
Hydrogeochemistry of the Middle Benue Trough, Nigeria

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Abstract: There are many sources of underground water in the Middle Benue Trough, which have varying composition and constituents. Water samples from saline springs, boreholes, hand-dug wells and rivers / streams from the Middle Benue Trough are collected and analysed for cations, anions and heavy metals, using atomic absorption spectrometry (AAS); with aim of determining the concentration of the cations and anions in relation to their suitability within the tolerance limit. The analytical results revealed that the major cations such as Copper (Cu), Sodium (Na), Potassium (K), Iron (Fe) and Magnesium (Mg) have their concentrations within World Health Organization (WHO) drinking water permissible limits. However, Lead (Pb), Arsenic (As), Selenium (Se), Zinc (Zn) and Manganese (Mn) had concentration above the WHO standard and the Standard Organisation of Nigeria (SON) limits. These high values are mostly associated with the Baryte and Lead-Zinc mineralisation associated with either Keana or Awgu formations in the Middle Benue Trough and the saline brine origin of some few aquifers. This situation could potentially have a negative impact on the available water resources in the area with high risk for human consumption, although suitable for agricultural purposes. It is highly recommended that the water quality in this area is monitored from time to time and water borne diseases be systematically and promptly handled.

Keywords: Benue Trough, Nigeria, Groundwater, Hydrochemistry

1. Introduction

Geographical and Climatic Setting of the Study Area

The study area falls within Latitudes 8°25'43"N and 8°20'40"N on its northern and southern boundary, and Longitudes 8°48'8"E and 8°55'55"E on its eastern and western boundaries (Figure 1).

Climatologically the area enjoys the spatial and temporal distribution of the climatic elements. Temperatures are generally high partly because of its location in the tropical sub-humid climatic belt. There is gradual increase in temperature from January to March. The onset of rainfall in April ushers in a noticeable decline in temperature. This was made possible by the blanket effect of cloud cover over the region. Relative humidity rises from February to a maximum of about 88% in July. Steady rains commence in April when the relative humidity will reach about 75%. The variation in rainfall has significant effect on the underground water accumulation, yield, recharge and even

economic activities particularly rain-fed agriculture. Rainfall occurrences are between April and October yearly while November to March is characterised by dryness. The average rainfall value during rainy season ranges from 1100mm to about 2000mm [1-2].

The vegetation falls within the southern guinea savannah zone between the wet high forest zone of the south and the dry savannah zone of the north. The clearing of the vegetation for farming, fuel wood extraction for domestic and cottage industrial uses and saw milling has led to the development of regrowth vegetation at various levels of several developments.

Brief Geology of the Middle – Benue Trough

The geological mapping of the Middle Benue Trough was undertaken [3], where six major lithostratigraphic units were identified and that work constitutes until now the reference document in the study area. The Benue Trough is a rift basin in central West Africa that extends NNE – SSW for about 800km in length and 150km in width (Figure 1).

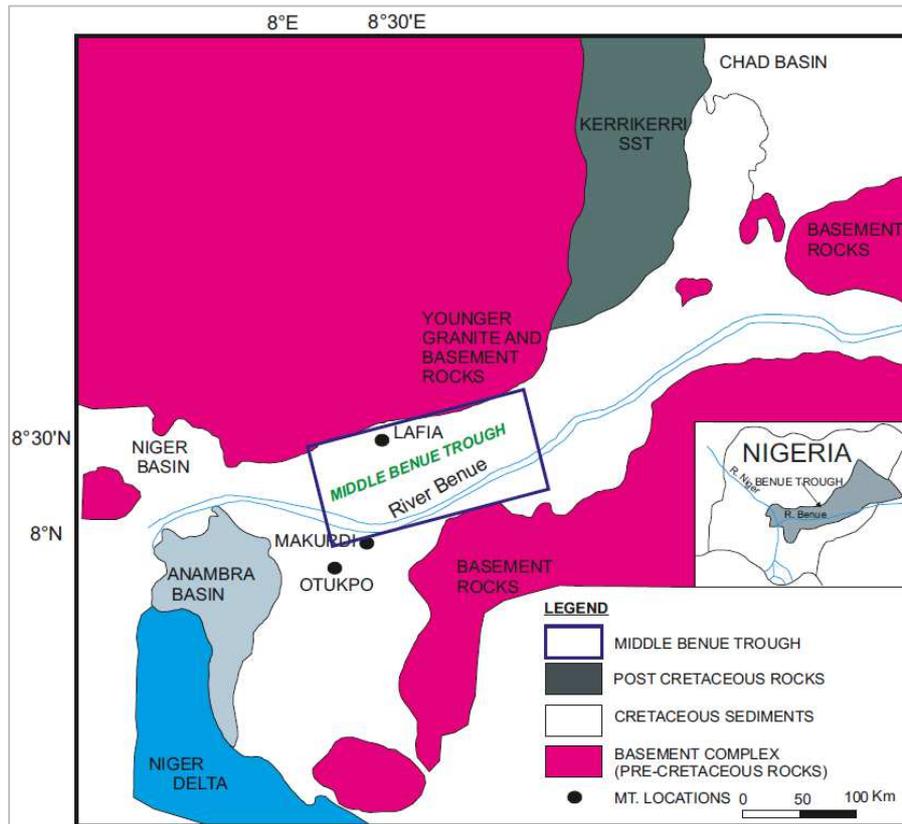


Figure 1. Geological Map of the Benue Trough and the Surrounding areas showing an insert of the Middle Benue Trough.

The Benue Trough originated in the latest Jurassic? to Early Cretaceous when lithospheric stretching resulted in the simultaneous initiation of the various structural elements making up the West and Central African Rift System [4]. It contains up to 6000m of Cretaceous – Tertiary sediments of which those predating the mid – Santonian have been compressionaly deformed, faulted, and uplifted in several places. Compressional Folding during the mid – Santonian episode affected the whole Benue Trough and quite intense, producing over 100 anticlines and synclines [5]. Stratigraphic description of the trough has been presented by [5-7].

The origin and tectonic history of the Benue Trough is associated with the break – up of the continents of Africa and South America [break – up of Gondwanaland]. This break – up was followed by the drifting apart of these continents, the opening of the South Atlantic, and the growth of the mid – Atlantic ridges [5, 8]. The geology of the Benue Trough as it relates to its origin and tectonic evolution has been widely discussed and reviewed by the following [3, 7, 9-11].

Stratigraphy of the middle Benue trough

According to [3, 12], there are six litho-stratigraphic successions identified in the middle Benue Trough, these are:

1. Asu River Group (Albian Arufu, Uomba, Gboko formations)
2. Awe Formation (Late Albian – Early Cenomanian)
3. Ezeaku Formation (Late Cenomanian)

4. Awgu Formation

5. Lafia Formation

Asu River Group (Arufu-Uomba-Gboko)

The Asu River Group is the oldest marine deposit in Nigeria. The Asu River Group is deposited during the Mid-Albian marine transgression of the South Atlantic-Gulf of Guinea. The lithologic composition of this group/ formation comprises mainly limestones, shales and calcareous shales, micaceous siltstones, mudstones and clays. In middle Benue Trough, the Asu River Group crops out mainly in the anticline east of Keana town and south of Azara. This formation is very fossiliferous. Ammonites and foraminifera (mainly agglutinated forms) occur abundantly in the formation [7].

Awe Formation

The Awe Formation is regarded as passage (i.e. transition) beds during the Late Albian Early Cenomanian Regression [3, 8]. This formation overlies the Asu River Group. The type locality is in the town of Awe where the thickness is about 100m (Figure 2). The formation consists of flaggy, whitish, and medium to coarse-grained calcareous sandstones, carbonaceous shales and claystone's. The sandstones become fine-grained and more micaceous towards the base with fine current beddings. The Awe Formation is generally not fossiliferous. However, a few gastropods and pelicycypods occur in the formation.



Figure 2. Outcrop of Awe Formation. Here sandstone beds intercalated with Shale & siltstone indicating Transgressive/Regressive deposits in Awe area.



Figure 4. Highly fracture Sandstone/intercalated with mudstone intruded by Hydrothermal veins of Baryte of Keana Formation.

Keana Formation

The Keana Formation (Figure 3 & 4) resulted from the Cenomanian regression, which deposited fluviodeltaic sediments. In the Lafia-Awe area, the Keana Formation can be located southwards into the Makurdi Formation and it is believe to be its lateral equivalent. This formation consists mainly of cross-bedded, coarse-grained feldspathic sandstones. The sandstones are poorly sorted, and occasionally contains conglomerates and bands of shales and Limestone’s towards the top. The Keana Formation flanks both sides of the Keana anticline. Massive, outcrops (Figures 4) occur at many locations as recorded in the studied sections. Example are Keana, Azara and Daudo. The Keana Formation generally is not fossiliferous. Many reviews on this area were reported [7].

Awgu Formation

The Awgu Formation conformably overlies the Ezeaku Formation. The Awgu Formation was desposited in a generally shallow sea during a third transgression presumed to have begun in the latest Turonian, peaked during the early Coniacian and terminated in early Santonian. The type locality as described by [8] lies between the town of Awgu and Ndeaboh in Anambra State. The deposition of the Awgu Formation marks the end of marine sedimentation in this part of the Benue Trough. The formation is composed of bluish-gray to dark-black carbonaceous shales, calcareous shales, shaley limestone, limestones sandstones, siltstones, and coal seams (Figure 5).

Age	Formation	Thickness	Lithology	Lithologic Description
CENOMANIAN	KEANA	1m	[Yellow triangle]	Ferrugenised though cross bedding medium to coarse grained reddish Sandstone RS5
			[Purple triangle]	Ferrugenised planner cross bedding fine to medium Grained reddish Sandstone RS4
			[Orange triangle]	Ferrugenised inter bedded greenish shale bed
			[Green triangle]	Greenish glauconitic fine to medium Sandstone RS3
			[Red triangle]	Parallel laminated medium grained milky Sandstone RS2
		3m	[Purple triangle]	Bioturbated flat bedded fine grained milky Sandstone RS1

Figure 3. A section of Keana Formation at River Okpalaga, Keana.



Figure 5. A section of Awgu Formation depicting bluish-gray to dark-black carbonaceous shales along Keana - Awe road.

Aim and Objectives of the paper

This paper is aim at assessing the quality of groundwater from different sources such as saline springs, boreholes, pounds, streams and hand dug wells. The study is to determine the physico-chemical parameters of water and to compare them with the permissible limits of the World Health Organization drinking water and Standard

Organisation of Nigeria (SON) standard.

2. Material and Methods

Sampling was jointly performed with staff of the department of Hydrogeology Nigeria Hydrogeological Services Agency (NIHSA). More than ten saline springs at Keana, Ribì, Awe Tsohon Gari and Akiri were recorded and twenty (20) water samples collected (Table 1 and Figure 6). At the time of sampling in the field, basic physico-chemical parameters such as temperature, pH and electrical conductivity were determined in-situ using portable standard digital equipment (Hatch Meter). The waters were poured into 100 ml HDPE polythene bottles from the sources. A separate sample for

nutrient analyses was collected and treated for chloroform. The bottles were rinsed three times, and then filled to prevent degassing. Water samples were filtered through a 0.45 μm membrane and kept under refrigerated condition prior to their shipment to the laboratory.

While in the laboratory, water samples were analysed for major cations and anions and for nutrient content. For quality control, ionic error balance was determined by calculation, where the error balance did not exceed 5%.

The analyses was performed at the Geochemical Laboratory, Department of Geology, University of Jos using a Dionex DX-120 ionic chromatograph for anions and a Perkin Elmer 300 Atomic Absorption Spectrometer (AAS) for cations.



Figure 6. Water sampling at one of the Saline Springs at Tsohon Gari, Awe by the first author.

Table 1. Water sampling locations with corresponding physical parameters (in-situ).

S/N	Name	pH	Temp (°C)	Latitude N (°'")	Longitude E (°'")	Altitude (Ft)	Remark
1	G. S. S Lafia	5.46	30.5	8° 30.01'	8° 30.91'	700	Borehole
2	Nasarawa Estate	6.80	29.8	8° 28.79'	8° 32.81'	500	Hand-dug Well
3	Agwantashi 1	7.20	29.1	8° 19.25'	8° 50.99'	600	Borehole
4	Agwatashi 2	7.70	32.7	8° 19.91'	8° 51.01'	600	Borehole
5	Adudu	8.20	30.6	8° 17.57'	9° 00.35'	-	Hand-dug Well
6	Awe Police Station	7.20	32.0	8° 06.35'	9° 00.51'	-	Borehole Taste salty
7	Awe, Tsohon Gari	6.54	41.2	8° 06.03'	9° 07.70'	-	Saline spring (Salt Taste)
8	Keana	7.5	31.0	8° 08.93'	8° 17.78'	400	Borehole
9	Obi Agada	7.20	31.7	8° 22.02'	8° 16.20'	600	Hand-dug Well
10	Ope Obi	6.40	30.5	8° 22.13'	8° 16.15'	600	
11	Sabon Gida	8.00	33.0	8° 37.96'	8° 57.11'	400	Borehole
12	DEP Project	5.40	29.7	8° 37.47'	8° 56.21'	500	Hand-dug Well
13	Asakio PHC	6.20	32.1	8° 35.18'	8° 58.31'	500	Borehole
14	Gidan Mai Akuya	5.40	31.7	8° 32.73'	8° 11.21'	600	Hand-dug Well
15	Barkin Rijija	4.70	31.9	8° 31.34'	8° 37.09'	800	Hand-dug Well
16	Lamba	5.50	33.7	8° 23.61'	8° 21.51'	-	Hand-dug Well
17	Tudun Angba	4.50	31.8	8° 34.49'	8° 38.86'	600	Borehole
18	Shabu	5.40	31.8	8° 34.49'	8° 33.11'	500	Hand-dug Well
19	Coll. Of Agric, Lafia	6.10	33.7	8° 33.27'	8° 32.76'		Borehole
20	Savannah Hotel Lafia	5.30	32.7	8° 31.17'	8° 031.20'	600	Borehole

3. Results

The results obtained are as shown in tables 2 and 3 below.

Table 2. Physico-chemical parameters of water samples from the Middle Benue Trough.

S/No	Parameter/Sample ID	SW004	RW008	W002	W001	RS07	SW006
1	pH	7.80	7.33	6.44	6.21	7.83	7.26
2	Phosphate (mg/l)	0.004	0.000	0.007	0.009	0.000	0.000
3	Chloride	6.74	4.69	7.88	5.34	6.67	5.009
4	Nitrate	0.0	0.0	0.0	0.0	0.0	0.0
5	Bicarbonates (mg/l)	14.53	9.66	12.11	12.1	10.93	11.33
6	Turbidity	1.96	3.42	9.53	37.90	0.92	1.73
7	Conductivity (m/s)	0.99	0.28	0.12	0.70	0.94	0.80
8	Alkalinity	1.27	1.21	0.94	1.14	0.88	1.89
9	TDS (mg/l)	781	810	902	1420	899	508
10	BOD	7.58	7.55	4.34	6.53	6.59	8.99
11	Total Hardness	3.42	5.99	7.22	8.56	4.94	3.66
12	% DO2	59	88	57	77	78	69

Table 3. Chemical analysis of Water Samples in (mg/dm³) [Preliminary results] in the Middle Benue Trough (Units are in Mg/l).

S/No	Sample ID	Na	K	Ni	Cu	Mg	Fe	Ca	Zn	Pb	Cd	As	Se	Cr	Mn
1	SW004	3.24	2.71	0.05	0.12	5.44	1.89	16.88	0.22	0.02	0.00	0.32	0.04	0.40	0.07
2	RW008	3.49	2.24	0.07	0.31	7.77	2.66	10.89	0.44	0.06	0.00	0.09	0.20	0.19	0.19
3	W002	1.88	2.97	0.19	0.10	8.95	2.23	8.40	0.53	0.01	0.00	0.16	0.34	0.11	0.23
4	W001	3.56	1.95	0.09	0.21	12.91	1.66	13.93	0.30	0.02	0.00	0.03	0.07	0.55	0.19
5	RS07	2.11	2.00	0.18	0.40	9.98	2.51	5.95	0.21	0.02	0.00	0.03	0.45	0.23	0.50
6	SW006	2.98	1.01	0.02	0.26	9.13	0.79	13.01	0.31	0.17	0.00	0.31	0.21	0.01	0.22
	NIS Standard	200		0.02	1	0.20	0.3		3.0	0.01	0.003	0.01		0.05	0.2

Physical Parameters

The pH measurements of groundwater samples in the study area are slightly acidic and ranges from 4.50 to 8.20 with average mean of 7.15. The water samples have a pH within the guidelines range of 6.5 to 8.5. Groundwater temperature varies between 29.1 °C to 41.2 °C with a mean of 33.0 °C. Specific electric conductivity values of 0.0.12m/s to as high as 0.99m/s. Average is 0.70m/s. The corresponding values of total dissolved solids (TDS) measured in-situ range from 781mg/l to 1420mg/l with a mean of 550mg/l (Tables 2 & 3).

Major Cations

The major cations that are present in the water samples from the area of study include sodium, potassium, calcium, magnesium, copper, zinc and iron. Sodium (Na⁺) has concentrations that range from 1.8 mg/l to 3.56 mg/l and mean of 2.88 mg/l. This falls within the permissible limit (<50 mg/l) of the Standard Organization of Nigeria (SON) and the WHO [18, 20-21]. Potassium (K⁺) has concentrations varying from 1.01 mg/l to 2.97 mg/l with a mean of 12.03 mg/l. Calcium (Ca²⁺) concentrations range from 5.95 mg/l to 16.88 mg/l with mean value of 58.22 mg/l, which is within the permissible limit. Magnesium (Mg²⁺) concentrations range from 5.44 mg/l to 12.98 mg/l with a mean of 46.57

mg/l. Copper (Cu) has concentrations range from 0.10-0.40 mg/l with an average of 0.23 mg/l which is within the permissible limit. Zinc (Zn) occurs in concentrations ranging from 0.21-0.53 mg/l with an average of 0.34 mg/l, which is above permissible limit. Iron (Fe²⁺) occurs in concentration ranges from 0.79 to 2.66 with an average of 1.96 mg/l, which are within permissible limit that is suitable for drinking

For the major anions, Nitrate (NO₃) concentration was nil. Phosphate (PO₄) concentrations range from 0.00 mg/l to 0.009 mg/l with an average of 0.007 mg/l within the permissible limit and suitable for drinking. Sulphate occurs with concentrations within the permissible limit (Table 4).

Heavy Metals

Cadmium (Cd) was not detected at any concentration level. Nickel (Ni) has concentrations ranging from 0.02 mg/l to 0.19 mg/l with an average of 0.1 mg/l which is within the permissible limit of 0.07mg/l or 70µg/l of (WHO) but above the (SON) maximum permissible limit [18, 20-21]. The concentrations of Lead (Pb) range from 0.01 mg/l to 0.06 mg/l with mean of 0.05 mg/l, which is above WHO standard of 0.002 mg/l [20-21]. The concentrations of Manganese (Mn) range from 0.07 mg/l to 0.50 mg/l with mean of 0.233 mg/l, which is also above the permissible limit for Drinking Water (Table 3 and 4).

Table 4. Range of concentration of various major and Traced elements in Water Samples in (mg/dm³) [Preliminary results] in the Middle Benue Trough (Units are in Mg/l) and their comparison with WHO 2011 and NIS 2007.

Constituents	WHO 2011		NIS 2007		Mean Values in Study Area
	Highest Desirable Level	Maximum Permissible Limit	Highest Desirable Level	Maximum Permissible Limit	
pH	7-8.5	6.5-9.2		6.5-8.5	7.15
Total Hardness	Not a health concern at levels found in drinking water			150	
TDS (mg/l)	100	500		500	550
Electrical conductivity (m/s)				1000	0.70
Temperature (°C)				Ambient	33.0
Calcium					58.22
Magnesium				0.20	46.57
Sodium				200	2.88
Potassium	No health concern				12.03
Chloride				250	
Cyanide				0.01	
Fluoride	1.5	10		1.5	
Nitrate	3	50		0.2	Nil
Phosphate					0.007
Copper	2.0	3.0		1	0.23
Iron	No health concern			0.3	1.96
Lead		0.01		0.01	0.05
Manganese				0.2	0.233
Cadmium				0.003	Nil
Nickle	0.02	0.07		0.02	0.1
Cobalt					
Chromium		0.05			
Zinc				3	0.34
Selenium		0.04			
Aluminum				0.2	
Mercury		0.006		0.001	
Arsenic				0.01	

4. Discussion

Water is one of the most important resources that sustains human life. The importance depends on many parameters, such as the quality for the intended use, which in turn depends on the geological environment, natural movement of fluid, recovery and utilization [13]. The availability and access to fresh water is a critical issue all over the world. Groundwater constitutes the only reliable water supply for drinking and irrigation purposes [14]. Hence understanding the groundwater quality changes, solute transport mechanism and identifying recharge areas in the groundwater zone has become important in protecting human health. This is because groundwater contains a wide variety of dissolved inorganic species in various concentrations because of the biochemical interactions between the water and geological materials through which it flows and to a lesser extent because of contributions from the atmosphere, surface water bodies and anthropogenic activities [15-7].

Considering the concentration of Nickel in samples SW001, RW008, W001 and SW006 (representing stream water, river water and saline water respectively) the amount of Nickel is above the permissible limit of the SON [18]. Nickel and Arsenic are associated with carcinogenic, and has the risk of exposing the inhabitant of the study area to cancer related diseases [19].

Zinc on the other hand has average concentration above

both SON and WHO permissible limits [18, 20-21]. It is one of the common cause of cancer and has the risk of interference with vitamin D metabolism, which can easily affect the mental development in infants, and is toxic to the central and peripheral nervous systems [18].

Manganese mean value of 0.233 mg/l, is recorded from the analysis and this value is above the permissible limit. Excess of manganese in the human body system can lead to Neurological disorder. As time goes on, it will affect the health delivery system and subsequently will reflect on the GDP of the country.

Mean value of lead concentration of 0.05 mg/l is also higher than permissible limit. This is observed in samples RW008 and RS07. The area is characterised by baryte and Lead-Zinc mineralization. Previous studies showed that the area is experiencing potential danger of the release of Pb associated toxic elements (As, Cd, Sb etc.) into the water system [21]. Moreover, trace elements study in the same area has indicated that Pb, As, Cd, Sb etc., are released into water bodies, rendering such waters unsafe for human consumption [23]. Most common symptoms of lead poisoning are symptoms to anemia, severe intestinal pain, paralysis of nerves and to some extent loss of appetite and fatigue in adults [24]. It can also lead to irreversible mental damage in children.

The presence of selenium as well as arsenic, cadmium and mercury in water endangers its use. Selenium was detected in almost all the samples analyzed for heavy metals. Health problems related to it include decay in hair, nail and teeth and

neurological and skin disorder [25]. The presence of persons with brown teeth in the study area were observed but not very common and this might be an indication of excess selenium or fluoride in the waters and caution needs to be taken when using the waters, preferably it must be treated, and the quality checked on regular basis.

5. Conclusion

Chemical analysis of water from spring, streams and boreholes in the study area reveals concentrations of lead, arsenic, selenium, nickel and manganese are above the WHO Drinking Water Standards. This situation is caused by the geology of the area specifically the occurrence of barite and lead/zinc mineralisations in the study area. The use of such water for drinking mostly for long-term consumption may have serious health problems, there is need for adequate treatment of the water regularly. However, the water can be put to use for both Industrial and Irrigation purposes with minimal concern.

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