

Evaluation of Groundwater Resources of the Middle Niger (Bida) Basin of Nigeria

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Abstract The Middle Niger Basin lies in the sedimentary terrains of the middle part of Nigeria. It has an area coverage of about 27,000km². The area falls under the middle Nigeria climatic belt which is mainly tropical with an average rain fall of about 1250mm. This paper evaluates the hydrogeological potential of the terrain. The methods of investigation include analysis of meteorological, drilling, pumping tests and water quality data. A total of about 50 boreholes located in the area were selected for study. Results of the analyses of the data showed that groundwater occurs both in confined and semi-confined conditions. Depth to water rarely exceeds 50m, though in some few cases may be over 70m. Averagely, well yield varies between 1.08 and 19m³/hr. Transmissivity values obtained using various methods vary between 1.365 and 393m²/day. Hydrochemical analyses of groundwater samples showed poor mineralization with low TDS (Total Dissolved Solids) rarely over 300mg/l. The water is fresh, soft and free of chemical pollution and therefore suitable for many purposes.

Keywords Evaluation, Niger Basin, Groundwater, Hydrochemical Analyses, Transmissivity

1. Introduction

1.1. The Study Area and Collection of Data

The Middle Niger Basin stretches between longitudes 4°E to 7°E and latitudes 7°N to 12°N occupying parts of Niger, Kwara, Kogi States and Federal Capital Territory (Figure 1). The climate is moist sub-humid according to Thornthwaite's classification. The mean average annual temperature varies from 26.5°C to 27.8°C. The area experiences two distinct seasons: the wet season which extends from April to October and a dry season between November to March. The rainy season is characterized by heavy downpours accompanied by groundwater infiltration and percolation. Average annual rainfall ranges between 1000 to 1500mm.

The area is of low to moderate relief with a few scattered laterite-capped hills where elevations rarely exceed 400m above sea level. The area is generally well drained. A regional dendritic pattern is most prominent; however, rectilinear patterns are occasionally exhibited by the short tributaries. River Niger is the most significant drainage element in the area, having its main tributaries as Kaduna, Gbako, Gurara, Chanchaga and Kampe rivers.[1, 2]. The area is sparsely populated with agriculture being the main activity in the area. There are several large-scale agricultural

projects in the area.

A total of about 50 boreholes drilled in the study area were used in the compilation of this report. Most of these boreholes were drilled by the Geological survey of Nigeria, Federal Department of Water Resources, Preussag Drilling Engineers, National Water Resources Institute (NWRI) and other private drilling engineers. The data compiled from these boreholes are presented in Table 1. Aquifer characteristics such as transmissivity, hydraulic conductivity, specific yield were determined through pumping test data analysis for boreholes especially where required data for the calculation of these parameters are available. Water quality analysis of some of the boreholes selected for study were carried out by the Hydrogeology Department of NWRI Kaduna. These were supplemented by existing water quality data in the study area.

All the above data were used to draw up a conclusion on the groundwater situation in the basin.

1.2. Stratigraphy and Sedimentation

The stratigraphy of geological units which occur in the investigated area is given after Dessauvage[3]. The Bida sandstone is the basal sediment of the Middle Niger Basin and it consist mainly of fine to coarse grained sandstones, conglomerates, siltstones and claystones. The sandstone which underlies the Mokwa and Kontagora plains are generally angular to sub-angular, well sorted to poorly sorted and very fine to very coarse and pebbly. The occurrence of Sakpe ironstone formation is limited to the slopes of mesas belt between Bida town and River Niger. The formation

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overlies conformably the beds of Bida sandstone. It consists of coarse-grained oolitic ironstones, dark brown to dark yellow in colour.

The Enagi siltstone formation lies directly on the Bida sandstone. The siltstones are commonly laminated to thinly laminated. The thickness varies from 10 to 70m. The Batati formation occupies the highest stratigraphical position among the sedimentary series of the Nupe sandstone. Around Bida they are referred to as the Batati Ironstone formation and the Agbaja Ironstone formation around the

Niger/Benue Confluence[4]. The alluvial deposits reach considerable thickness and extension particularly in the main river valleys of Niger, Benue and Kaduna. These sediments consist of unconsolidated gravels coarse to fine sands, silts and clays which have been deposited in and along river channels. Figure 2 shows the geological map of the study area.

2. Hydrogeological Situation

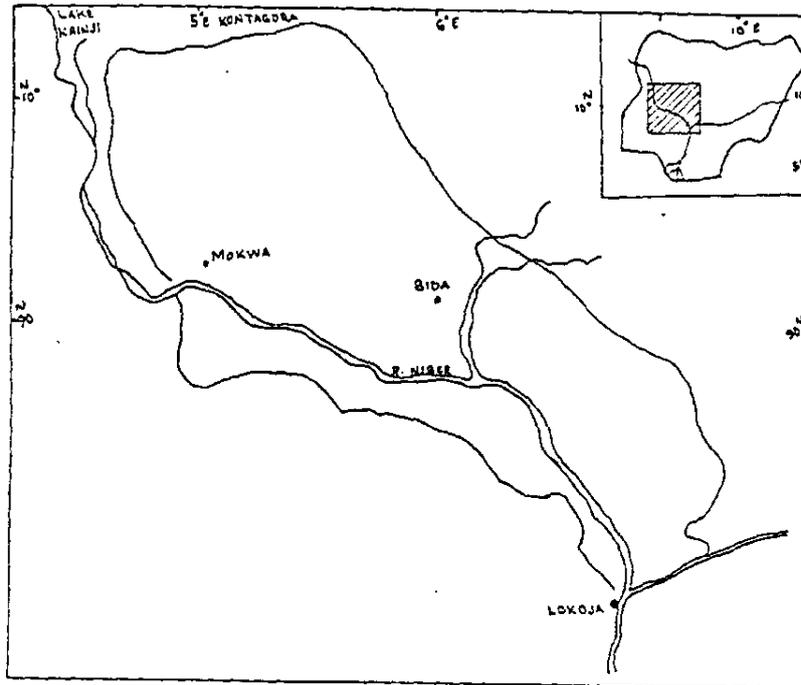


Figure 1. Location of the Study Area

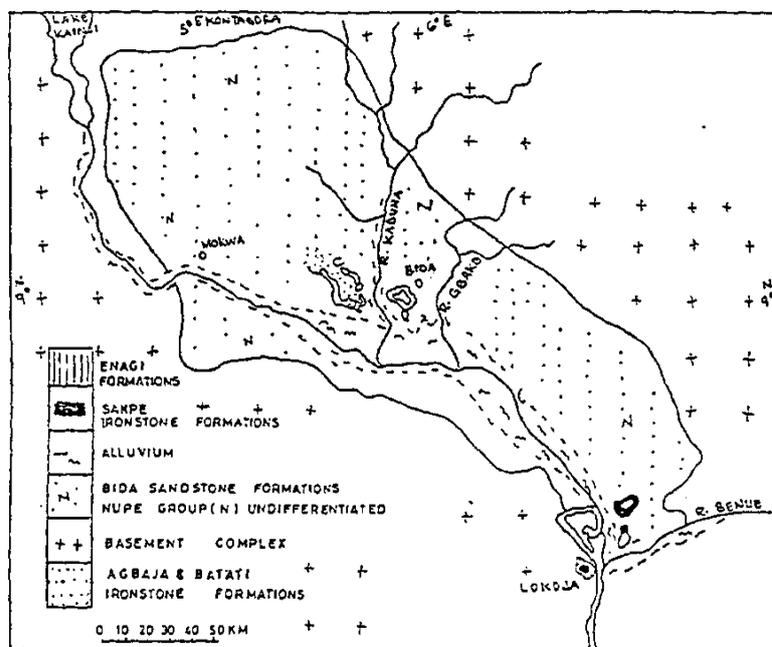


Figure 2. Geological Map of the Study Area

Table 1. Borehole Inventories in the Study Area

Locality	Altitude (m) (A.S.L)	Total Depth (m)	Stratigraphy	Aquifer Depth From - To	Thickness	Diameter inches	Screen Length m	Water S.W.L. m	Dynamic Level m	Drawdown m	Yield m ³ /h	Specific Capacity
Mokwa	160	99.1	Nupe Sand Stone	74.7-99.1	24.4	4	6.5	73.4	73.7	0.3	5.5	18.33
Mokwa	160	96.0	Nupe Sand Stone	74.1-96.0	21.9	5/8	7.9	70.0	-	-	6.4	-
Mokwa	110	76.7	Nupe Sand Stone	35.0-76.7	41.7	5/8	2.2	35.0	36.7	1.7	4.9	2.88
Mokwa	130	85.6	Nupe Sand Stone	48.5-85.6	37.1	6	-	48.5	52.2	3.7	18.2	4.92
Mokwa	160	91.4	Nupe Sand Stone	71.9-91.4	19.5	5/8	13.7	71.9	-	-	14.6	-
Mokwa	140	78.0	Nupe Sand Stone	57.3-78.0	20.7	5/8	10.3	57.8	-	-	13.6	-
Mokwa	110	51.2	Nupe Sand Stone	32.3-51.2	18.9	6	12.1	32.3	-	-	8.2	-
Mokwa	130	73.0	Nupe Sand Stone	-	-	6	2.3	53.6	54.6	1.0	4.9	4.9
Mokwa	10	50.3	Nupe Sand Stone	31.4-50.3	18.9	4	4.2	31.4	-	-	5.6	-
Shonga	120	62.8	Nupe Sand Stone	36.5-62.8	26.3	6	9.5	36.5	-	-	10.0	-
Kutigi	75	38.8	Alluvium	0.9-30.5	29.6	8	-	0.9	7.0	6.1	136.5	22.37
Kutigi	140	44.8	Bida Sand Stone	14.6-16.1	1.5	-	-	9.1	37.8	29.7	4.1	-
Kutigi	140	158.5	Bida Sand Stone	14.6-16.1	1.5	8	-	9.1	79.1	70.1	4.6	0.06
Kutigi						4	9.2	15.8	-	-	-	-
Bida	150	103.6	Bida Sand Stone	79.2-100.6	21.4	5/8	9.2	15.8	-	-	5.5	-
Bida	150	62.5	Bida Sand Stone	-	-	-	7.9	12.8	24.4	11.6	9.1	0.78
Bida	150	185.9	Bida Sand Stone	35.0-53.3	18.3	-	12.5	18.9	-	-	6.4	-
Bida	140	65.2	Bida Sand Stone	8.5-65.2	56.7	5/8	28.4	8.2	-	-	6.6	-
Bida	150	62.5	Bida Sand Stone	22.9-62.5	39.6	5/8	9.4	22.9	-	-	3.2	-
Bida	150	47.2	Bida Sand Stone	14.3-47.2	32.9	6	-	14.3	-	-	4.6	-
Bida	150	50.0	Bida Sand Stone	96.5-50.0	33.5	6	9.4	16.5	-	-	4.5	-
Bida	150	61.0	Bida Sand Stone	-	-	8	20.9	19.8	-	-	4.8	-
Bida	150	67.0	Bida Sand Stone	-	-	8	3.9	18.3	-	-	4.8	-
Bida	150	61.0	Bida Sand Stone	-	-	8	12.2	15.3	-	-	4.8	-
Badeggi	75	82.3	Bida Sand Stone	-	-	5/8	9.7	16.8	-	-	-	-
Badeggi	75	76.2	Bida Sand Stone	-	-	6	3.4	18.3	22.0	3.7	3.2	-
Lafiagi	85	36.6	Bida Sand Stone	16.8-29.0	12.2	5/8	3.0	16.8	25.6	8.8	37.7	4.28
Lafiagi	85	35.2	Bida Sand Stone	15.2-20.5	15.3	8	9.2	8.2	10.9	2.7	41.0	15.2
Lafiagi	85	132.6	Alluvium	126.5-129.5	3.0	8	3.0	+1.2	62.8	64.0	2.8	0.04
Doko	170	57.9	Alluvium	-	-	10	3.3	1+1	41.6	30.5	7.3	0.24
Pategi	100	131.1	Nupe Sand Stone	128.0-131.1	3.1	5/8	2.2	6.7	35.4	28.7	19.6	0.68
Pategi	115	153.3	Nupe Sand Stone	143.2-147.8	4.6	6	1.6	15.2	39.9	24.7	19.7	0.80
Pategi	100	137.2	Nupe Sand	101.2-102.4	1.2	3/8	4.6	+0.3	28.6	28.9	11.40	0.40

Pategi	100	89.9	Stone Nupe Sand Stone	73.1-76.2	3.1	6	4.4	-	-	-	4.1	-
Lapai	145	66.8		82.6-89.3	7.1	6	9.0	11.59	13.70	2.11	-	-
Kutigi	140	115	Bida Sand Stone	54-66.6	12.6	6	12	8.7	15	6.3	3.12	0.49

2.1. Occurrence of Groundwater

The distribution and circulation of groundwater are controlled by geological factors such as the lithology, texture and structure of the rocks and by hydrological and meteorological factors such as stream flow and rainfall. Groundwater occurs both in confined and unconfined condition. In the study area, two types of aquifer are identifiable; one is semi-confined but locally confined in some places, while the other is unconfined. The first is most widespread and occupies about 80% of the land area, while the second is limited to small portions of the central and northern part of the basin[5, 6].

2.2. Aquifer Thickness and Lateral Extent

The unit aquifer (Nupe Sandstone) spreads over a large area within the Middle Niger Basin. At Mokwa area the average thickness is about 28m. The aquifer at the southern part of River Niger spreads as a belt along the basement complex boundary. This belt runs from Jebba in the north-west to Lokoja in the south-east having a maximum width of 30km[7]. From the available data (Table 1) it could be seen that the thickness of the aquifer increases in a south-east direction and amounts to the following:

- Lafiagi 3.0m (B.H. No.30) (126.5m to 129.5m)
- Pategi 9.0m (B.H. No.34) (128.3m to 137.2m)
- Kpada 33.5m (B.H. No.39) (146.3m to 179.8m)

The Nupe sandstone aquifer seems to completely thin out at the edges of Middle Niger Basin. This is confirmed by Share borehole (B.H. No.40) where the depth to the basement is about 33m.

2.3. Piezometric Characteristics

The Nupe Sandstone is unconfined at Mokwa area. The static water level varies between 31-72.5m. Averagely the static water level is about 49m. At Pategi area, the top of the aquifer is met at the depth of 128m to 143m (B.H. No.32 & 33). The static water level is between 0.3 - 15.2m. In Lafiagi, the Nupe sandstone confined aquifer acquired a flowing artesian character. Here the top of the aquifer is at the depth of 126.5m (B.H.30). The static water level is 1.2m above land surface with the corresponding head pressure of 127.7m.

2.4. Water Yielding Properties of the Aquifers

Du Preez and Barber[8] reported the occurrence of large quantities of groundwater from the Nupe sandstones in the area between Kontagora and Mokwa. Eastward towards Bida, the formation changes laterally into fine-grained sand and silt from which poor yields were obtained. Yields of the

boreholes penetrating the Nupe sandstone in Mokwa areas range from 0.9 to 18.2m³/hr. The specific capacity values range from 1 to 18.33m³/h/m. In Pategi, the average yield is about 13.7m³/h with specific capacity ranging between 0.4-0.8m³/h/m. Average drawdown is about 27m (Table 1).

The Bida sandstone is characterized by very low yield which range from 3.2m³/hr to 9.1m³/hr with an average yield of 4.5m³/hr. The average drawdown is about 11m while the average specific capacity is about 0.8m³/h/m. The alluvium areas are highly productive. They are characterized by direct continuity with the water of the river. The yield as observed in Shonga (B.H.12) is 136m³/hr.

3. Hydraulic Characteristics

The hydraulic properties of an aquifer are assessed by the values of its parameters such as coefficient of transmissivity, permeability or hydraulic conductivity, specific yield and storage coefficient. Transmissivity represents the water transmitting capacity of a unit width of the entire saturated thickness of the aquifer. On the other hand, it can be defined as the rate at which water of prevailing kinematic viscosity is transmitted through a unit width of the aquifer under a unit hydraulic gradient[9, 10]. Both semi-equilibrium Jacob analysis and the Recovery method were used in the analysis of data obtained from pumping test.

3.1. Semi – Equilibrium Jacob Analysis

The Jacob’s method is based on the Theis’s formula with some restriction in its application[11]

The Theis’s equation is expressed as

$$S = \frac{Q \cdot W(u)}{4\pi KD}$$

This reduces to

$$S = \frac{2.30Q}{4\pi KD} \log \frac{2.25KDt}{r^2 S}$$

where Q = discharge in m³/day; W(u) = well functions of u represent an exponential integral; K = hydraulic conductivity in m/day; D = is the aquifer thickness or saturated thickness of the aquifer in meters and, r = well radius in metres.

Equation (2) is solved by plotting linear drawdown versus logarithm of time and reading off two parameters: s, the single log cycle drawdown increment, and t₀, the time when the straight line portion of the plot extrapolated backwards cuts the zero drawdown axis. Transmissivity KD can then be calculated by substituting the values for Q and S. Illustration of this is given in Figure 3.

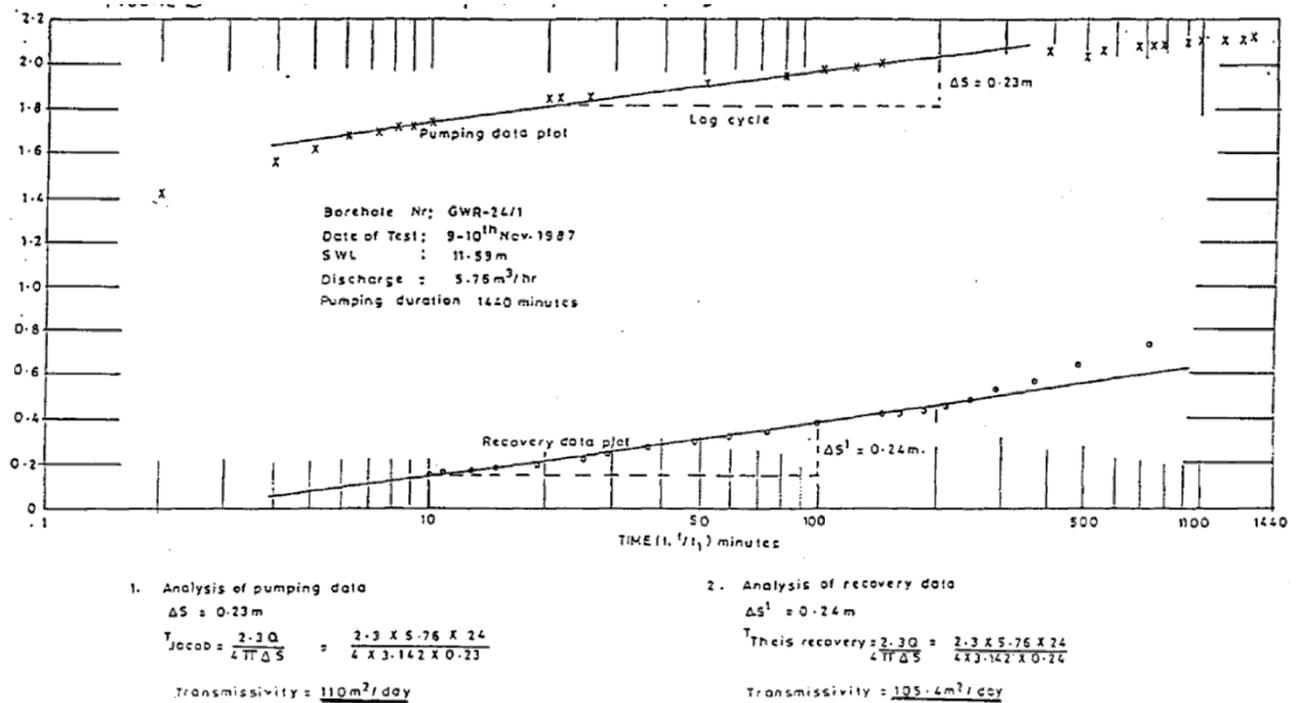


Figure 3. Central Mosque, Lapai – Pumping Test Data

Table 2. Main Hydrogeologic Parameters of Selected Boreholes in the Study Area

S/N	Location	Transmissivity	Yield (m³/day)
1	Lapai (Central Mosque)	110	
2	Bida Fed.Govt.Col	31.27	242
3	Mokwa	123.55	230
4	Kutigi	22.03	125
5	Doko	4.87	312
6	Agai	7.86	69
7	Kaboji	237	86
8	Boku	393	154
9	Bida Guest.House	1.40	69.6
10	Gbadako	137	130
11	Mokwa Guest.House	15.81	30
12	Etsu-Tasha	1.365	86.4
13	Shabakolo	12.44	30.2
14	Lokogoma	10.62	91.8

3.2. Theis's Recovery Method

Theis's recovery method can be used to calculate the hydraulic properties of an aquifer if the assumptions and conditions of Jacob's method are satisfied [11]. A plot of t/t' (on the log axis) against S'' yield a straight line whose slope is

$$T = \frac{2.3Q}{4\pi\Delta S}$$

Here t is the time since pumping started, t' is the time since pumping stopped, s'' is the residual drawdown, T is transmissivity. An illustration of this method is presented in Figure 3. The transmissivity value of an aquifer can be calculated using any of the two methods. Table 2 is a compilation of the transmissivity values at different areas within the basin.

4. Hydrogeochemistry of the Aquifers

The chemical water characteristics described in this report are based on eleven analyses tabulated in Table 3. The above data were supplemented by field determination of electrical conductivity (E.C.) of some hand dug wells located in the study area. This method aims to indicate the quality of water by definition of total mineralization. The result of the exercise is given in Table 4. Figure 4 shows ranges of main chemical characteristics of analysed water. The predominant cations are calcium, sodium and manganese. The main anions are bicarbonate and chloride. Sulphate sometimes is also present. Iron content is generally negligible less than 0.3mg/l except at Shonga, where 0.44mg/l of iron was recorded. Manganese is predominantly absent.

Table 3. Chemical Analysis of Groundwater from Bida Basin

Location	Shonga	Share	Sunti	Mokwa	(Well) Mokwa	Pategi	Pategi	Kutigi	Lapai	MCRI Mokwa	
Aquifer	Alluvium		Nupe SDST			Nupe SDST	Nupe SDST			Nupe SDST	Badeggi
Electrical Conductivity	66.61		34		-	345	349	86	112		
Total Solids	450.0	240	-	48.0	114.0	217	77	-		33	28
Total Hardness	51	295.5	12		-	140	11.5	46		48	
Total Alkalinity (As CaCO ₃)	50	142.12	35		-	141	12	35	64		
pH	6.8	377.5	6.5	5.6	6.1	6.9	7	6.25	186		
Silica (SiO ₂)	1.08	8.4	-	24.0	50.0	39.0	58.0	50	7.8	6.5	6.3
Free CO ₂	45.0	20.0	3.0		-	-	-	0.02		10.5	
Calcium (Ca)	2.85	-	7	Nil	6.85	44.4	2.8	12.4	16.4		2.6
Magnesium (Mg)	12.16	21.02	3	0.4	TR	7.1	1.1	3.65	5.34	2	0.6
Sodium (Na)	-	25.94	-	1.7	2.6	9.4	1.9	-		0.729	1.5
Potassium (K)	-	-	-	Nil	TR	20.2	4.3	-		1.70	2.8
Total Iron (Fe)	19.0	-	0.3	0.2	0.04	1.2	0.05	0.05	0.12	TRACE	0.05
Manganese (Mn)	0.44	0.2	Nil	0.1	Nil	Nil	Nil	-		0.05	
Ammonium (NH ₄)	1.04	0.1	2	0.004	0.004	0.1	0.04	-			
Aluminium (Al)	-	-	-	0.01	Nil	0.05	0.1	-			
Copper	-	-	-	Nil	Nil	0.04	-	-			
Boron	-	-	-	-	Nil	-	-	-			Nil
Zinc	-	0.70	-	4.4	-	-	-	-			
Chloride	0.98	-	6.83	7.0	4.0	12.7	1.0	45	0.12		0.45
Sulphate			8.00	Nil	TR	TR	1.5	5.0	1.98	2.48	0.37
Bicarbonate			-	13.7	9.0	172	15.7	21.4		2.88	
Nitrate Nitrogen (No ₂)		Nil	Nil	0.001	-	1.32	TR	1.9			0.3
Flouride (F)	0.18	-	-	Nil	Nil	TR	TR	0.3	0.08	5.48	
Phosphorous (P ₀₃)	0.91	-	-	-	-	0.28	0.16	-			

Table 4. Electrical Conductivity of Selected Hand-Dug Wells

No.	Locality	Geological Unit (m)	Total Depth (m)	Depth to Water	Electrical Conductivity (mmhos/cm)
1.	Lafiagi	Nupe Sandstone	32.2	32	70
2.	Bokani	Sandstone	21.7	21.5	57
3.	Lobizhi	Sandstone	8.8	7.8	220
4.	Kutigi	Bida Sandstone	7.0	6.8	122
5.	Enagi	Enagi Siltstone	14.9	14.7	192
6.	Kusegi	Bida Sandstone	22.7	22.0	210
7.	Batati	Bida Sandstone	14.5	14.3	281
8.	Bida	Bida Sandstone	12.8	7.0	204
9.	Badeggi	Bida Sandstone	13.0	6.0	227
10.	Badeggi	Bida Sandstone	14.5	8.2	230
11.	Lapai	Bida Sandstone	12.1	12.0	267
12.	Share	Nupe Sandstone	8.4	5.8	140
13.	Share	Nupe Sandstone	13.8	13.8	145
14.	Lafiagi	Nupe Sandstone	19.7	19.7	285
15.	Kpada	Nupe Sandstone	19.5	19.5	110
16.	Baro	Bida Sandstone	17.0	16.8	180
17.	Shonga	Alluvium	-	-	66
18.	Mokwa	Nupe Sandstone	-	-	76
19.	Doko	Bida Sandstone	-	-	293
20.	Bacita	Nupe Sandstone	-	-	65

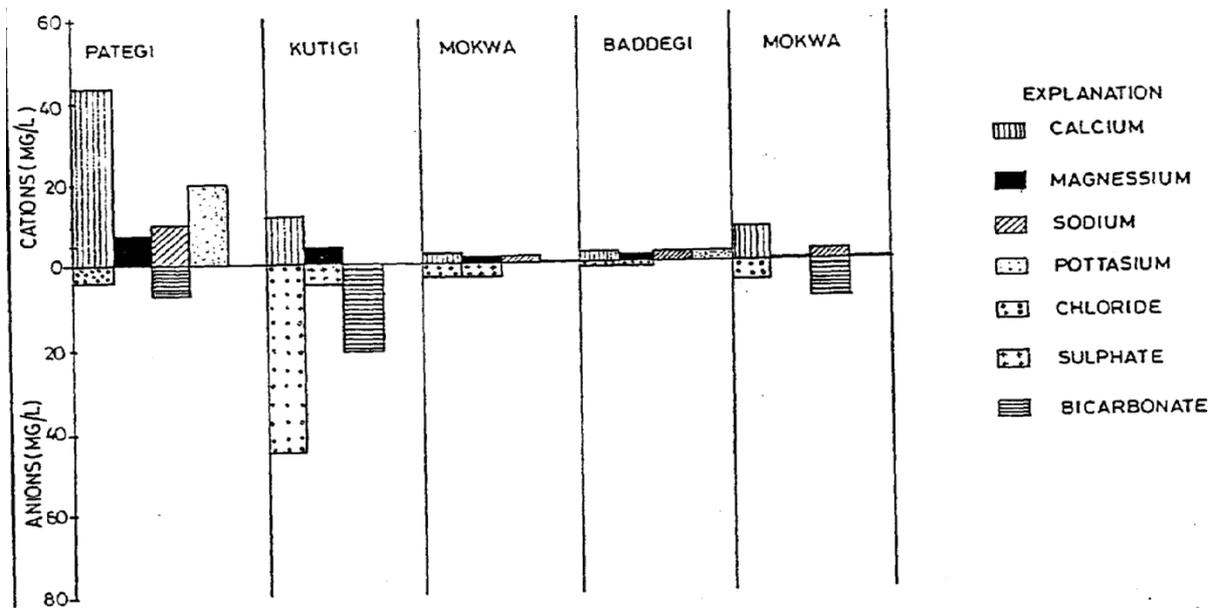


Figure 4. Bar Charts Illustrating Chemistries of Water from Selected Boreholes in the Study Area

Based on the classification system suggested by Gorell[12] which classify the quality of water based on TDS (Total Dissolved Solids) as shown below, it could be seen that the groundwater in this basin is fresh.

Freshwater 0-1,000mg/l TDS;

Brackish water 1,000 -10,000mg/l TDS;

Saline water 10,000-100,000mg/l TDS;

Brine >100,000mg/l TDS.

Even the highest values for the TDS obtained in this basin will fall far below the upper limit of the freshwater classification. Generally the water is free of chemical pollution and is therefore suitable for many purposes especially for irrigation.

The above conclusion agreed with the result of the study carried out by Kehinde and Loenhert[13] on the isotope analysis of water samples from the basin, and with similar studies by Bala and Onugba[14] as well as Olaniyan et al[15]. Results from the study reveal two water types: a poorly mineralised $\text{Ca}(\text{HCO}_3)_2$ to the north of the basin across the River Niger and a more mineralized NaHCO_3 type limited to the south of the Niger. The analysis also reveals that more water samples fit the meteoric water line and that the water contained tritium which is an indication of active recharge.

5. Summary of Major Findings

The main findings from this study are summarized as follows:

i. The region is underlain by sedimentary rocks which vary in thickness from 40m to 300m. The formation material consists mainly of very fine to coarse grain pebbly sandstone.

ii. Two major aquifer types have been identified in the study area i.e. confined and unconfined aquifer. The aquifer ranges between 3 and 34 meters thick and is composed of

fine to medium grained, poorly sorted sandstones. Large quantities of groundwater occur in the sediments of the basin especially in the alluvium areas of Shonga, Baddegi and Lafiagi. The vast underground resources in the area can be used for agricultural purposes.

iii. The evaluation of hydrogeological parameters of boreholes obtained from pumping test analysis gave borehole yield ranging from $0.9\text{m}^3/\text{hr}$ to $136.5\text{m}^3/\text{hr}$. The high variability of borehole yield in this basin is due to rapid changes in its hydrogeological characteristics.

iv. Average transmissivity values computed using Jacob and Theis' methods range between 1.365 and $393\text{m}^3/\text{day}$.

v. The water in this basin is very soft and portable. It can be used for domestic, agricultural or industrial purposes. The electrical conductivity which is an indication of the general level of mineralization ranges from 34 - 349 micro-ohm/cm.

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