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GROUNDWATER OCCURRENCE AND DEVELOPMENT IN THE DAURA AREA OF KATSINA STATE, EXTREME NORTHERN NIGERIA

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ABSTRACT

Groundwater resources of the Cretaceous Gundumi Formation and the underlying crystalline basement rocks have always been the source of water supply in Daura. Records of thirty-one boreholes drilled in the area between 1959 and 1996 were reviewed to deduce the hydrogeology of the area. The lithology of the study area obtained from strata logs and geophysical survey comprises decomposed crystalline rocks overlain by basal conglomerate, loosely cemented gravely sandstone, ferruginous sandstone and clay horizons, capped in places by laterite or silty fine sands. The area is divided into the northern and southern wellfields with average thicknesses of the Gundumi Formation of 50 m and 35 m, respectively. The average yield of the productive boreholes is 4.1 lps. The aquifer of the Gundumi Formation in the Daura area has low to moderate groundwater potential. However, the low capacities of the production boreholes are adequate to sustain the domestic water requirements of the population. Borehole site selection should be based on geophysical investigation, while the drilling rig should be capable of both rotary and downhole-hammer drilling. The borehole completion materials should be resistant to corrosion because of the low pH of the groundwater. The quality of the groundwater is generally suitable for domestic uses, though aeration or lime treatment may be necessary in some cases because of the slightly acidic nature of the groundwater.

Contribution/Originality: This study is one of the very few studies which have investigated the aquifer properties, groundwater potential and quality in the Daura area of Katsina State, Nigeria using geophysical, borehole and physicochemical data, in a view to appraise the groundwater resources, improve borehole siting, construction and development in the area.

1. INTRODUCTION

1.1. Background

Water means life. It is no doubt the most precious resource on earth. Despite the fact that nearly three-quarters of the surface of the earth is covered by water, groundwater occurs more widely than surface water (Offodile, 1992). However the availability of groundwater is limited by so many factors, including the permeability of rocks in the zone of saturation, the ability of the zone of saturation to support long-term practical exploitation and whether or not the chemical composition is within tolerable limits (Offodile, 1992). In order to meet the domestic, agricultural and industrial needs of the people, the search for potable water has often been extended into the subsurface.

1.2. Geological Settings

Daura town is situated in Daura Local Government Area of Katsina State in northern Nigeria. Daura is 80 km east of Katsina town near the border of Niger Republic, approximately centred on latitude 13° 06' N and longitude 08° 21' E (Figure 1). The sedimentary strata of Katsina-Daura area belong to the Cretaceous Gundumi Formation on the southeastern fringe of the lullemenden basin, referred to locally as the Sokoto basin. The Katsina-Daura sedimentary strata lies on the north-eastern part of the Sokoto basin and are bordered on the south by crystalline Basement Complex rocks and on the north by the Nigeria-Niger Republic borders (Figure 1).

The main occupation of the Daura people are farming (livestock and crop production) and traditional handicrafts (Katsina State Government, 2016); although more recently, there have been the establishment of some industrial and administrative centres. The farming activities rely heavily on the availability of water. The Daura Water Supply Scheme covers Daura Municipality, the villages of Dunu, Gurjiya and Karkarku south of Daura along Daura - Sandamu Road, and Sandamu Municipality, about 12 km south-east of Daura. Due to the attendant problems of lack of good quality surface water and the irregular water supply by the Daura Water Supply Scheme, groundwater exploration became necessary.

The development of groundwater in the Daura area began with the villagers constructing hand-dug wells near their settlements to tap groundwater. However this method depends on chance and luck in digging water-bearing horizons. This haphazard approach does not always yield desired results. The use of boreholes in the exploitation of groundwater in Daura area started around 1957 (Geological Survey of Nigeria, 1957). Subsequently, due to the poor performance of some of the boreholes, the rehabilitation of existing boreholes in Daura and its environs under the National Water Rehabilitation Project - Zone "B" between 1992 and 1996 began.

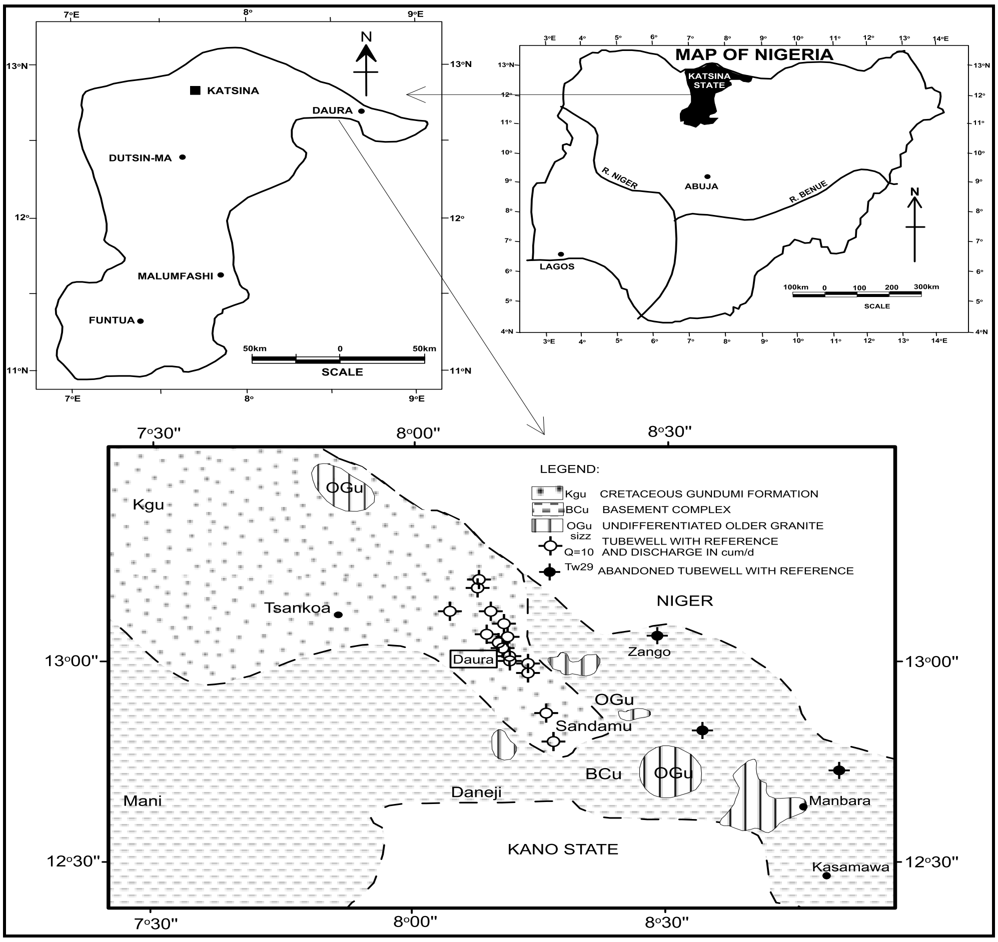

Figure-1. Location of Daura in Katsina State, Nigeria.

Till date, the shortage in potable water supply is still a problem in Daura area and in fact most rural communities in Nigeria (Ahmad & Daura, 2019). In 2006, the projected population of Daura area comprising Daura, Sandamu and the three villages of Dunu, Gurjiya and Karkarku was 224,884, while the projected water demand for the year 2005 was 11.67 million litres per day (Mlpd) from the existing water supply of 2.25 Mlpd in 1995 (Parkman Consultants, 1994). The population of the area as at the year 2016 had grown to a projected population of 303,600 (City Population, 2016) without a corresponding growth in water supply. This has worsened the crisis of potable water shortage. There is therefore the need to evaluate the water-bearing potential of the aquifer within Daura area, as well as determine the groundwater quality and recommend strategies to optimize groundwater exploitation through borehole in the Daura area and by extension, other similar terrains in northern Nigeria.

1.3. Available Data

Records of thirty-one boreholes drilled in the study area were available for this study (Table 1). There are information on depths of borehole, drawdowns, pump tested well yields as well as screened intervals. Twenty-one boreholes have lithologic logs, fifteen boreholes have records of resistivity depth sounding survey comprising resistivity values and thicknesses of strata encountered. Twenty-six boreholes have pump test data, including aquifer thickness.

Among the available records of thirty-one boreholes only twenty-six boreholes can be located on the map. This information was used to prepare the depth to water-table map. Only sixteen out of the twenty-six boreholes have lithological logs. The structural interpretation of the aquifer was based on this information.

Results of laboratory analysis of groundwater samples in terms of chloride and sulphate content, alkalinity, pH and hardness conducted by Katsina State Water Board were also available for use in this study. However the result of the chemical analysis of the groundwater samples did not indicate which groundwater sample belongs to which borehole. Regardless of this limitation an idea of the general groundwater quality in the area could still be determined.

2. METHODS AND MATERIALS

The data obtained from the record of thirty-one boreholes were analysed to determine the hydrogeology of the area. The available pump test data were evaluated to determine the hydraulic properties of the aquifer. These properties are transmissivity (T), hydraulic conductivity (K) and specific capacity (Q/s). The suitability of the groundwater for domestic uses was also determined from the available groundwater quality data. Recommendations on the appropriate groundwater development strategies for the area were made based on the results of the data analyses.

3. HYDROGEOLOGY

3.1. Geophysical Investigation for Groundwater

In groundwater exploration, geophysical survey is an important tool in identifying subsurface features in which groundwater occurs. The geophysical method used in the groundwater exploration in the study area is the resistivity depth sounding technique.

The results of the resistivity depth soundings was interpreted to give the various lithology encountered and their depth of occurrence (Table 2). All the results show a bottom layer with low resistivity which is indicative of decomposed Basement Complex rocks. The base of the decomposed Basement rocks could not be established from the results, thus the depth to fresh rock could not be determined.

Table-1. Summary of Borehole Completion.

S/N	Borehole	Year of Completion	Depth (m)	Aquifer Thickness (m)	Screen Interval (m)	Initial WL (m)	Pumping WL (m)	Drawdown (m)	Yield (lps)
1	DR1	1959	56.39	12	34.1 – 56.4	18.10	23.10	5.00	3.75
2	DR2	1959	56.69	12	N.A	18.10	24.05	5.95	2.00
3	DR3	1969	78.33		43.3 – 50.0	18.59	N.A		3.13
4	DR4	1959	45.72	12	30.4 – 41.2	19.80	25.90	6.10	2.50
5	DR5	1959	51.82		44.1 – 47.3	15.24	N.A		3.75
6	DR6	1978	44.81		14.7 – 21.3 35.8 – 40.4	12.40	18.20	5.80	7.00
7	DR7	1978	52.73		13.7 – 18.9 26.2 – 31.4 41.5 – 46.6	11.10	13.67	2.57	13.22
8	DR8	1988	56.00	12	32.1 – 42.1 48.1 – 54.1	16.83	28.55	11.72	3.10
9	DR9	1978	38.10		13.9 – 24.0 28.4 – 32.8	6.40	8.53	2.13	13.22
10	DR10	1989	39.00	8	28.5 – 37.5	12.20	22.89	10.69	2.70
11	DR11	1988	63.50	16	39.3 – 45.3 51.3 – 57.3	10.65	26.29	15.64	2.10
12	DR12	1988	63.50	20	48.3 – 51.3 54.3 – 60.3	8.60	23.95	15.35	1.60
13	DR13	1978	66.00		N.A	N.A	N.A	N.A	1.52
14	DR14	1988	61.00	20	44.5 – 47.5 52.5 – 58.5	7.23	26.12	18.89	3.20
15	DR15	1988	48.90	16	33.2 – 36.2 41.4 – 47.4	6.36	28.16	21.80	3.10
16	DR16	1978	54.00		N.A	N.A	N.A	N.A	2.20
17	DR13/96	1996	53.00	28	28.5 – 34.5 40.5 – 43.5 48.3 – 51.3	12.06	37.06	25.00	3.50
18	DR14/96	1996	69.00	32	32.0 – 35.0 44.0 – 47.0 58.5 – 64.5	8.00	34.64	26.64	4.00
19	DR15/96	1996	65.00	34	26.2 – 29.0 35.2 – 38.0 54.0 – 60.0	11.62	32.08	20.46	5.00
20	DR16/96	1996	63.00	33	22.6 – 32.1 51.6 – 48.6 54.6 – 60.6	7.00	28.00	21.00	5.00
21	DR17/96	1996	59.00	26	26.0 – 29.0 42.0 – 48.0 54.0 – 57.0	9.13	44.13	35.00	3.00
22	DR18/96	1996	45.00	20	22.5 – 25.5 31.5 – 37.5	12.38	17.38	5.00	4.25
23	DR19/96	1996	43.00	15	21.2 – 24.2 31.2 – 36.2	11.45	25.45	14.00	3.00
24	DR20/96	1996	49.00	22	21.0 – 24.0 30.0 – 39.0	8.45	28.45	20.00	4.25
25	DR21/96	1996	49.00	12	24.0 – 27.0 33.0 – 39.0	7.85	31.05	23.20	3.50
26	DR22/96	1996	46.00	15	24.0 – 27.0 33.0 – 39.0	10.10	30.92	20.82	3.00
27	BH30	1996	60.00	14	30.8 – 33.8 49.8 – 55.8	8.02	40.00	31.98	1.00
28	BH32	1996	60.00	11	28.0 – 34.0 46.0 – 49.0 55.0 – 58.0	8.00	52.00	44.00	1.00
29	BH33	1996	61.00	15	30.8 – 33.8 49.8 – 55.8	9.50	52.00	42.50	<1
30	BH35	1996	65.00	30	39.0 – 45.0 51.0 – 57.0	9.00			<1
31	BH44	1996	58.00	12	30.0 – 39.0	12.55	21.20	8.65	4.25

3.2. Lithology

The drilling records which are closely correlated by the geophysical results show an indurated basal conglomerate overlying the decomposed crystalline rocks unconformably. This layer is shown in the geophysical survey results as a layer of relatively high resistivity (Table 2). This layer is overlain by loosely cemented gravelly sandstone of moderate resistivity values, indurated ferruginous sandstone and clayey horizons. There is much lithological variation both laterally and vertically and the whole sequence is capped in places by laterite.

Table-2. Interpretations of the vertical electrical sounding (VES) Survey in Daura Area.

VES Number	Resistivity (Ohm-m)	Depth (m)	Lithology
VES DA2	250	0.3	Sand
	690	1.0	Laterite
	60	4.0	Clay
	120	9.0	Sand
	680	43.0	Sandstone
	160	Unknown	Decomposed basement
VES DA3	1330	1.1	Hard laterite
	88	4.0	Clay
	330	20.0	Loosely cemented sandstone
	600	50.0	Sandstone
	400	Unknown	Decomposed basement
VES DA4	1100	0.7	Indurated laterite
	60	3.5	Clay
	380	15.0	Loosely cemented sandstone
	560	38.0	Sandstone
	230	Unknown	Decomposed basement
VES DA12	550	0.5	Sand
	40	2.0	Clay
	300	6.0	Loosely cemented sandstone
	530	25.0	Sandstone
	200	Unknown	Decomposed basement
VES DA13	2000	0.4	Indurated laterite
	50	2.3	Clay
	150	5.0	Sand
	400	20.0	Loosely cemented sandstone
	290	Unknown	Decomposed basement
VES DA14	1300	1.0	Indurated laterite
	60	3.0	Clay
	100	6.0	Sand
	600	35.0	Sandstone
	300	Unknown	Decomposed basement
VES DA15	700	0.6	Indurated clay
	53	5.0	Clay
	480	30.0	Sandstone
	100	Unknown	Decomposed basement
VES DA16	600	0.6	Sand
	100	3.0	Clay
	220	12.0	Sand
	380	50.0	Loosely cemented sandstone
	250	Unknown	Decomposed basement
VES DA17	500	0.2	Drift (Sand)
	1400	1.4	Hard laterite
	150	10.0	Sand
	400	40.0	Loosely cemented sandstone
	200	Unknown	Decomposed basement
VES DA19	240	1.1	Sand
	40	3.0	Clay
	260	10.0	Sand
	550	35.0	Sandstone
	250	Unknown	Decomposed basement

3.3. Aquifer Systems

The aquifers in the study area are formed by the basal conglomerate overlying the Basement Complex rocks, the loosely cemented gravelly sandstone and the decomposed crystalline rocks. From the strata logs the aquifer system is essentially unconfined and groundwater occurs under water table conditions. However where the aquifer is overlain by clay or hard indurated laterite, locally confined aquifer may occur. This situation was encountered in some boreholes, when during drilling, the first inflow of water into the hole was noted at a deeper depth but the final static water level after drilling occurred at shallower depths (Parkman Consultants, 1994). This shows that the water has moved upwards under a confining pressure to shallower depths.

Table-2. (Cont'd): Interpretations of the Vertical Electrical Sounding (VES) Survey in Daura Area.

VES Number	Resistivity (Ohm-m)	Depth (m)	Lithology
VES DA29	650	0.5	Sand
	800	1.4	Laterite
	430	5.0	Sandstone
	200	8.0	Sand
	450	40.0	Sand conglomerate
	700	Unknown	Decomposed basement
VES DA32	1850	0.7	Laterite
	130	2.6	Sand
	240	7.0	Sand
	450	38.0	Sandstone
	100	Unknown	Decomposed basement
VES DA33	1200	0.8	Hard laterite
	710	1.7	Laterite
	120	5.0	Sand
	600	32.0	Sandstone
	120	Unknown	Decomposed basement
VES DA37	1200	2.0	Hard laterite
	550	4.0	Sandstone
	200	12.0	Sand
	400	45.0	Loosely cemented sandstone
	800	Unknown	Conglomerate

Source: Parkman Consultants (1994).

The correlation of strata from borehole lithologic logs in the northern and southern wellfields Figure 2 as well as geological section deduced from geophysical data (Figure 3) shows the aquifer zones to be generally continuous horizontally. The clay horizon and the hard indurated laterite are not horizontally continuous, hence the greater portion of the aquifer is unconfined. There is also an alternation of clayey sands which in some cases are indurated and act as aquicludes with respect to the main water-bearing horizons.

From the correlation sections the average aquifer thickness is about 50 m in the northern part of the study area. In the southern part of the study area the average aquifer thickness is about 35 m. Thus the aquifers of the northern wellfield have a higher water-bearing potential than the aquifers in the southern wellfield.

3.4. Groundwater Occurrence and Flow Conditions

In the Daura area the occurrence of groundwater is controlled by the geology of the area. Groundwater occurs under water table conditions in cracks and fissures of the sandstone and conglomeratic beds, in the surface laterite and in the decomposed basement rocks. The loosely cemented, coarse grained sandstone and conglomeratic horizons form good aquifers.

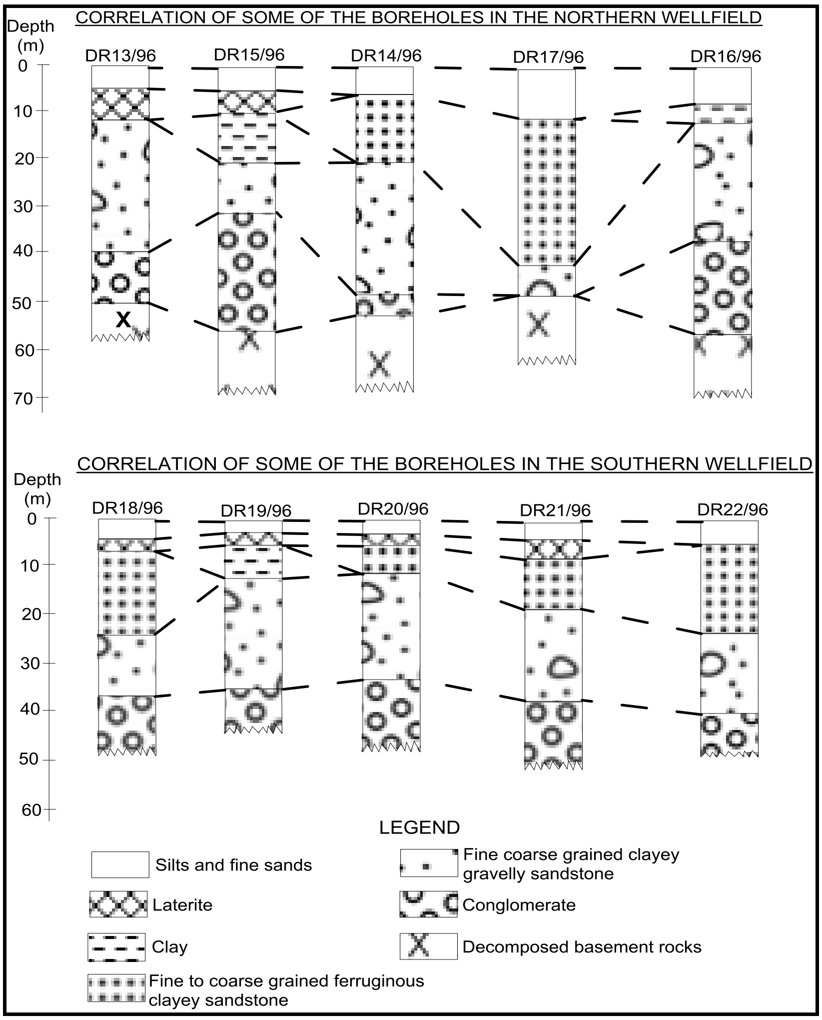

Figure-2. Correlation of Boreholes.

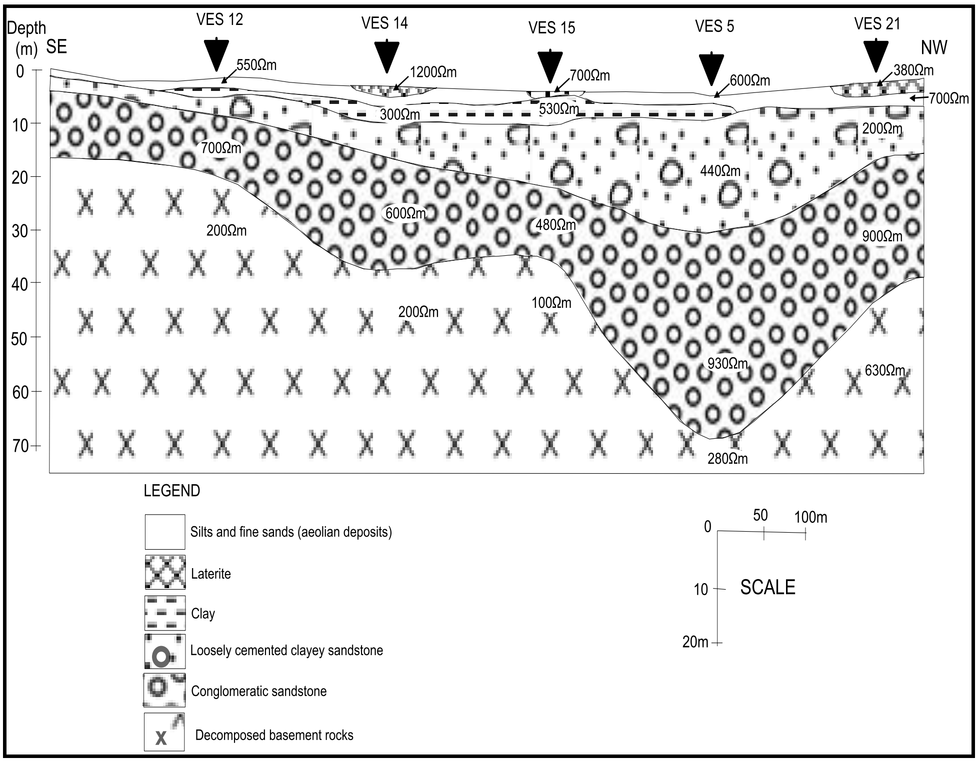

Figure-3. Geological Section of the Northern Wellfield from Geophysical Data

The water-bearing potential of the aquifers of the Gundumi Formation decreases towards the margin of the outcrop and near to the basement inliers because the sediments are too thin to contain groundwater in these areas. This is evident in the yields of the boreholes in the southern wellfield which are generally lower than those in the northern well fields (Parkman Consultants, 1994).

Measurements of static water levels in the thirty one boreholes used for this study indicate that the depth to regional water table ranges from 6.40 to 19.80 m, with an average depth to static water level in the northern and southern parts of the study area as 10 m and 14 m, respectively. The water table has remained fairly constant when compared with the water table map prepared by Jones (1957). This indicates that the increased abstraction of groundwater from the aquifer over the years has not significantly lowered the water table. Due to the sandy and permeable nature of the superficial deposits in the study area, it is probably that little rainfall is lost by direct runoff (Jones, 1957).

The static water levels were used to establish the groundwater flow direction in Daura area. The main groundwater flow direction in the study area is northwards from the southern parts. However groundwater also flows in the northeast direction because near the Kongolam River which flows in the northeast direction, a hand-dug well was observed to be free flowing in the rainy season (Ajayi, 1993; Haskoning Engineering Consultants, 1995) indicating effluent flow of groundwater into the river. Figure 4 shows the location of boreholes, depth to water tables and direction of groundwater flow in the study area.

3.5. Analysis and Interpretation of Pumping Test Data

In the study area pumping tests were carried out on twenty-six boreholes by pumping the boreholes at a constant rate for between 12 and 24 hours. The drawdowns were measured in the production boreholes being pumped. There were no observation wells used during the pumping test.

The available pump test data were used to evaluate hydraulic properties of the aquifer at 26 locations. These properties are transmissivity (T), hydraulic conductivity (K) and specific capacity (Q/s). The storage coefficient or storativity of the aquifer could not be determined from the available data because there were no observation wells drilled for the pumping tests.

The available data from which these aquifer properties were determined include the pump test yields, the drawdown, the discharge rates and the approximate aquifer thickness. In evaluating transmissivity values the Logan equation described by Kruseman and DeRidder (1970) was used. The method was developed for wells in confined aquifers with steady state conditions and it is a simplification of the Theim formula (Equation 1):

$$\frac{KD}{2\pi s_{max}} = 2.30 \times Q\log {}^{r_{max}}/_{r_w} \tag{1}$$

where:

KD = transmissivity value (m^2 day^{-1}).
Q = pump discharge (m^3 day^{-1}).
r_{max} = radius of cone of depression well (m).
r_w = radius of pumped well (m).
s_{max} = maximum drawdown in the pumped well (m).

The ratio Q/s cannot be accurately determined because it is difficult to determine without the use of observation wells. The variation in r_{max} and r_w may be substantial, but the variation in the logarithm of their ratio is much smaller. Thus assuming average conditions of radii, a value of 3.33 for the log ratio may be assigned as a rough approximation. This leads to the Equation 2.

$$\frac{KD}{2\pi s_{max}} = 1.22 \times Q \qquad 2$$

Q and s_{max} are readily available from the pump test data and this method is clearly feasible for estimating transmissivity values, although it gives a rough estimate of the actual values. This method is very useful where other methods of analysis of pump test data are not feasible.

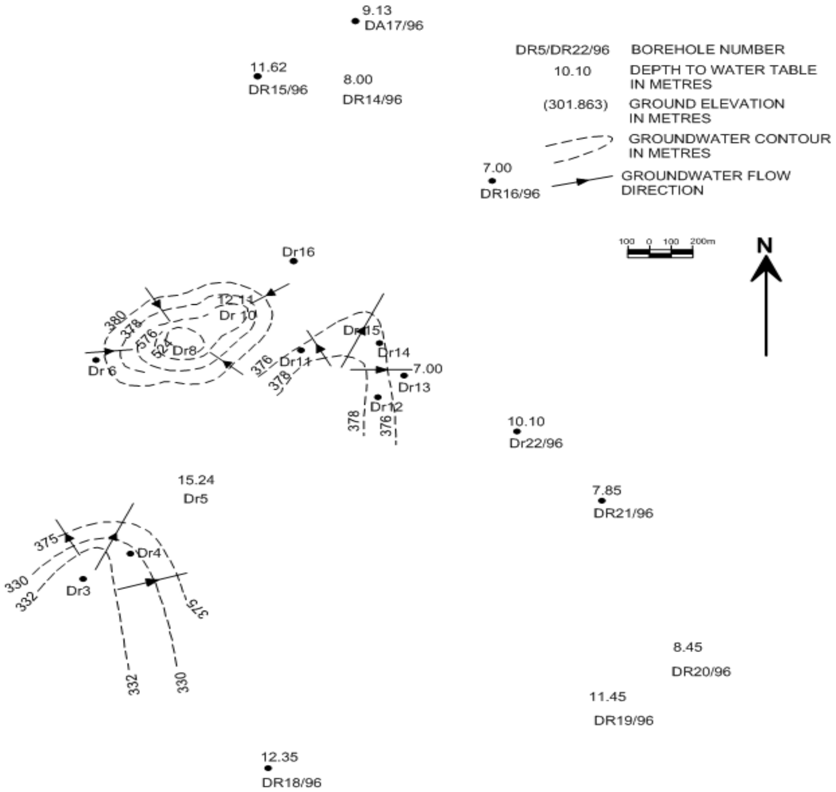

Figure-4. Map Showing the Location of Boreholes and Groundwater Flow Direction.

The method is simple and removes the subjectiveness of the straight line graph method, especially where there is a lot of scatter in the data. The method can also be used in groundwater reconnaissance survey. Hydraulic conductivity was determined from Equation 3.

$$K = T/D \qquad 3$$

where:

K = hydraulic conductivity (m day^{-1}).

T = transmissivity (m^2 day^{-1}).

D = aquifer thickness (m).

Specific capacity (Q/s) of a well is defined as the pumping rate or yield per unit drawdown, where Q is the yield or discharge rate (L^3T^{-1}) and s is the drawdown in the well at the end of pumping period (L). The specific capacity of a well decreases with time for a given pumping rate because drawdown increases with time under a non-equilibrium condition. The specific capacities of the aquifer in the study area were determined at 12 hours, after pumping started, for some boreholes and at 24 hours, after pumping started, for other boreholes depending on the pumping history of the boreholes. The summary of the aquifer properties determined from the available data are shown in Table 3.

Table-3. Summary of aquifer properties.

BH Code	Aquifer Thickness (m)	T (m^2 day^{-1})	K (m^1 day^{-1})	Q/s (m^2 hr^{-1})
DR1	12	79.1	6.60	2.70
DR2	12	53.4	4.40	1.21
DR4	12	43.2	3.60	1.48
DR6	-	127.2	-	4.30
DR7	-	542.2	-	18.50
DR8	12	27.9	2.30	0.95
DR9	-	654.2	-	22.30
DR10	8	6.9	0.90	0.24
DR11	16	14.2	0.90	0.48
DR12	20	11.0	0.50	0.38
DR14	20	17.9	0.90	0.61
DR15	16	15.0	0.90	0.51
DR13/96	28	19.0	0.68	0.65
DR14/96	32	12.3	0.38	0.42
DR15/96	34	25.0	0.74	0.84
DR16/96	33	21.1	0.64	0.72
DR17/96	26	13.0	0.50	0.44
DR18/96	20	105.4	5.27	3.60
DR19/96	15	30.1	2.00	1.03
DR20/96	22	17.4	0.79	0.60
DR21/96	12	16.4	1.37	0.56
DR22/96	15	18.2	1.21	0.62
*BH30	14	2.6	0.18	0.09
*BH32	11	2.0	0.18	0.09
*BH33	15	1.2	0.08	0.04
*BH44	12	9.9	0.83	0.34

*Abandoned borehole

3.6. Groundwater Quality

The chemistry of groundwater in any geological environment is controlled by such factors as the chemistry of the infiltrating water at the recharge source, the chemistry of the porous medium and the travel time or residence time of groundwater in aquifer medium which is dependent on the rate of groundwater flow in the medium (Offodile, 1992). The quality of the groundwater depends on the concentration of the chemical constituents dissolved in the water.

Table 4 shows the summary of the results of the groundwater chemistry in the study area. This summary includes chemical analysis of groundwater samples taken from boreholes DR6, DR7 and DR9; another set of results which did not indicate which sample was taken from which borehole.

The pH of the groundwater range from 4.51 to 7.50. The pH of water determines its corrosive properties and it is also useful in determining proper treatment for coagulation at water treatment plants (Yongjun & Kinjal, 2019).

The total hardness as $CaCO_3$ ranges from 5.00 ppm to 168.00 ppm. Hardness of water is recognized by the amount of soap needed to produce lather. Hard water requires a lot of soap to form lather while soft water produces lather easily with soap.

The chloride content ranges from 3.55 ppm to 24.10 ppm. There are no traces of sulphate ions in the groundwater samples analysed. Total nitrate in ppm was not determined for most of the groundwater samples. However the nitrate values obtained range between 0.30 and 3.53 ppm. Also total iron range from trace amount to 0.20 ppm. Total dissolved solids were not determined for most of the water samples.

Table-4. Summary of the results of chemical analyses of groundwater samples.

Borehole or Lab Code	pH	Alkalinity (Bicarb) as $CaCO_3$ (ppm)	Alkalinity (Carbon) as $CaCO_3$ (ppm)	Total Alkalinity as $CaCO_3$ (ppm)	CO_2 (ppm)	Chloride (ppm)	Fluoride (ppm)	SO_4 (ppm)	Total Hardness as $CaCO_3$ (ppm)	Total Fe (ppm)	Total N (ppm)	Total Dissolved Solids (ppm)
DR6	6.60	5.00	Nil	5.00	7.00	3.55	0.10	NT	5.00	0.15	3.53	ND
DR7	6.20	4.00	Nil	4.00	8.00	7.09	0.10	NT	40.00	0.20	0.30	106.00
DR9	5.50	0.40	Nil	0.40	10.00	17.73	0.20	NT	44.00	TR	3.45	54.00
WBC/CA/DR/6H/3/1/89	ND	24.00	Nil	24.00	114.00	24.10	ND	NT	168.0	ND	ND	ND
WRL/CA/DR/BH/4/1/89	ND	40.50	Nil	40.50	98.00	21.30	ND	NT	132.0	ND	ND	ND
WBL/CA/DR/BH/4/2/89	7.30	24.00	Nil	24.00	84.00	19.80	ND	NT	128.0	ND	ND	ND
WBL/CA/DR/BH/5/1/89	7.50	38.00	Nil	38.00	68.00	8.50	ND	NT	24.00	ND	ND	ND
WBL/CA/DR/BH/5/2/89	7.40	24.00	Nil	24.00	108.00	8.50	ND	NT	32.00	ND	ND	ND
WBL/CA/DR/BH/6/1/89	7.40	36.00	Nil	36.00	72.00	8.50	ND	NT	12.00	ND	ND	ND
WBL/CA/DR/BH/6/2/89	7.40	32.00	Nil	32.00	408.00	5.70	ND	NT	12.00	ND	ND	ND
WBL/CA/DR/BH/7/1/89	7.50	32.00	Nil	32.00	80.00	5.70	ND	NT	12.00	ND	ND	ND
WBL/CA/DR/BH/8/1/89	7.30	28.00	Nil	28.00	92.00	8.00	ND	NT	ND	ND	ND	ND

Source: Katsina State Water Board, Parkman Consultants (1994).

Note:

Nil	-	Negligible.
ND	-	Not determined.
NT	-	No trace.
TR	-	Trace amount.

3.7. Borehole and Groundwater Development

3.7.1. Borehole Siting

The water supply of Daura comes from two wellfields; the southern wellfield and the northern wellfield. In selecting a site for borehole drilling the depth to the water table and its relation to the saturated thickness of the aquifer is an important consideration. In locating the boreholes in the study area the resistivity method of geophysical survey was particularly found useful in determining where the aquifer is very thick and where it is underlain by decomposed basement rocks. As the Gundumi Formation dips northwards, the more northerly the site selected the thicker the sandstones are likely to be and higher the water-bearing potential of the site.

Five of the boreholes drilled in the southern wellfield were abortive because of insufficient yield (less than 1.0 lps) as the Gundumi Formation is thinner in the south than in the north. Thus the southern portion of the aquifer has lower water-bearing potential.

3.7.2. Borehole Construction

The method of groundwater exploitation employed by the villagers is digging of hand-dug well by hand. This method was only able to produce shallow hand-dug wells with very low yield and it is popular among private, low scale water users. However to drill deep boreholes, the most commonly used methods are the cable tool method, the rotary method and the air-percussion or downhole-hammer drilling method.

Parkman Consultants (1994) had recommended the use of drilling rig capable of both rotary and downhole-hammer methods in borehole construction so that it would be possible to shift from one method to another, depending on the hardness of the formation. This method is most appropriate based on the variation in the hardness of the formations delineated from the geophysical interpretation (Table 2). The use of drilling rig capable of only mud flush drilling was employed in drilling some boreholes in the northern wellfield. The rig could not penetrate the underlying basement rocks to the specified depth because of lack of facility for pneumatic downhole-hammering. The mud flush drilling method resulted in abortive boreholes caused by the caking and blocking of potential aquifers by the drilling mud, having been left in the hole for a long time before borehole development. This problem of blocking of potential aquifers can be averted through drilling by air-percussion method and the use of working case in drilling the boreholes. The working case ensures that the walls of the boreholes did not collapse.

3.7.3. Borehole Completion

Borehole completion involves the installation of the casings, screens, gravel parks and cement grout in the drilled hole. Borehole completion provides for ready entrance of groundwater into the borehole with minimum resistance in and around the casing.

The most appropriate casing for the Daura water supply system is the API steel, coated on the inside and outside with bitumen to prevent corrosion. The borehole screening material is the Johnson continuous wire wound stainless steel screens. The selection of slot should be done after a sieve analysis of the potential aquifer material. All the boreholes in the northern wellfield screened three aquifer horizons, while those in the southern wellfield screened two aquifer horizons.

Gravel packing in the successful boreholes were carried out around the screened portions of the casing from the bottom of the hole to about 6 m below ground level. The gravel increases the effective diameter of the hole and acts as a strainer to keep fine materials out of the borehole. Cement grout is placed between the remaining annular space from about 6 m depth to the surface to prevent draining of germ-laden water into the borehole.

3.7.4. Borehole Development

Borehole development is the final stage in borehole construction and it involves the removal of fine materials from the natural formation surrounding the perforated areas of the casing. This is to increase porosity and permeability and prevent sand infiltration into the borehole. Borehole development can be by mechanical surging, air surging, back washing or high velocity jetting.

Borehole development in the Daura area yield more desirable result by jetting and flushing with compressed air. Fresh water is used to wash the completed boreholes, while calgon solution is used to remove drilling mud.

3.7.5. Borehole Maintenance

The components of a borehole water supply are the aquifer, the borehole, casings, screens, pump, pipes, storage tanks and power supply. Routine maintenance of these components will ensure proper performance of the borehole system. The borehole casings are to be coated with bitumen to prevent corrosion. The rising main also has to be resistant to corrosion. This is especially necessary because of the low pH of groundwater in Daura area.

Pump should be taken out periodically and inspected together with the riser pipe. Any corroded component can be replaced. Storage tanks should be free of leaks to prevent wastage and should be well covered to prevent bacteria contamination. Burst pipes should be replaced.

Power supply to the pump should be regular and constant to ensure optimal performance of the pumps. The borehole should be redeveloped periodically to enhance its yield.

4. DISCUSSION OF RESULTS

The pump tests were conducted on production boreholes fitted with submersible pumps. Five of the tested boreholes were abortive due to insufficient yields or the collapse of the wall of the boreholes. The tests lasted between 12 and 24 hours. The results of the pump tests for 26 boreholes were analysed. During the test, the yields were in the range 2.20 to 13.22 lps, except for the abortive boreholes whose yields were generally below 1.0 lps. The average yield of the productive boreholes is 3.2 lps. However this value is increased to 4.1 lps by the contribution of three exceptionally high-yielding boreholes whose yield range from 7.0 lps to 13.22 lps.

Transmissivity values range from 1.2 m^2 day^{-1} to 654.2 m^2 day^{-1}. Three boreholes have transmissivity in the range 0.5 – 500.0 m^2 day^{-1} while two boreholes have transmissivity above 500.0 m^2 day^{-1}. Based on Georghe (1978) classification of aquifer performance using range of transmissivity values, the aquifers of the Gundumi Formation in the Daura area are considered as having low to moderate groundwater potential.

The specific capacity determined at 12 hours for some boreholes and 24 hours for others since pumping started range from 0.38 m^2 hr^{-1} to 22.3 m^2 hr^{-1}. Specific capacity decreases with time because drawdown increases with time as the cone of influence of the pumped borehole expands. Specific capacity is an indication of transmissivity. As evident in Table 3, high specific capacity of 22.3 m^2 hr^{-1} corresponds to high transmissivity values of 654.2 m^2 day^{-1} and low specific capacity of 0.38 m^2 hr^{-1} corresponds to low transmissivity value of 11.0 m^2 hr^{-1}. However specific capacity is not an exact criterion of estimating transmissivity because specific capacity is often affected by partial penetration of wells, well loss and hydrogeological boundaries (Ajayi & Umoh, 1998; Fetter, 2001).

The general low capacities of the production boreholes in the study area are consistent with the sand-clay sequence typical of the Gundumi Formation. However based on the yields and transmissivity values obtained, the boreholes are adequate to sustain domestic water requirements of the population, and the volume of groundwater withdrawal is of lesser regional significance (Krásný, 1993).

The suitability of groundwater for any use depends on standards or criteria of acceptable quality for that particular usage. The available information on groundwater quality in the study area were compared with internationally acceptable standards in order to assess if the groundwater found in Daura area is suitable for domestic use.

From Table 4, pH values range from 4.5 to 7.5. The pH of groundwater samples from 12 boreholes in the study area are not within the permissible limits of 6.5 – 8.5 given by the Nigerian Standards for Drinking Water Quality (NSDWQ) (2015) and WHO (2017). Twelve pH values fall between 4.5 and 6.2 which makes the water acidic and is the cause of chemical corrosion of screens, casings and other metal parts of the water supply equipment observed in the study area. The corrosion effect of the water on metal parts has adverse effects on the operation and useful lifespan of the borehole as a whole. Some boreholes have their screens and casings damaged by corrosion or their pumps lost completely by falling into the borehole.

The total nitrate values range between 0.30 and 3.35 ppm. These values are well below the upper limit of 5.0 ppm given by WHO (2017). The minor traces of nitrate indicates that the groundwater is generally free from domestic and industrial pollution. Fluoride values range between 0.1 and 0.2 ppm. Chloride values range between 5.7 and 24.1 ppm. All these values are still within the permissible WHO (2017) limits. Total $CaCO_3$ hardness range between 5.0 and 168.0 ppm. Seventy-three percent (73 %) of the groundwater samples analysed have total hardness within 5.00 and 44.00 ppm while twenty-seven percent (27 %) of the groundwater samples analysed have total hardness in the range 128 to 168 ppm. The groundwater samples in the study area are soft to hard, based on the Durfor and Becker (1964) classification of water.

In general when groundwater quality in the study area is checked against international standards for drinking water, the groundwater of Daura is generally suitable for domestic uses, except that lime treatment may be necessary in some cases because of the slightly acidic nature of the groundwater.

5. CONCLUSIONS

In the Daura area the lithologic sequence consists of an indurated basal conglomerate overlying the decomposed Basement Complex rocks. This basal conglomerate is overlain by loosely cemented gravelly sandstone, indurated ferruginous and clay horizons. The loosely cemented gravely sandstone, basal conglomerate and the decomposed crystalline rocks form good aquifers in the study area.

The aquifers are essentially unconfined and the static water levels occur at shallow depths, generally between 6 and 20 m. The aquifers are generally thicker in the northern part of the study area, with an average thickness of 50 m and thinner in the southern part with an average thickness of 35 m. This divides the study area into two wellfields: the northern wellfield with a high water bearing potential and a southern wellfield having a lower water bearing potential depending on the aquifer thickness.

The regional groundwater flow direction is mainly northwards. Localized groundwater flow is towards the discharging boreholes and there is no evidence of borehole interference because of the wide spacing between boreholes drilled in the study area.

High specific capacities correspond to high transmissivity in the study area. The boreholes sited in the northern wellfield generally have higher specific capacities than those in the southern wellfield. Hence the northern wellfield is better for siting high yielding boreholes than the southern wellfield. The aquifers have low to moderate groundwater potential, adequate to sustain domestic water requirements of the population. The volume of groundwater withdrawal is of lesser regional significance.

The quality of groundwater in the study area is generally suitable for domestic uses. The groundwater is slightly aggressive because of its low pH. There has been severe corrosion of the casings, riser pipes and other metal parts used for water supply in the study area and chemical treatment or water blending may be necessary in some cases to maintain the pH at acceptable levels. The groundwater is generally soft to moderately hard and is free from domestic and industrial pollution.

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