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INTERNATIONAL JOURNAL OF CHEMICAL SCIENCES

ijcs

Int. J. Chem. Sci. Vol. 2 No. 2, 2009 ISSN: 2006-3350
www.ijcsnsuk.org

A PUBLICATION OF THE DEPARTMENT OF CHEMISTRY, NASARAWA STATE UNIVERSITY, P. M. B. 1022, KEFFI, NASARAWA STATE, NIGERIA.

ASSESSMENT OF AQUIFER CHARACTERISTICS AND GROUNDWATER QUALITY IN PARTS OF NIGER STATE, NORTH-CENTRAL NIGERIA

[1]Amadi, A. N., [1]Olasehinde, P. I., [2]Okunlola, I. A. and [3]Egharevba N. A.
[1]Department of Geology, Federal University of Technology, Minna, Niger State
[2]Geosciences (Nigeria) Limited, 27 Agba road, Ilorin, Kwara State
[3]Department of Agricultural and Bio-Resources Engineering,
Federal University of Technology, Minna, Niger State
Corresponding author email: akoamadi@yahoo.com
Date Received: July 5th, 2009. Date Accepted: November 4th, 2009

Abstract

For an effective water supply and management, the quantity and quality of water sources must be known. To this end, an assessment of the aquifer transmissivity, yield and groundwater quality in parts of Niger State, North-central Nigeria has been made. Niger State lies between longitude 4°00'E to 7°15'E of the Greenwich Meridian and latitude 8°15'N to 11°15'N of the Equator covering a land mass of about 80,000 km^2. Transmissivity values were calculated using Jacob and Theis methods. Jacob's method reveals that transmissivity values range from 2.0 m^2/d to 700.0 m^2/d with a mean value of 82.6 m^2/d while transmissivity via Theis method varies from 4.0 m^2/d to 1000.0 m^2/d with an average value of 152.0 m^2/d. The borehole yield varies from (0.810.0) l/s and a mean value of 3.0 l/s while the static water level (SWL) ranges from 2.3 m to 38.7 m with an average value of 8.3 m. The total drill depth (TDD) is of the order of 18.0 m to 98.0 m and an average drill depth of 59.0 m. The local geology hosting the wells is majorly the Basement Complex followed by sedimentary basins while few locations occurred along transitional zones. The findings show that the area has low to high groundwater potentials according to Gheorghe and Kransy standards. The analyzed physio-chemical and bacteriological parameters agree favorably with the World Health Organization and Nigerian Standard for Drinking water Quality. This implies that the water is fit for domestic, agricultural and industrial purposes.

***Keywords:** Aquifer Transmissivity, Yield, Groundwater Quality, Niger State, Nigeria*

Introduction

Niger State also known as Power-State, because of her three hydro-electric power generating stations, lies between longitude 4°00'E to 7°15'E of the Greenwich Meridian and latitude 8°15'N to 11°15'N of the Equator covering a land mass of about 80,000km^2(Fig 1). It shares boundary in the west with Kwara State and Benin Republic and in the East with the Federal Capital Territory, Abuja. It is bordered in the north by Kaduna and Kebbi States and in the south by Kogi State (Fig.1). The Climate of the state is similar to other West African States. The daylight temperature varies from 24°C at the peak of rainy season to above 35°C at the climax of dry season. The seasonal rainfall gives rise to a longer wet season of about 7 months (April-October) with an average rainfall of 250mm and a dry season of about 5 months (November-March) with little or no rain (Shekwolo, 1993). The area is well-drained by river Niger and its tributaries while the vegetation comprises of grasses, shrubs and trees, and the vegetation is usually thicker along the river channels. The Area has a good road network and drainage system and hosts three major hydro-electric power stations in Nigeria at Kainji, Shiroro and Jebba respectively.

Groundwater moves through subsurface rocks and assumes the nature of the rock through which it flows. The interaction of groundwater with the host rock makes hydrogeology a salient point between geology and chemistry (Abimbola, et al., 2008, Olasehinde and Amadi, 2008). Groundwater quality can naturally be influenced through bedrock dissolution by groundwater or be anthropogenically affected by human agency such as dumpsites, cemetery and farming.

The present study evaluates the amount and quality of the groundwater in different parts of the state and the results compared to the standards recommended by World Health Organization and Nigerian Standard for Drinking Water Quality.

MATERIALS AND METHODS

Geology of the Area

About half of the land mass of Niger State is underlain by the Basement Complex rocks while the remaining half is occupied by the Cretaceous Sedimentary rocks of the Bida Basin. The boundary between these runs in a northwest-southeast direction, with the Basement rocks to the north and the Sedimentary formation to the south.

The Basement rocks consist of a suite of Precambrian gneisses, migmatites and meta-sedimentary schist which are crosscut by intrusive granitoid (Ajibade and Woakes, 1976). The gneisses and the meta-sedimentary schist which constitute the host rocks to the granitoids and are found mostly as flat-lying outcrops are often ill exposed except along river channels and road cuttings. A typical weathered profile of the Basement rocks in the area consists of two main zones; the surperficial zone of about 2m thick and the fractured zone with an average thickness of 18m. Granites and gneisses weather into medium to coarse grained sand while schists weather to clays. The sedimentary formation consists of loosely cemented sandstones of varying grain sizes, shale and clay and are capped by lateritic and or ironstone concretions, particularly in upland areas (Shekwolo, 1993). The geology of Bida Basin was first described by Falconer (1911). He named the Cretaceous sedimentary rocks outcropping in Bida area as Nupe Sandstone. The name Nupe Sandstone was replaced by Lokoja Sandstone (Jones, 1958). Adeleye (1976) described them as laterial equivalent and composed of fine to coarse grained sandstone, clays, gravelly-sandstone, siltstone, shale and lignite with maximum thickness of about 300m below the ground surface. Hydrogeological investigation of the area had been worked out and different aquifer types identified in the area (Shekwolo, 1993).

Fieldwork

Pumping test data were obtained from 25 locations using drawdown, recovery and step-drawdown methods, and the result correlated with their respective borehole logs. The pumping tests were carried out to give an estimate of the transmissivity of the aquifer and borehole yield. It is one of the fundamental measures of how good an aquifer is. It indicates how easily groundwater can flow through a rock to a borehole. It is measured in m^2/d and is defined as the rate at which groundwater will flow through a unit width of aquifer for a unit difference in hydraulic head. The aquifer transmissivity in the area was determined using **Theis (1935) and Jacob (1946) methods** respectively (Table 1).

The Theis equation (recovery) for calculating transmissivity is given as:

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

Where: T = Transmissivity (m^2/d), Q = Discharge (m^3/d), ΔS = Slope/log cycle.

While the Jacob equation (drawdown) of determining transmissivity is shown below:

$$T = \frac{264Q}{\Delta S}$$

Where: T = Transmissivity (m^2/d), Q = Discharge (m^3/d), ΔS = Slope/log cycle.

A total of 16 water samples were collected in pairs using a glass and a plastic container from borehole samples in the area (Fig.1). The physical parameters (pH, conductivity, temperature and turbidity) were determined on the field using a calibrated pH-metre, conductivity meter, thermometer and turbidometer respectively. The chemical parameters (cations, anions and trace elements) were analyzed using Atomic Absorption Spectrometer (AAS) while bacteriological determination of coliform and E.coli were obtained using presumptive count and differential count respectively.

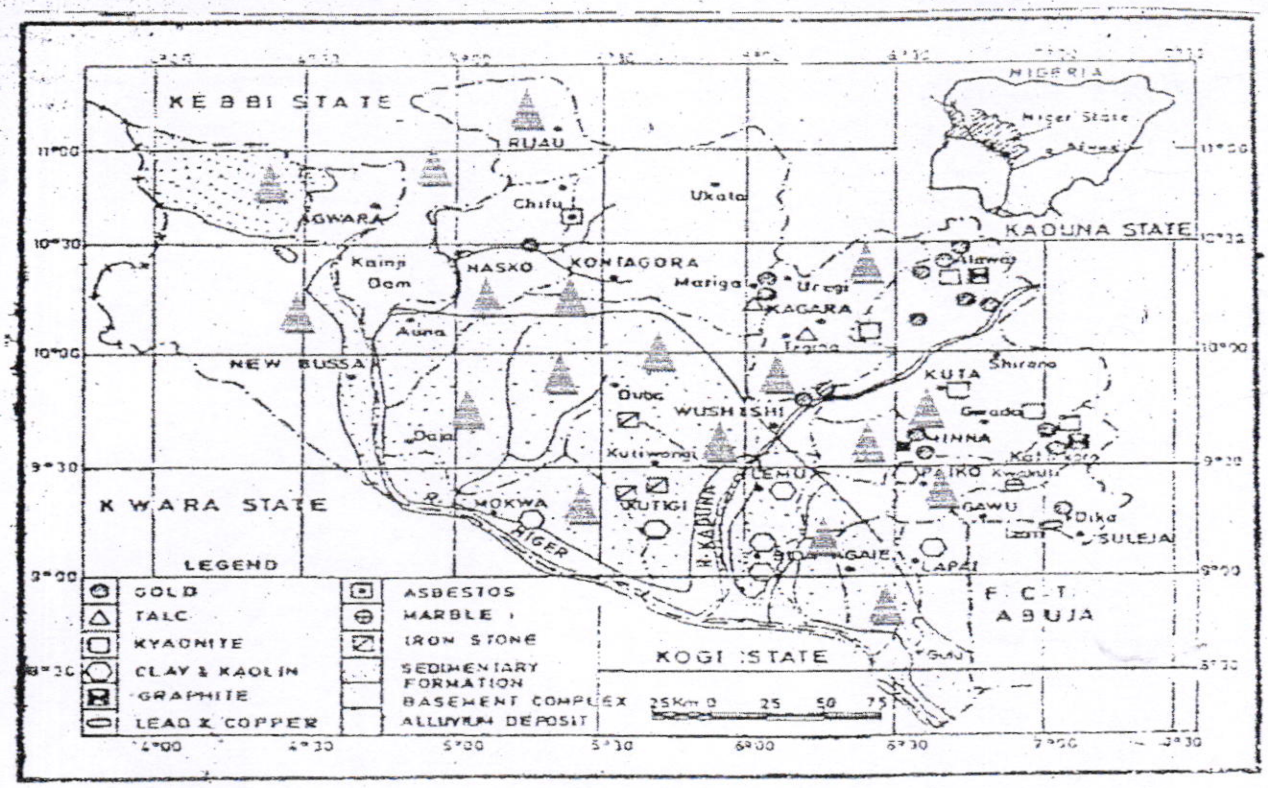

Fig.2: Geological map of Niger State showing some Minerals, bordering States and the sampling locations (Source: Nigerian Geological survey Agency, 2004) Sampling location

RESULTS AND DISCUSSIONS

Pumping Tests

Pumping tests are one of the most important tools for assessing groundwater resources. They test the response of groundwater in an aquifer to pumping. By carefully measuring and interpreting this response, it is possible to deduce various pieces of information, which are useful in quantifying key aquifer parameters such as transmissivity and storativity. Aquifer pumping tests provides data used in evaluating the groundwater potential of different rocks in the study area. Pumping tests were carried out in 25 locations to obtain information about the aquifer yield and borehole performance in the area. The borehole yields gave a range of 0.8-10.0 l/s with the highest in the sedimentary rock while the least is in the Basement Complex terrain. There is no significant difference in borehole depths from the two terrains but differences exist in static water level. The static water level in the basement terrain is shallower, ranging from 2.3 m to 13.7 m while in the sedimentary terrain, the static water level is deeper, ranging from 3.6 m to 38.7 m.

Table 1 is a summary of the borehole yield, total depth drilled (TDD), static water level (SWL), transmissivity according to Jacob and Theis in relation to their local geology. The results indicate that the area has low to good groundwater potentials as in Gheorghe and Krawny Standards for Transmissivity (Table 2). It is these data that were also used to determine the borehole transmissivity in the area. It can be deduced that, the local geology determines the groundwater potential of an area. Boreholes drilled in sedimentary terrain had more yield and higher transmissivity value than those from Basement Complex terrain while along the transitional zones; the well yield and transmissivity rate are moderate. The graph of drawdown and recovery against time are contained in figures 2 and 3 respectively, while flow-rate and step-drawdown graph are shown in Figure 4.

Table 1: Summary of Pumping Test Data across the study area

S/N	Borehole Locations	TDD (m)	Borehole Yield (l/s)	SWL (m)	Transmissivity (m^2/d)		Local Geology
					Jacob	Theis	
1	Lambata	54.0	7.1	3.8	40.0	55.0	Basement
2	Kagara	60.0	2.0	3.7	5.0	12.0	Basement
3	Kuta	65.0	2.1	6.1	10.0	15.0	Basement
4	Tungan-Mallam	60.0	3.0	13.7	9.0	53.0	Basement
5	Kaffin-Koro	60.0	3.6	5.5	18.0	25.0	Basement
6	Ija-Koro	90.0	1.0	8.0	4.0	10.0	Basement
7	Gwada	93.0	2.9	4.8	17.0	23.0	Basement
8	Maje	30.0	0.8	2.8	9.0	10.0	Basement
9	Tegina	51.0	1.0	6.4	15.0	20.0	Basement
10	Farindoki	60.0	2.1	2.3	2.0	10.0	Basement
11	Beji	90.0	3.1	4.3	30.0	41.0	Basement
12	Mariga	75.0	2.0	5.2	4.0	11.0	Basement
13	Pandogari	60.0	2.0	7.0	22.0	42.0	Basement
14	Yikila	90.0	2.6	3.2	5.0	12.0	Basement
15	Kwakuti	90.0	2.0	2.4	9.0	15.0	Basement
16	Maitangi	36.0	1.5	2.5	5.0	20.0	Basement
17	Ibeto	72.0	1.3	5.0	2.0	4.0	Basement
18	Lemu	32.0	10.0	8.0	4.0	10.0	Sedimentary
19	Edozhiji	18.0	3.0	3.6	380.0	700.0	Sedimentary
20	Saho-Rami	51.0	3.5	26.1	80.0	123.0	Sedimentary
21	Auna	30.0	6.1	8.2	430.0	860.0	Sedimentary
22	Enagi	51.0	3.0	9.0	20.0	30.0	Sedimentary
23	Rafin-Gora	98.0	3.2	38.7	130.0	200.0	Sedimentary
24	Salka	30.0	6.5	14.6	700.0	1000.0	Transition Zone
25	Wushishi	30.0	3.0	13.2	115.0	500.0	Transition Zone
Mean		59.0	3.1	8.3	82.6	152.0	
Range		18.0-98.0	0.8 10.0	2.3 38.7	2.0 700.0	4.0 1000.0	

TDD = total drilled depth SWL = static water level

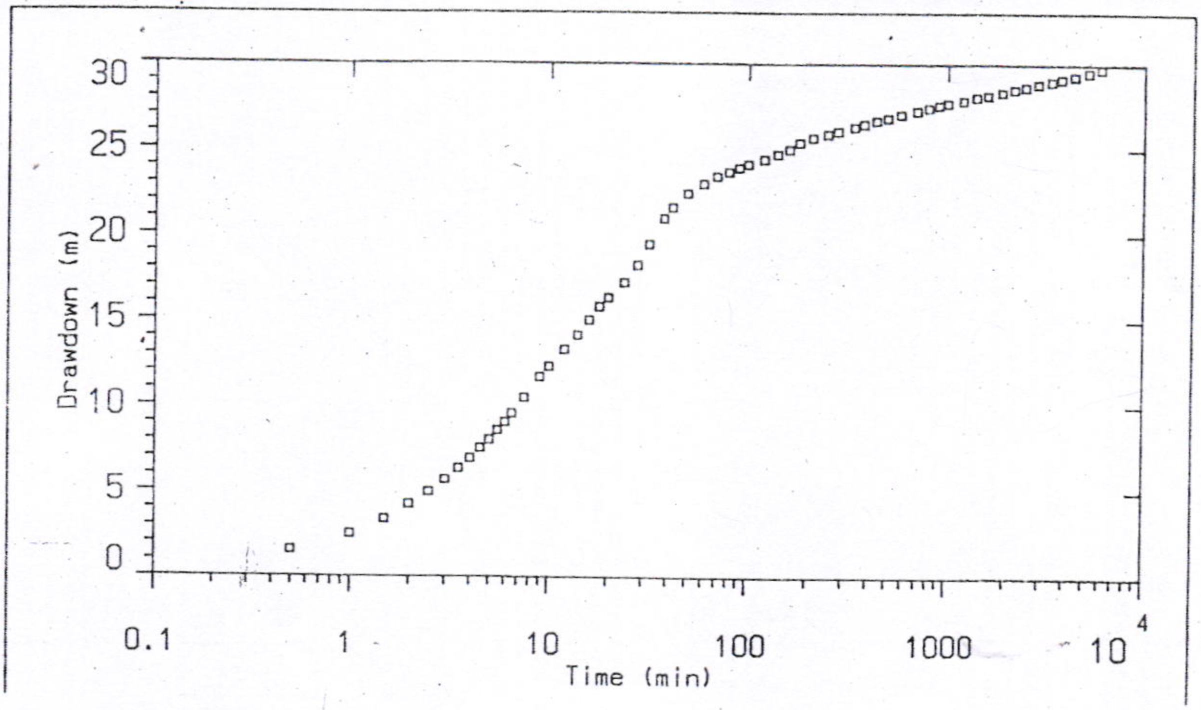

Fig.2: Drawdown versus time graph for Ibeto, (S/No.17).

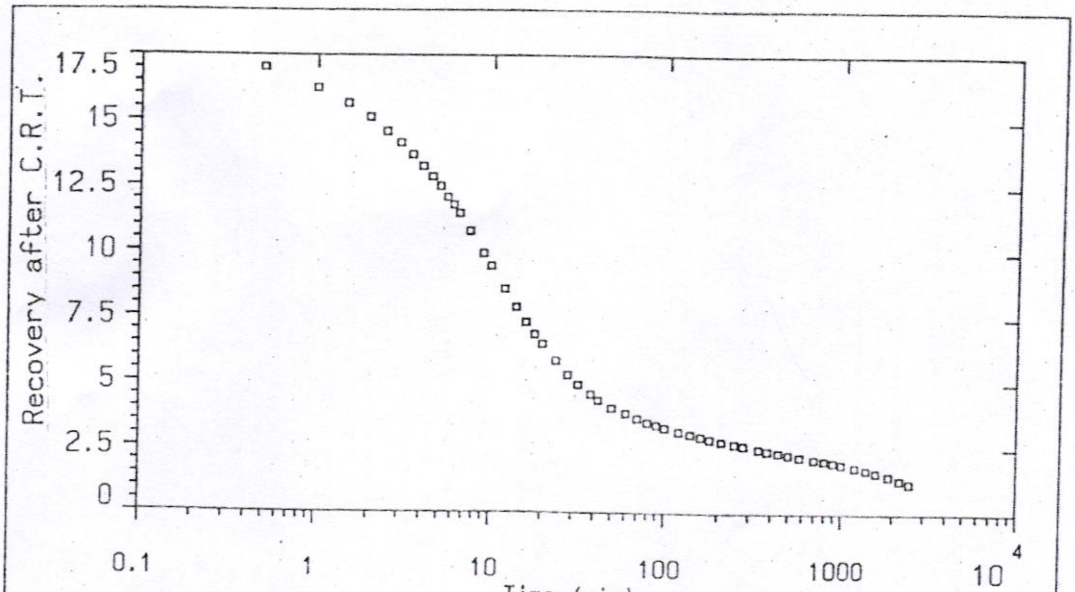

Fig.3: Recovery versus time graph for Ibeto, (S/No. 17).

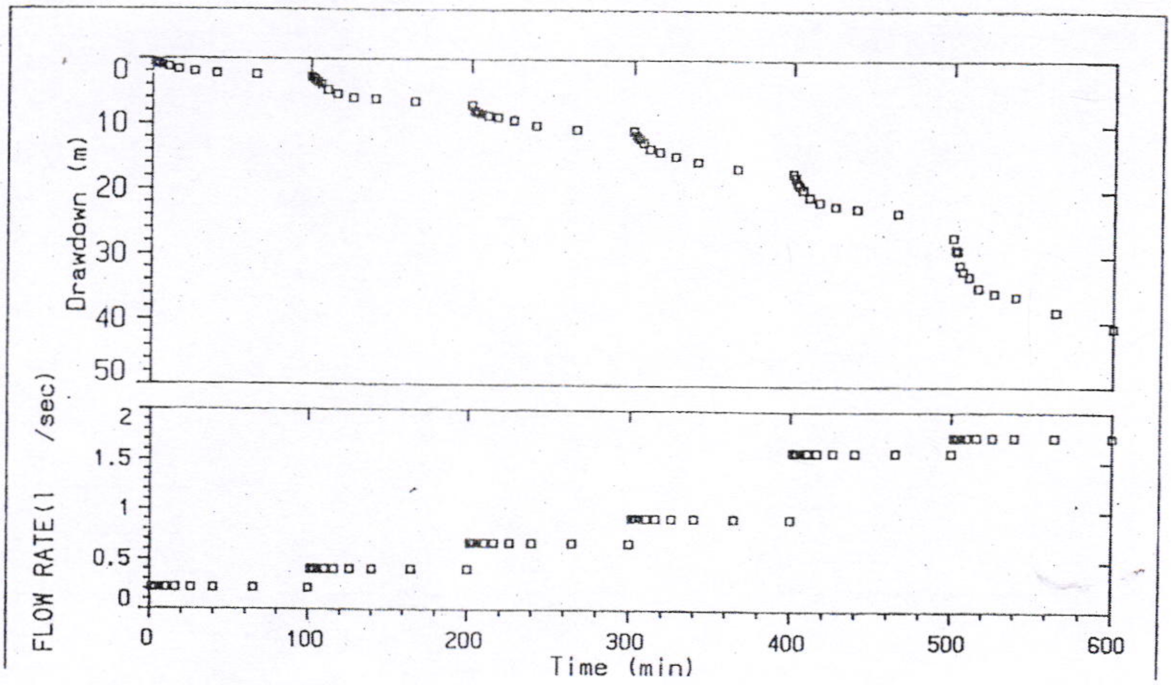

Fig.4: Step-drawdown and flow rate against time for Ibeto, (S/No.17).

Borehole-log and Design

Borehole-log and casing tally typical of the basement terrain is shown in Figure 5. The screen was positioned below the fractured zone. Wells in the Basement rock terrains are generally low in yield and transmissivity compared to the Sedimentary area while the transition zones have moderate values.

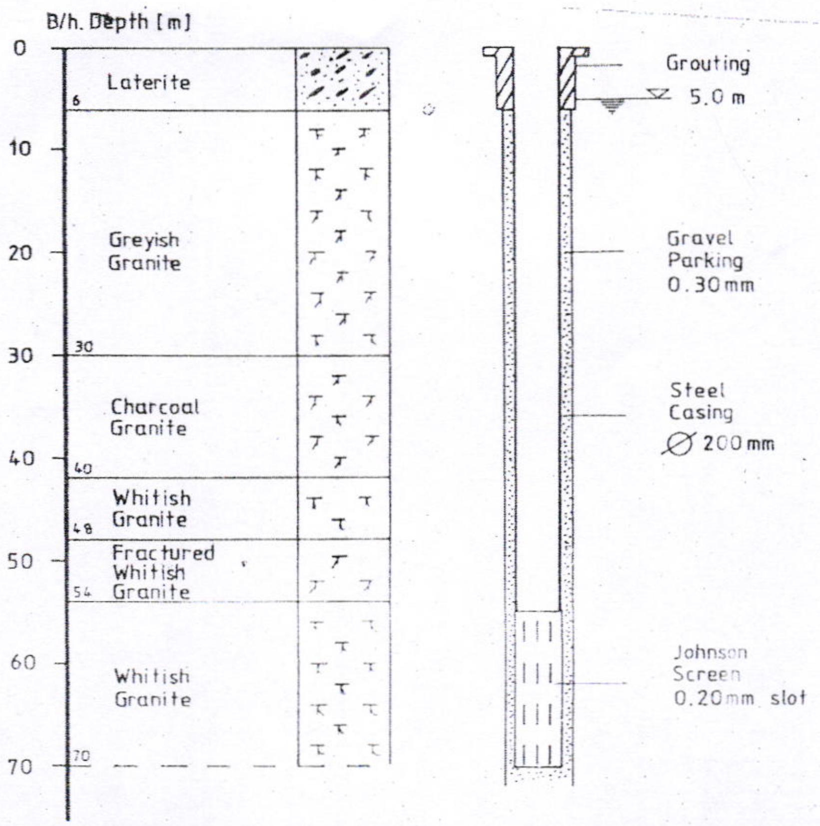

Fig. 5: A typical borehole-log and casing tally in the Basement complex showing the geologic sections.

Physical Parameters

The results of the physical, chemical and bacteriological analyses are contained in Table 3. Generally, the results of the groundwater samples in the area indicated that the water is odourless, colourless and clear in appearance. The pH values ranged from 6.3-8.1 with an average value of 7.17 and these values fall within the acceptable pH range of 6.5-8.5 by the World Health Organization (WHO, 2006) and the Nigerian Industrial Standard (NSDWQ, 2007). The total dissolved solid (TDS) varied from 65.6 mg/l to 184.3 mg/l with an average value of 116.6 mg/l while dissolved oxygen (DO) ranged from 0.74 mg/l to 5.54 mg/l with a mean value of 2.03 mg/l. The concentrations are below the permissible limits of WHO, (2006) and NSDWQ, (2007). Electrical Conductivity ranged from 98mg/l to 275 mg/l with a mean value of 176.6 mg/l while turbidity varied from 1.12 mg/l to 16.25 mg/l with an average value of 11.29 mg/l. Temperature is of the order of 24.8°C to 29.7°C with a mean temperature of 26.3°C. The concentration of the physical parameters analyzed were lower than the maximum allowable guideline value by the WHO (2006) and NSDWQ (2007) except turbidity in locations 6 and 7 (Urapna and Dutse-Oho in Rijau LGA) having 16.0 NTU and 16.25 NTU respectively as against the permissible value of 5 NTU (WHO, 2006 and NSDWQ, 2007). The groundwater in these locations is cloudy in appearance, which may reduce its usability.

Microbial Parameters

The microbial analyzes carried out on the groundwater samples were total coliform and E.coli (Table 3). There were no E.coli detected in the 16 samples analyzed while the concentration of total coliform are below the WHO and NSDWQ guideline values for a safe drinking water, which implies that most of the groundwater in the area are free from bacteriological contamination.

Chemical Parameters

Ammonian gas had values that ranged from 0-0.94 mg/l and a mean value of 0.12 mg/l while ammonia concentration varied from 0-0.96 mg/l with an average value of 0.13 mg/l. Ammonium is of the order of 0-1.04 mg/l with a mean of 0.15 mg/l. The concentration of chloride ranged from 15.99 mg/l to 137.95 mg/l with a mean value of 44.55 mg/l while fluoride varied from 0-13 mg/l with an average value of 1.02 mg/l. Sulphate concentration ranged from 13.0 mg/l to 35 mg/l with a mean value of 23.2 mg/l while phosphate varied from 0-1.77 mg/l with an average value of 0.23 mg/l. Phosphorus is of the order of 0-0.57 mg/l and a mean value of 0.11mg/l while phosphate penta-oxide varies from 0-1.32 mg/l with an average value of 0.13 mg/l. The low concentration of phosphate in the area indicates a controlled application of phosphate-rich fertilizer in the area. The concentration of magnesium varied between 0.97mg/l and 7.81mg/l with a mean value of 2.13 mg/l while calcium ranged from 7.62 mg/l to 30.48 mg/l with an average value of 9.57 mg/l. The concentration of iron ranged from 0-1.16mg/l with a mean value of 0.19 mg/l while manganese varied from 0-0.03 mg/l with an average value of 0.005 mg/l. Copper is of the order of 0-1.16 mg/l and a mean value of 0.23 mg/l. The concentration of iron, manganese and copper fall within the tolerable limits as recommended by WHO (2006) and NSDWQ (2007). The mean concentrations of calcium and magnesium hardness are 24.46 mg/l and 8.33 mg/l respectively. Their presence is responsible for hardness in water, which is the tendency of water not to foam easily with soap. Calcium is vital for strong bone and tooth formation in animals. Nitrate concentration varied from 0-15 mg/l with a mean value of 4.61mg/l while nitrite ranged from 0-0.17 mg/l with an average value of 0.03 mg/l. Nitrogen is of the order of 0-3.4 mg/l and a mean value of 1.24 mg/l. These values are far below the maximum acceptable value of 50mg/l by NSDWQ (2007) and WHO (2006). It implied that the use of nitrate-rich fertilizer in the area is very minimal and the groundwater is free from natural and anthropogenic contamination.

Table 2: Gheorghe and Krawny Standards for Transmissivity

Gheorghe (1978)		Krawny (1993)		k m/day	Materials
T	Potential	T	Potential	0.01-0.2	Surface Clay
	High	: 1,000	Very High	-	Deep Clay
50	Moderate	100-1,000	High	0.1-1	Surface Loam
5-	Low	10-100	Intermediate	1-5	Fine Sand
0.5-	Very Low	1-10	Low	5-20	Medium Sand
	Negligible	0.1-1	Very Low	20-100	Coarse sand
			Imperceptible	100-1,000	Gravel
				5-100	Sand & Gravel

Parameters	L-1	L-2	L-3	L-4	L-5	L-6	L-7	L-8	L-9
Appearance	Clear	Clear	Clear	Clear	Clear	Slightly Cloudy	Slightly Cloudy	Clear	Clear
Colour	Colorless	Colorless	Colorless	Colorless	Colorless	Colorless	Colorless	Colorless	Colorless
Odour	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless
pH	7.48	7.43	7.24	7.12	7.45	6.77	6.81	7.4	6.9
TDS	104.50	131.99	117.12	152.76	115.24	73.03	77.72	36.45	98.6
Dissolved O_2	1.10	1.11	1.23	0.74	1.41	1.25	1.20	0.05	0.9
Temperatures	25.2	25.4	25.2	25.2	25.2	26.1	26.2	24.8	28.3
Conductivity	156.0	197.0	173.0	228.0	172.0	109.0	116.0	155.0	131.0
Turbidity	5.5	4.7	5.1	4.6	4.8	16.0	16.25	9.0	8.5
Ammonia gas	0.01	0.08	0.02	0.08	0.07	ND	ND	0.8	0.04
Ammonia	0.012	0.096	0.024	0.96	0.084	ND	ND	ND	0.08
Ammonium	0.013	0.104	0.026	1.04	0.091	ND	ND	ND	0.1
Chloride	24.99	19.99	27.49	22.49	24.99	16.49	15.99	16.5	23.67
Fluoride	0.35	0.00	0.45	0.21	0.30	0.38	0.18	0.41	0.32
Sulphate	30.0	19.0	35.0	13.0	19.0	ND	ND	20.9	26.1
Phosphate	ND	ND	ND	1.77	ND	0.91	0.27	0.15	0.04
Phosphorus	ND	ND	ND	0.57	ND	0.30	0.09	0.3	0.2
P_2O_5	ND	ND	ND	1.32	ND	0.68	0.20	0.23	0.28
Total Hardness	44.04	66.05	52.05	80.07	50.04	33.0	41.0	59.7	65.3
Magnesium	1.95	7.81	2.93	0.97	1.95	ND	ND	3.4	6.8
Calcium	14.44	13.64	16.05	30.48	16.84	ND	ND	15.3	19.6
Mg^{2+} Hardness	8.01	32.02	12.01	4.01	8.0	13.2	16.4	13.4	11.5
Ca^{2+} Hardness	36.03	34.03	40.04	76.06	42.04	19.8	24.6	38.07	46.7
Copper	0.10	0.15	0.14	0.14	ND	ND	ND	0.21	0.12
Iron	ND	0.01	ND	0.04	0.01	ND	ND	0.19	0.15
Manganese	ND	ND	ND	0.030	ND	ND	ND	0.002	0.01
Nitrate	ND	ND	ND	11.70	ND	15.0	6.4	5.11	14.3
Nitrogen	ND	ND	0.04	2.70	ND	3.4	1.4	1.23	2.2
Nitrite	0.03	0.07	0.04	0.027	0.06	0.0075	0.005	0.03	0.06
Alkalinity	63	102	53	90	68	23	38	76	42.3
Total Coliform	0	5	4	2	0	7	2	4	5
E-Coli	0	0	0	0	0	0	0	0	0

Parameters	L-10	L-11	L-12	L-13	L-14	L-15	L-16	Range	Mean
Appearance	Clear	Clear	Clear	Clear	Clear	Clear	Clear	-	-
Colour	Colorless	Colorless	Colorless	Colorless	Colorless	Colorless	Colorless	-	-
Odour	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	-	-
pH	7.30	7.03	6.77	6.30	8.1	7.6	6.79	6.3 8.1	7.16
TDS	127.97	165.49	150.75	103.85	184.25	138.69	65.66	65.66 - 184.25	122.07
Dissolved O_2	1.09	1.85	4.81	5.03	2.1	5.54	3.11	0.74 -5.54	2.26
Temperatures	26.0	26.0	24.8	27.0	28.9	29.7	26.6	24.8 29.7	26.25
Conductivity	191	247	225	155	275	207	98	98 275	182.07
Turbidity	3.92	5.02	4.75	1.36	3.4	5.82	1.12	1.12- 16.25	5.88
Ammonia gas	0.00	0.00	0.77	0.00	ND	0.00	ND	0 0.94	0.085
Ammonia	0.00	0.00	0.934	0.00	ND	0.00	ND	0 0.96	0.18
Ammonium	0.00	0.00	1.001	0.00	ND	0.00	ND	0 1.04	0.19
Chloride	31	25.99	137.95	30.99	29.99	25.99	31.99	15.99 137.95	33.31
Fluoride	0.10	0.29	ND	ND	13	0.29	0.17	0 13	1.31
Sulphate	ND	ND	ND	ND	ND	ND	ND	13 35	23.2
Phosphate	ND	ND	ND	ND	0.70	ND	ND	0 1.77	0.46
Phosphorus	ND	ND	ND	ND	ND	ND	ND	0 0.57	0.14
P_2O_5	ND	ND	ND	ND	ND	ND	ND	0 1.32	0.31
Total Hardness	78.07	106.09	96.08	37.03	76	48.06	37	33 106.09	60.32
Magnesium	ND	ND	ND	ND	5.13	ND	3.17	0.97 7.81	3.41
Calcium	ND	ND	ND	ND	7.62	ND	9.62	7.62 30.48	15.52
Mg^{2+} Hardness	ND	ND	ND	ND	ND	ND	13	4.01 -32.02	13.33
Ca^{2+} Hardness	ND	ND	ND	ND	ND	ND	24	19.8 76.06	37.07
Copper	0.39	1.16	0.59	0.08	ND	0.01	0.00	0 1.16	0.23
Iron	0.01	0.00	0.00	0.14	0.00	0.00	0.04	0 0.14	0.019
Manganese	ND	ND	ND	ND	ND	ND	ND	0 0.03	0.005
Nitrate	3.4	3.9	14.08	7.2	1.18	3.9	ND	0 15	5.14
Nitrogen	0.8	0.9	3.2	1.6	ND	0.9	ND	0-3.4	1.24
Nitrite	0.0	0.00	ND	0.00	ND	0.0	0.17	0 0.17	0.03
Alkalinity	70	73	150	72	ND	70	16	16 150	68.30
Total Coliforms	0	0	0	0	0	0	0	0- 7	1.53
E-Coli	0	0	0	0	0	0	0	0 0	0

ND-Not Detected

CONCLUSION

The groundwater quality in the area was assessed through physio-chemical and microbial analyses carried out in the laboratory while the groundwater potential were evaluated using pumping test data obtained in the field. The groundwater potential indicate a variation of low to high while the laboratory analyses shows a contaminant free groundwater sources. The physio-chemical and microbial analyses were found to be below the maximum permissible limits recommended by World Health Organization. The groundwater sources in the whole of Niger state can be used to supplement existing water supply provided adequate investigations and supervised drilling are made. The Basement Complex, Transition Zone and Sedimentary Terrain correspond to low, moderate and high groundwater potentials respectively. At every location, the transmissivity value obtained using Theis method was higher compared to values obtained using Jacob method. Theis method is more reliable because it tests the natural ability of the aquifer, by making use of the recovery method which cannot be influenced by human interference. Within the Basement terrain, the degree of fracturing varies with higher values in areas close to the transition zone.

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