, magnesium hazards, and salinity hazards also show that except for three sample locations, all other samples are within values recommended for agricultural purposes. Industries like Rubber manufacturing, sugar processing, textile mills, dairy product manufacturing, and paper industry can be situated in the study area.

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1. Introduction

Groundwater has been adjudged the purest form of water, especially for drinking purpose, owing to the process of natural purification it undergoes (Todd, 1980). However, because of the interactions between groundwater and rocks during its flow or residency, certain inorganic ions get dissolved from rocks and are added to water. The addition of these ions may increase concentration of certain elements and or deplete others, which may affect the use of the water for domestic, agricultural, and industrial purposes. The World Health Organization has put in place limits for some certain elements in water which should be consumed for the well being of man. Organizations and individuals have also set other limits which should be consumed by different animals and their use to irrigate agricultural lands. The presence and or absence

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of several harmful and or beneficial elements in groundwater are not easily detected either by taste or smell unless they are detected by scientific methods. Hence, the need for groundwater consumed in most rural communities, who do not have access to portable water supply to be subjected to chemical analysis

Awe town is an important Local Government Headquarters in Nassarawa state. The Local Government Area with a population of 88,674 (NPC, 1991) have a very serious water supply problem because of the presence of brines in the area. The Awe Brine field is one of the several isolated brine fields characterizing the Benue Valley of Nigeria. The availability of potable ground water is generally problematic because of their peculiar hydrogeological situations. As a result, water supply can only be easily obtained from rivers, streams, lakes, and other open water bodies which unfortunately, are not only infested by malaria transmitting mosquitoes but also water borne parasites like guinea worm, trypanosomaisis and other related disease-causing parasites (Ofodile, 1976a), but this problem has been slightly overcome by the provision of boreholes in and around the Local Government Areas. The aim of this work was to assess major and trace composition of groundwater in Awe and environs and how this composition has affected, the use of the water by the inhabitants.

2. Description of the Study Site

2.1. Location and geology

The study area is located within the Middle Benue Trough. It lies approximately between Latitudes 8°02′55″N and 8°08′55″N and Longitudes 9°03′E and 9°11′E, with total area of approximately 164 km^2. Villages constituting the study area are Awe, Mahanga, Kyekwura, Minga, Ayere, Jangari-gari, Kuma, Gbagun, Shagbaor, Orkaa, and Sheigba (Figs. 1 and 2)

The Basement Complex rocks and the Asu River Formation are overlain in the study area by the Awe Formation, which appears to be the oldest outcropping sedimentary formation. Its lowermost part, exposed on the Awe Lafia road, indicate a sequence of rapidly alternating thin, fine grained, and cross laminated pinkish sandstone, siltstones, and mudstone (Offodile, 1992). This sequence appears overlain by the more typical transitional, current bedded, flaps, whitish, medium to coarse, felspathic sandstones alternating with shales, crystalline Shelly limestone's, and clay representing the basal parts of the Keana sandstone. The sandstones on the average are 30 cm in thickness and sometimes calcareous. The brines appear to issue from the interbedded shales and the more porous sandstone beds. The sandstone sequence appears to be capped by a thin whitish to milky, high quality limestone bed which is preserved beneath remnant of the overlying more massive sandstones of the Keana Formation.

Elsewhere in the brine area, this basal Keana sandstone appears to have been removed by erosion, more especially along the river channel, thereby exposing the underlying Awe Formation. The formation, presumed from its stratigraphic position, to be Late Albian- Cenomanian in age, is estimated to be about 1,000 m thick (Offodile, 1976a). The transitional beds are very well exposed on the embarkments of the River Bakiabu and its winding tributaries. The Awe formation, as a result, forms an irregular belt round the old town and terminates abruptly against a northwest–southeast fault, which appears to have displaced the Keana Formation on the eastern flanks of the fault. This fault structurally determines the straight course of the River Bakiabu on the western flank of the old town site.

Hemming the outcrop areas of the Awe Formation, along the stream channel are outcrops of the more homogeneous, massive and predominantly crystalline fine, coarse, and pebbly sandstone beds of the Keana Formation (Offodile, 1992). This formation appears to layuncomformably on the Awe Formation, dipping at a smaller angle away to the north, south, and east sides of the core of the anticline.

The beds of the Ezeaku Formation dip away below the new town center now described as "Sabon Gari". The rocks of the Ezeaku Formation, though unexposed in the Sabon Gari area of the brine field, are revealed in excavations in newly dug up hand-dug wells. The sediments consist of thick calcareous shales, micaceous siltstones and fine-to-medium grained sandstones. Its marine origin indicated by the tests of pelecypods and other unidentified marine organisms, distinguishes it from the underlying continental Keana Formation.

The area is endowed with minerals such as salt and brines, lead-Zinc (Pb-Zn sulphides), and Baryte ($BaSO_4$) mineralization amongst others.

2.2. Hydrogeology of the area

The favorable hydrogeological situation in the new township area is no doubt due to the contrasting geological characteristics of the much younger Ezeaku Formation. This, markedly, different hydrogeological condition is confirmed by the resistivity depth probes undertaken across the area, from Awe to Kyekura (Fig. 1). The apparent resistivity values range from 10 Ohm/meter to 100 Ohm/meter showing low value attributed to the effect

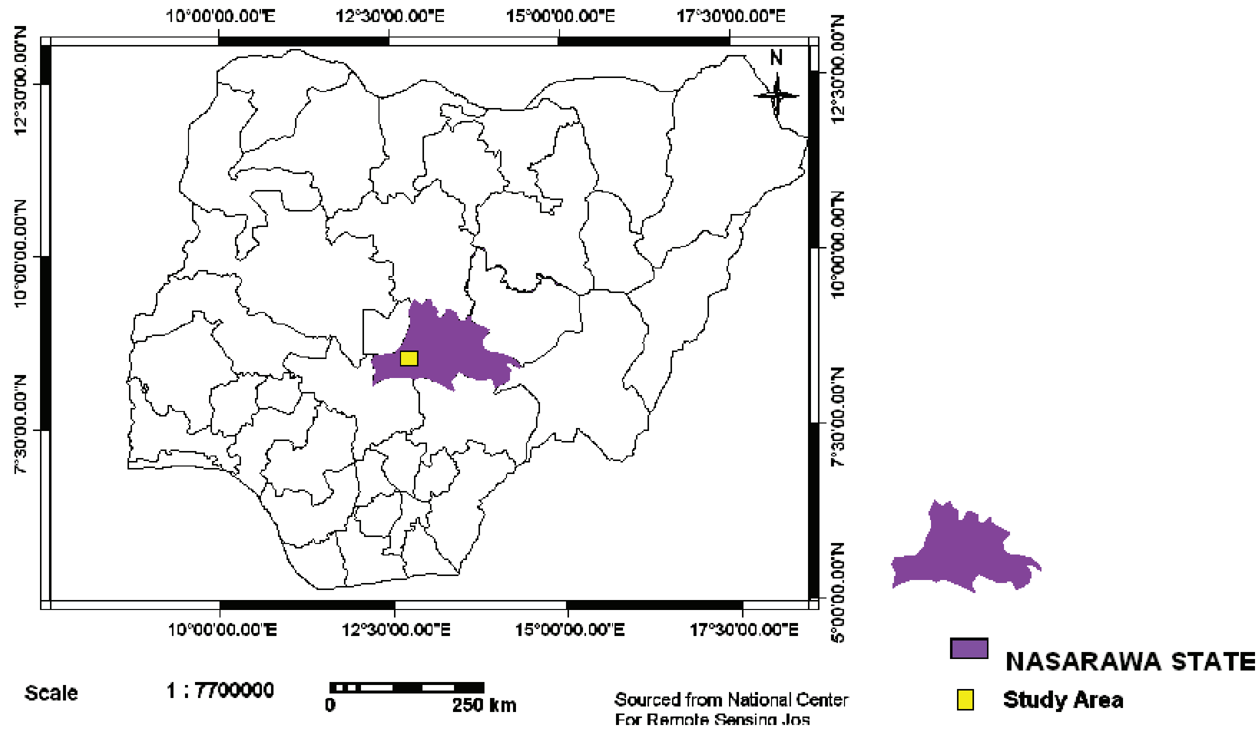

Figure 1. Location of the study area.

of strong brine concentration within fosiliferousshales and porous sandstone of the formation. Southwards, outcrops of fossiliferous limestone and shales overlie the Keana Formation and possibly represent the lower part of the Ezeaku Formation. Eastwards, in the town of Kyekura, some 2–5 km from Awe Township a predominantly sandstone formation was revealed by the survey to be the overlying clay shale-limestone, sandstone beds of the Ezeaku Formation as identified in the new Awe township area. The sandstone formation which from the field indication appears to be the top member of the Ezeaku Formation invariably thickens in the direction of dip, towards the east, and is restricted to the northeast extremity of the area. This situation was confirmed by means of the comprehensive geo-electric survey, together with two boreholes sited on the two of the favorable vertical electrical sounding Location (Offodile, 1992) which gave fairly good yields of 3 l/seconds and 3.3 l/seconds, respectively. The aquiferous sandstone sequence is located at a much higher stratigraphic level than the siliceous Awe Formation and hence devoid of any salinity problem.

3. Methods of Study

3.1. Field sample collection

Groundwater samples were collected from 15 locations in Awe town and environs. The samples include

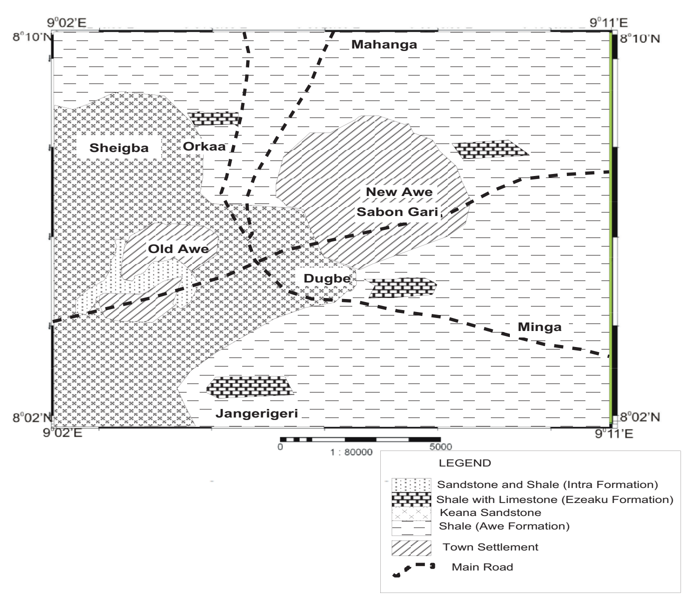

Figure 2. Geology of the study area (Source: Offodile, 1976a).

1 artesian well, 1- open pond, 1- spring, 1- hand dug well, and 11- boreholes (motorized and hand pumps) (Fig. 3).

The sample bottles were first washed with a mixture of acid and distilled water (1% HNO_3) and rinsed again with distilled water and allowed to dry.

Water samples from the boreholes (motorized and hand pump) were pumped for several minutes to avoid

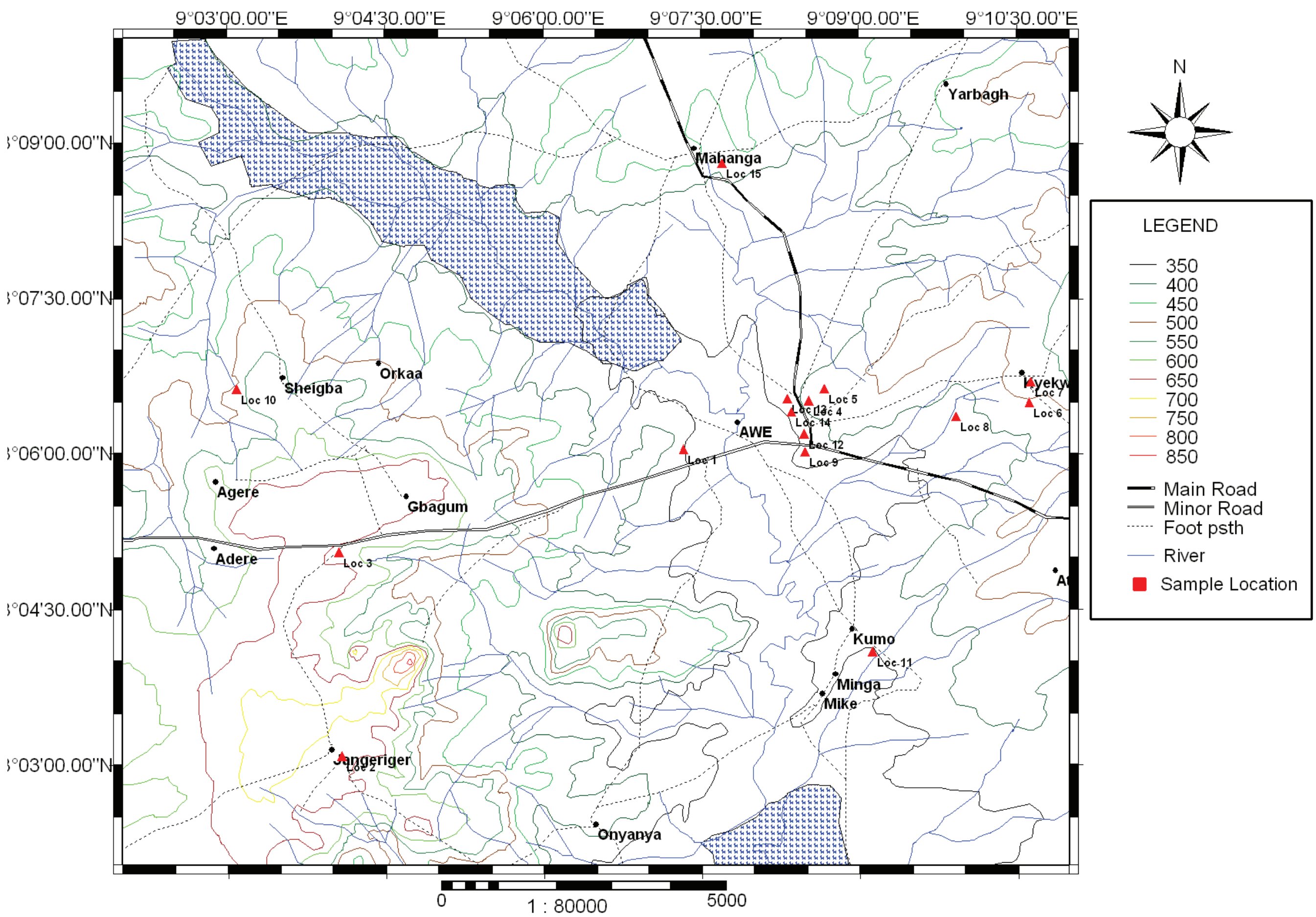

Figure 3. Sample location points.

sampling stagnant water within the pipe. Water from hand dug well was collected using a plastic bucket tied to a rope as suggested by Davies (1994). Two water samples were collected at each location in a 250 ml polyethylene bottle capacity, one of the 250 ml bottle was acidified with concentrated HNO_3 to a pH of < 2. Depth to water level from the hand dug well was measured using a metrictape, while static water levels for the borehole were obtained from Reports of Geo-explore Nigeria ltd

Determination of pH, temperature, and conductivity were carried out using the Oakton pH/ temperature /MV meter. This was done by dipping the meter into the sampling bucket immediately after collection and the reading taken after minutes when the value has stabilized.

3.2. Sample preparation and preservation

The polyethylene bottles containing all the water samples were wrapped and sealed after adding two drops of concentrated nitric acid. Prior to analyses, the water samples were filtered to remove suspended particles in the water. Samples were labeled properly, according to nature of sample, date of collection and sample number. Samples were kept in the refrigerator at room temperature.

3.3. Laboratory analysis

Concentration of major cations, anions, and trace elements were analyzed at the Acme Analytical Laboratories Vancouver Canada.

The combined inductively coupled plasma atomic emission spectrophotometer/inductively coupled plasma mass spectrophotometer were used to analyze major cations and trace elements, Ion Chromatography was used to detect the anions and bicarbonate by titration method.

3.4. Statistical analysis, modeling of water types and speciation

The data were statistically processed with the Statistical Package for the Social Sciences version 16 software for windows to evaluate the relationship among the variables and the behaviors of the elements in the hydro geological environment, the water type, total dissolved solids (TDS), total hardness was modeled with the AQqA software. Numerous computer software programs are in used today to facilitate speciation of dissolved ions among which are MINTEQA2 (USEPA) (Langmuir, 1971) PHREEQC (Parkhaust and Apello, 1999), The Geochemist's Workbench (Bethke, 2002) and WATEQ4F (Ball and Nordstrum, 2004). The speciation of dissolved ions was carried out by the WATEQ4F.

4. Results and Discussion

4.1. Physical and chemical parameters in the waters of the study area

The physical and major cations and anions chemical composition of the ions in the water samples are presented in (Table 1). Table 2 shows the mean and standard deviation of the major cations and anions. Hydrogen ion concentration (pH) in the Awe water samples ranges from 4.69 to 6.57 indicating acidic to slightly acidic groundwater in the area. Electrical conductivity ranges from 5.04 to 10,571 µhmo/cm and Total Dissolved Solids from 2.5 to 9,160 ppm with 95% of the waters being fresh and only 5% as saline. Total hardness ranges from 1.17 to 513 ppm with over 95% of the water in the area classified as soft and the artesian borehole classified as very hard. Calcium concentration in the water samples ranges from 6.67 to 154.70 ppm. Magnesium concentration ranges from 1.24 to 54.84 ppm. Sodium concentration ranges from 7.92 to 3,346 ppm. Potassium contents ranges from 1.85 to 79 ppm. Bicarbonate ion ranges from 24.4 to 378.2 ppm. Chloride concentration ranges from 2.3 to 5,200 ppm. Except for sample Loc 1 and 6, all the other locations have values below 100 ppm of chloride. Higher values of all the parameters are encountered in the artesian borehole located in Old Awe town. This may probably be local geochemical anomaly.

4.2. The trace elements and equilibrium speciation

Concentration of the trace elements in the waters is presented in Table 3. Arsenic ranges from < 0.5 to 17 ppb. All the samples have H_3AsO_3 aq as the dominant species (Table 4). Cadmium and mercury are virtually absent in almost all the sources except for location 7, 11 and 13 with cadmium content of 0.23, 0.20, and 0.40 ppb. The dominant species in which cadmium occur in the waters is as Cd^{+2} and only (Loc 1, 2, 4, 7, and 9) have $CdCl^{+1}$ and $CdCl_2$°aq. Only 5 out of the 15 water samples show the presence of iron and the remaining sources are below detection limit. Generally, iron occurs as Fe^{+2} and $FeHCO_3^{+1}$ in all the samples, but the Fe^{+2} dominate. Manganese ranges from 3.24 to 386.82 ppb with Mn^{+2} and $MnHCO_3^{+1}$ as the dominant species except for (Loc 1) which has $MnCl^{+1}$. Zinc ranges from 1.80 to 788.80 ppb and dominant species are the Zn^{+2} and $ZnHCO_3^{+1}$. Three locations (1, 5, and 10) have led below the detection limit, other, sources have led ranging from 0.10 to 9.00 ppb and all the locations have the $PbCO_3$°aq and $PbHCO_3^{+1}$ rather than the Pb^{+2} as the dominant species. Sample location 1, however, has $PbCl^{+1}$ although the Middle Benue Trough is known for Lead and Zinc Sulphide and Baryte mineralization, content of their elements in the waters of the study area are low. However, Lar and Sallau (2005) recorded presence of Cu, Zn, Pb, As and S in the waters of the Kaena area with higher values in the surface water sources. Chromium ranges from <0.5 to 13 ppb with dominantly the $CrOH^{+2}$ and Cr $(OH)_2^{+1}$ in all the waters. Uranium, however, show variation in the species it occurs in some of the water locations. In location 1, it occurs as $UO_2(CO_3)_2^{-2}$, but the species $UO_2CO_3^0$ and $UO_2(CO_3)_2^{-2}$ occur in (location 2, 3, 5, 9, 12, and 14). $UO_2^1$and $UO_2CO_3^0$ in (location 4, 6, 11, and 13). The species $UO_2(CO_3)_3^{-4}$ occur only in location 15. It appears that most of the metal species obtain in the area indicates a dominantly reducing environment. With respect to saturation index to some of the minerals in the waters, 70% of the waters are oversaturated with uraninite (c), this may probably be uranium (IV) which has formed oxide phases. Uranium IV is insoluble and may be the reason for its low concentration in the waters. Also, more than 80% of the waters are over saturated with respect to Cr_2O_3 and $FeCr_2O_4$, only few of the samples show oversaturation with respect to gibbsite, diaspore, and goethite. The probable reason for the low content of the trace elements may be the insolubility of their minerals, complexation, adsorption to organic materials, clays and some oxides which has immobilized them.

4.3. Water types in the study area

Sixty six percent of the waters in the area are of the alkaline earth metals with bicarbonate as the major anion composition indicating composition of meteoric water origin. The remaining 26% is dominated by the alkalies, of which 13% each are sodium bicarbonate water type and the other dominantly sodium chloride water type reflecting the composition of sea water. One sample representing 7%%, however, has a composition of magnesium and sulphate. Four groundwater facies are, therefore, obtained in the study area; Ca+Mg-HCO_3, Na+K-HCO_3, NaCl, and Mg-SO_4 (Fig. 4).

4.4. Source of the brine water in the Awe area

The origin of the brines in the Benue trough is still debatable. While pioneer workers, (Cartchley and Jones, 1965) are of the view that the brines were due

Table 1. Chemical analysis of groundwater sample collected from Awe area.

										Elements												
LOC	Coord	Source	Well depth (M)	Elev (M)	T°C	pH	TDS	EC	TH	Na)	K	Ca	Mg	F	Cl	SO_4	HCO_3	SAR	Cl/Br	Ca/ mg	Mg Ratio	% Na	Kelley ratio
LOC 1	09°07.771′ 08°06.085′	BH	Artesian water	281	70	5.96	313.32	483.14	369.07	3,346	79	154.7	30.3	0.968	5,200	9.6	305	64.14	1,961	5	24.4	92.2	14.19
LOC 2	09°04.018′ 08°03.069	BH	19	239	27	5.46	17.987	34.91	2.3	14.17	7.43	58.55	54.84	0.239	52	9.9	244	0.27	912	1	60.69	7.45	0.08
LOC 3	09°04.020′ 08°05.092′	BH	15	215	27	5.55	9.95	21.19	2.41	16.64	5.79	38.79	16.45	0.242	3.9	1	171	0.56	65	2	41.14	17.3	0.22
LOC 4	09°08.762′ 08°06.455′	BH	15	153	27	4.69	6.07	13.7	3.41	22.83	8.9	10.31	4.48	0.121	2.7	12	110	1.49	208	2	41.72	13.5	1.12
LOC 5	09°08.426′ 08°06.700′	BH	10	145	28	6.15	18.56	37.17	2.28	37.33	2.45	115	35.93	0.4	42	26	195	0.78	519	3	34	15.6	0.19
LOC 6	09°10.57′ 08°06.686′	BH	18	167	28	4.84	18.23	37.43	14.61	74.67	62.46	104.9	26.36	0.057	130	36	48.8	1.68	783	4	29.29	26.4	0.44
LOC 7	09°10.482′ 08°06.664′	Sp	-	170	25	4.76	2.5	5.04	1.17	8.61	2.43	12.24	1.46	0.037	16	4.3	24.4	0.62	119	8	16.42	32	0.51
LOC 8	09°09.130′ 08°06.664′	BH	18	165	28	6.23	15.58	32.01	2.15	18.05	1.85	92.74	19.4	0.285	12	24	232	0.44	522	5	25.62	11.1	0.13
LOC 9	09°O8.709′ 08°06.716′	BH	17	145	27	5.93	32.56	67.3	15.03	136.7	2.93	140.3	50.61	0.276	5.4	230	317	2.51	284	3	37.29	34.5	0.53
LOC 10	09°03.020′ 08°06.716′	BH	18	161	29	6.5	23.97	52.11	11.6	101.9	6.06	82.8	33.32	0.18	Nil	Nil	378	2.38	-	2	39.88	38.6	0.64
LOC 11	09°09.147′ 08°04.130′	Pond	-	134	25	5.22	3.84	8.44	2.03	10.85	8.1	12.53	1.55	0.06	11	3.2	61	0.77	67	8	16.89	32.9	0.63
LOC 12	09°08.73′ 08°06.138′	HW	7.3	145	25	6.02	4.03	8.71	1.42	7.92	5.47	18.41	3.16	0.142	5.7	9	61	0.45	184	6	22.05	20.7	0.29
LOC 13	09°08.560′ 08°06.487′	BH	15	158	26	4.72	4.95	10.87	5.13	37.17	11	6.67	1.24	0.077	18	64	24.4	3.45	529	5	23.45	69.2	3.7
LOC 14 New Awe Town	009°8.780′ 08°06.646′	BH	15	159	26	5.44	8.07	18.02	4.2	33.89	4.89	16.69	7.92	0.226	2.3	3.2	146	2.7	235	2	90.4	14.3	0.17
LOC 15 (Mah-anga)	009°7.383′ N08°08.957′	BH	19	-	25	6.57	13.91	30.01	6.88	61.98	2.1	50.86	11.98	0.144	16	16	207	2.02	470	4	27.96	42.9	0.76

SAR: Sodium Absorption Ratio

Table 2. Minimum, maximum mean and standard deviation for major and minor element in the study area.

Element	Minimum	Maximum	Mean	Standard deviation
Temp	25	70	29.53	11.27
pH	4.69	6.57	5.60	0.65
TDS	2.50	313.32	32.81	78.04
EC	5.04	483.14	57.33	119.09
TH	1.17	369.07	29.71	94.00
Ca	6.67	154.84	61.03	50.72
Mg	1.24	54.84	19.91	17.94
Na	7.94	3,346	261.91	854.01
K	1.85	79.00	14.06	23.38
HCO_3	24.40	378.20	168.80	113.25
Cl	2.30	5,200	368.80	1,336.91
SO_4	0.00	230	29.88	57.86
F	0.04	0.96	0.23	0.23
Br	0.01	2.65	0.23	0.67

to salt impregnations in the pore spaces in the sands, Phoenix and Kiser (1966) linked them to evaporitic origin with a possibility of the existence of a salt dome beneath the Cretaceous sediments. Recent studies (Offodile, 1976b; Tijani, 2004; Tijani et al., 1996) gave different suggestion to the origin of the brines. While Offodile was of the view that the brines are magmatic in origin; Tijani suggested the origin of the brines in Ogoja (Lower Benue Trough) area to be of marine origin and that of the Middle Benue Trough based on ionic ratios, Na–Cl–Br systematic and divalent cations suggest two likely sources of primary salinity: a fossil seawater source and dissolution of halite for the brine. Cl/Br ratio calculated for water samples in the Awe area (Table 4), shows majority of the values fall between those which are of marine in origin and those of domestic sewage category, However, in the Authors opinion, since domestic activities is quite limited in the Awe area to have contributed this large amount of chlorine/bromine ratio, contribution may probably be the result of mixing between the saline water and that of meteoric water origin. The artesian borehole with chlorine/bromine ratio value of 1,961 mg/l, fall within category of water affected by the dissolution of halite according to Davis et al., 1998, 2001). Here, we are of the opinion that, the origin of the brine may be evaporitic in origin with a possibility of the existence of a salt dome beneath the Cretaceous sediments as suggested by Cartchley and Jones (1965).

Table 3. Trace elements composition of Awe and environs.

LOC	Coord.	Source	Fe	Mn	Zn	Sr	Br	Co	Cr	Cu	Hg	Li	As	Al	B	Be	Cd	Mo	Ni	Pd
LOC 1	09°07.771′08°06.085′	BH	0.1	0.1	0.01	9.87	2.65	0.00002	0.012	0.001	0.001	1.38	0.017	0.001	0.219	0.00005	0.00005	0.001	0.0002	0.002
LOC 2	09°04.018′08°03.069	BH	0.01	0	0.79	0.64	0.06	0.00028	0.0036	0.0032	0.001	0.001	0.0006	0.005	0.00005	0.00005	0.00005	0.0003	0.0013	0.0002
LOC 3	09°04.020′ N08°05.092′	BH	0.01	0.38	2.54	0.15	0.06	0.00058	0.0047	0.0004	0.0001	0.0079	0.00005	0.009	0.00005	0.00005	0.00005	0.0001	0.0005	0.0002
LOC 4	09°08.762′ 08°06.455′	BH	0.01	0.16	0.03	0.1	0.01	0.0022	0.00005	0.001	0.0001	0.0042	0.00005	0.007	0.007	0.00038	0.00005	0.0001	0.0031	0.0002
LOC 5	09°08.426′08°06.700′	BH	0.01	0.06	0.01	0.4	0.1	0.00002	0.0111	0.0007	0.00001	0.0338	0.0014	0.004	0.009	0.00005	0.00005	0.0008	0.0017	0.0002
LOC 6	09° 10.57′08°06.686′	BH	1.87	0.03	0.11	1.1	0.17	0.00099	0.00005	0.01	0.0001	0.0014	0.0011	0.023	0.00005	0.00007	0.00005	0.0001	0.0031	0.0002
LOC 7	09°10.482′08°06.664′	Sp	0.41	0.07	0.05	0.07	0.13	0.0016	0.00005	0.0029	0.0001	0.0021	0.00005	0.042	0.006	0.00005	0.00023	0.0001	0.0017	0.0002
LOC 8	09°09.130′ 08°06.664′	BH	0.01	0.32	0.22	0.2	0.02	0.00002	0.0058	0.0005	0.0001	0.0063	0.00005	0.002	0.006	0.00005	0.00005	0.0006	0.0002	0.0002
LOC 9	009°08.709′ 08°06.716′	BH	0.01	0.12	1.71	1.5	0.02	0.00004	0.0131	0.0012	0.0001	0.1047	0.00005	0.004	0.028	0.00005	0.00005	0.0004	0.0002	0.0002
LOC 10	009°03.020′ 08°06.716′	BH	0.01	0.08	0	0.82	0.02	0.00002	0.0131	0.0005	0.0001	0.0693	0.00005	0.003	0.023	0.00007	0.00005	0.0003	0.0002	0.0002
LOC 11	009°09.147′ 08°04.130′	Pond	0.516	0.15	0.06	0.06	0.16	0.00098	0.00005	0.0028	0.0001	0.0009	0.00005	0.056	0.008	0.0001	0.0002	0.0001	0.0012	0.0002
LOC 12	009°08.73′ 08°06.138′	HW	0.05	0.08	0.02	0.08	0.03	0.0003	0.00005	0.0014	0.0001	0.001	0.0031	0.291	0.007	0.00014	0.00005	0.0003	0.007	0.0002
LOC 13	09°08.560′ 08°06.487′	BH	0.1	0.06	0.2	0.05	0.03	0.00855	0.00005	0.0029	0.0001	0.0016	0.0007	0.027	0.013	0.00138	0.0004	0.0001	0.0129	0.0002
LOC 14	009°08.780′ 08°06.646′	BH	0.01	0.39	0.06	0.05	0.02	0.004	0.00005	3E-05	0.0001	0.0049	0.00005	0.008	0.009	0.00017	0.00005	0.0001	0.0051	0.0002
LOC 15	009°07.383′ 08°08.957′	BH	0.01	0.14	0.02	0.67	0.03	0.017	0.00005	0.0048	0.0001	0.0279	0.00005	0.024	0.019	0.00007	0.00005	0.0012	0.0002	0.0002

Table 4. Species of some trace element in groundwater of Awe area.

Loc	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
As 0(total)															
$H_2AsO_3^{-1}$	0.37	0.03	0.04		0.13			0.16	0.09	0.30	0.01	0.08		0.02	0.31
$H_3AsO_3^0$ aq	85.71	99.97	99.96	100.0	99.73	99.99	100.0	99.59	99.89	97.57	99.99	99.89	100.0	99.98	97.89
$HAsO_4^{-2}$	2.39				0.02			0.04	0.02	0.58		0.03			0.56
$H_2AsO_4^{-2}$	11.52				0.12			0.21		1.55					1.33
Cd^{+2}	11.24	86.43	98.25	94.37	81.08	73.67	82.98	91.52	92.33	89.05	81.85	92.83	88.66	94.68	90.27
$CdBr^{+1}$	12.15	4.18	0.40	1.38	6.53	9.82	13.98	2.01	1.19	1.62	15.75	3.66	3.48	1.68	2.93
$CdBr2^0$ aq	1.20	0.01			0.03	0.07	0.10				0.14				
$CdCl^{+1}$	52.25	6.12	0.27	0.62	7.24	14.82	1.94	1.65	0.53	1.81	1.38	0.85	2.65	0.57	2.08
$CdCl_2^0$ aq	18.96	0.03			0.04	0.19									
$CdCl_3^{-1}$	4.02														
$CdHCO_3^{+1}$	0.14	2.95	1.05	2.74	3.90	0.64	0.62	3.75	2.36	7.46	1.33	1.75	0.43	2.87	4.01
$CdOHCl^0$ aq	0.03														
$CdSO_4^0$		0.27	0.02	0.88	1.15	0.78	0.37	1.04	3.54		0.23	0.90	4.64	0.19	0.06
Cr (total)															
Cr^{+3}	1.78	2.95	3.18	11.48	0.32	12.70	9.21	0.26	1.16	0.09	3.50	0.35	10.74	2.38	0.06
$CrOH^{+2}$	78.88	87.09	86.93	81.92	57.01	84.30	87.84	51.84	76.50	31.19	89.98	62.00	84.65	86.60	25.60
$Cr(OH)_2^{+1}$	13.79	7.55	7.82	1.49	27.38	1.60	2.03	29.04	16.55	31.53	5.76	26.29	1.68	8.36	31.02
$Cr(OH)_3^0$ aq	3.54	0.79	0.94	0.03	14.75	0.04	0.05	18.57	4.79	37.15	0.38	11.17	0.03	0.89	43.27
$CrCl^{+2}$	0.01														
CrF^{+2}	1.99	1.57	1.12	4.96	0.40	1.13	0.80	0.21	0.50	0.05	0.33	0.08	2.15	1.74	0.02
$Cr_2(OH)_2^{+4}$			0.01						0.03						
Fe (total)															
Fe^{+2}	90.88	89.97	96.69	91.07	85.84	96.40	97.40	87.74	90.41	78.45	94.87	93.77	95.05	91.12	86.87
$FeCl^+$	5.36	0.09			0.11	0.28	0.03	0.02		0.02	0.02	0.01	0.04		0.03
$FeCO3^0$ aq	0.04	0.03	0.01		0.19		2.29	0.19	0.06	0.67		0.06		0.02	0.43
FeF^+	0.01														
$FeHCO3^+$	3.49	9.72	3.28	8.38	13.04	2.67		11.37	7.32	20.79	4.93	5.58	1.81	8.73	12.21
$FeOH^+$	0.17				0.03			0.04	0.01	0.06		0.02			0.06
$FeSO4^0$ aq	0.05	0.18		0.54	0.74	0.65	0.27	0.64	2.19		0.17	0.56	3.11	0.11	0.39
Mn^{+2}	82.21	90.72	97.01	91.88	86.53	96.15	97.58	88.42	91.02	79.04	95.32	94.21	93.15	91.93	87.16
$MnCl^{+1}$	14.31	0.27	0.01	0.03	0.33	0.82	0.10	0.07	0.02	0.07	0.07	0.04	0.12	0.02	0.09
$MnCl_2^0$ aq	0.47														
$MnCl_3^{-1}$	0.02														
$MnCO_3^0$ aq	0.11	0.09	0.03	0.01	0.63	2.37		0.65	0.19	2.22	0.03	0.02		0.03	1.43
$MnHCO_3^{+1}$	2.81	8.74	2.93	7.53	11.72		2.05	10.21	6.57	18.67	4.41	4.99	1.61	7.85	10.92
$MnOH^{+1}$	0.02														
$MnSO4^0$ aq	0.05	0.18		0.54	0.79	0.65	0.27	0.64	2.21		0.24	0.56	3.11	0.11	0.40
Pb^{+2}	13.55	46.86	73.90	55.81	25.58	71.41	77.92	27.07	45.92	10.72	63.78	50.32	77.55	50.83	17.29
$PbBr^{+1}$	13.99	0.94	0.12	0.34	0.87	4.03	5.22	0.25	0.25	0.08	4.93	0.79	1.24	0.37	0.22
$PbBr_2^0$ aq	0.05														
$PbCl^{+1}$	60.77	1.44	0.09	0.16	1.01	6.38	0.76	0.22	0.11	0.10	0.45	0.19	0.99	0.13	0.17
$PbCl_2^0$ aq	3.50					0.03									

(Continued)

Loc	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
$PbCl_3^{-1}$	0.66														
$PbCl_4^{-1}$	0.14														
$PbCO_3^0$ aq	3.90	10.10	5.73	1.88	40.49	0.95	0.78	43.46	20.42	65.99	4.00	23.20	0.57	9.63	61.89
$PbHCO_3^{+1}$	4.13	40.22	19.89	40.77	30.87	15.69	14.56	27.87	29.53	22.57	26.32	23.77	11.71	38.68	19.39
$PbOH^{+1}$	0.09	0.15	0.24	0.04	0.45	0.05	0.07	0.55	0.36	0.39	0.14	0.77	0.06	0.18	0.76
$PbSO_4^0$ aq	0.01	0.28	0.02	1.00	0.70	1.45	0.68	0.59	3.39		0.36	0.95	7.87	0.19	0.25
U (total)															
UO_2^{+1}	0.39	11.15	26.15	59.43	0.57	69.72	77.42	0.49	2.22	0.03	47.91	8.01	77.97	17.89	0.11
UO_2^{+2}	0.07	0.68	1.89	2.94	0.03	4.49	3.40	0.03	0.16		2.19	0.35	3.70	0.92	
$UO_2CO_3^0$ aq	7.44	39.84	39.85	26.84	13.48		9.14	12.03	19.35	2.85	36.98	43.23	7.37	46.99	5.64
$UO_2(CO_3)_2^{-2}$	89.42	45.65	26.60	2.69	82.50	16.37	0.21	83.19	73.47	81.71	6.05	45.49	0.15	30.55	82.93
$UO_2(CO_3)_3^{-4}$	0.83	0.49	0.26		3.13	1.31		3.78	4.05	15.53		0.25		0.14	11.22
UO_2F^{+1}	0.12	0.41	0.85	1.25	0.04	0.47	0.28	0.02	0.09		0.20	0.07	0.73	0.69	
UO_2OH^{+1}	1.73	0.78	2.25		0.21	1.27		0.22	0.46	0.03		1.74	0.92	1.11	0.08
$U(OH)_3^{+1}$		0.01	0.03	0.46		0.05	0.56				0.12		0.59	003	
$U(OH)_4^0$		0.96	2.10	5.54	0.05	5.72	7.97	0.04	0.11		4.86	0.83	7.59	1.69	0.11
$UO_2SO_4^0$				0.14		0.25	0.77				0.03	0.02	0.97		
Zn^{+2}	55.98	87.44	95.78	88.96	81.59	95.21	96.67	83.81	87.77	70.92	93.51	91.80	93.65	88.90	81.42
$ZnBr^{+1}$	0.13				0.01	0.02	0.03				0.03				
$ZnCl^{+1}$	36.10	0.19		0.02	0.23	0.61	0.06	0.05	0.02	0.05	0.04	0.49	0.08	0.02	0.05
$ZnCl_2^0$ aq	3.33														
$ZnCl_3^{-1}$	0.88														
$ZnCl_4^{-2}$	0.20														
$ZnCO_3^0$	0.19	0.22	0.09	0.03	1.48	0.01	0.01	1.54	0.45	5.01	0.07	0.02		0.19	3.35
ZnF^{+1}	0.02				0.01										
$ZnHCO_3^{+1}$	2.71	11.90	4.09	10.30	15.61	3.31	2.86	13.68	8.95	23.66	6.12	6.89	2.24	10.72	14.41
$ZnOH^{+1}$	0.39	0.02	0.02		0.10			0.12	0.05	0.20	0.01	0.08		0.02	0.20
$ZnOHCl^0$ aq	0.05														
$ZnSO4^0$ aq	0.03	0.22	0.01	0.68	0.95	0.82	0.35	0.78	2.74		0.22	0.72	3.99	0.14	0.49

5. Water Quality in the Study Area

5.1. Domestic uses

Groundwater use in the area is largely for drinking and laundry purposes. However, recently, the use of the saline artesian borehole has been accorded balenological consideration.

With hydrogen ion concentration (pH) in the Awe water sample ranging from 4.69 to 6.57 with a mean value of 5.6, 87% of the water samples collected fall below the World Health Organisation 2004 Maximum (6.5–8.5) for human consumption. However, all other physical parameters except for the artesian borehole (Loc 1) have values within the World Health Organisatin Standard for drinking purposes. Trace elements content in the waters indicates that harmful element like, Pb, As, Cu, Cr, and Hg are all bellow the World Health Organization Maximum permissible limit and none of the species type is of the harmful type.With over 90% of the waters in the Awe area classified as soft, the waters have been found to be excellent with respect to laundry purposes. Laundry activities can be accomplished with little use of detergent. Stains of bath tubs, cutleries and kitchen sinks caused by hard water may probably be virtually absent owing to the softness of the waters.

5.2. Agricultural uses

With regards to the Total Dissolved Solid content of the waters in the area of less than 1,000 ppm, the water is considered satisfactory for the raising of all livestock as recommended by Jewell (1972). Classification of groundwater samples with respect to percentage

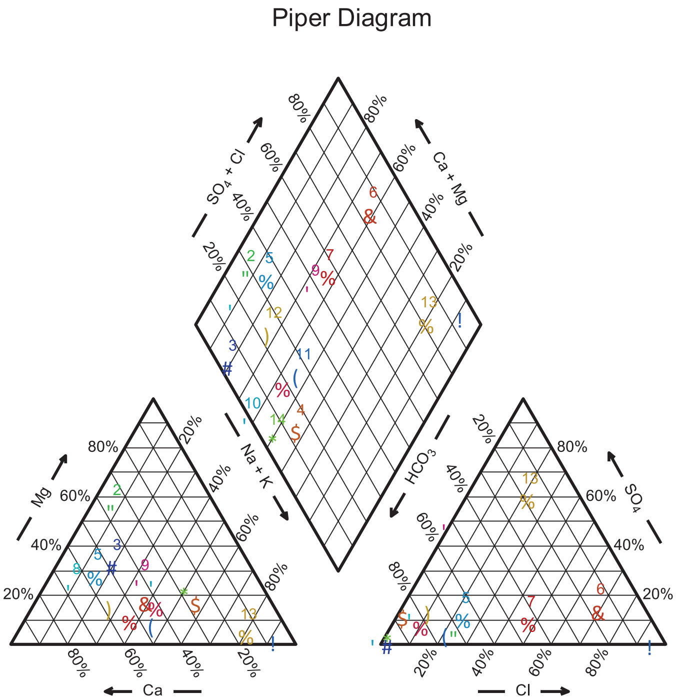

Figure 4. Water types in the study area.

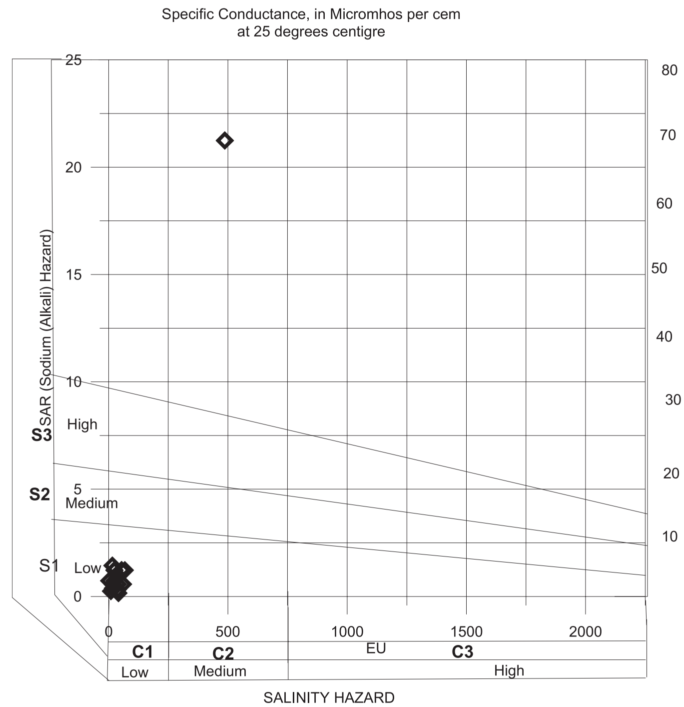

Figure 5. United State Salinity Laboratory classification of Awe salinity hazard.

Table 5 Sodium percentage water class.

Sodium (%)	Water class	Awe sample
<20	Excellent	7.45–17.34 (6 samples)
20–40	Good	20.65–38.58 (6 samples)
40–60	Permissible	42.88 (1 sample)
60–80	Doubtful	69.22 (1 sample)
>80	Unsuitable	92.22 (1 sample)

Adapted from Wilcox (1955).

sodium (Table 5) indicates 12 out of the 15 samples collected are within the ranges of good to excellent class. Three samples (Loc 1, 13, and 15) are within the permissible to unsuitable class,

Magnesium ratio for the Awe waters show that 87% of the water in the areahas less than the magnesium ratio values of 50 epm. Only 13% of the water, (Loc 2 and 14) have magnesium ratio greater than 50 epm.

The SAR value (US. Salinity Laboratory, 1954) for all the samples is found to be less than 10 indicating excellent quality, (Figure 5) with majority of the samples falling in the fresh water region while one sample falls within the salty water region (sample Loc 1).

5.3. Industrial uses

With over 80% of the water classified as soft and fresh, Industries like Rubber manufacturing, sugar processing, textile mills, dairy product manufacturing, and paper industry can be situated in the study area.

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