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GROUND WATER POTENTIALS OF NUMAN AND ENVIRONS, ADAMAWA STATE, NORTH-EASTERN, NIGERIA.

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ABSTRACT
Numan town is situated along the confluence of rivers Benue and Gongola and is a road junction town about some 60 km west of Yola. Lithologic logs of 7 boreholes, field measurement data, stream flow and meteorological data and hydrochemical data generated from sampling and analysis of groundwater from 17 points (7boreholes and 10 handdug wells) were evaluated to establish the potentials of groundwater in Numan area. The area receives about 800mm of rainfall annually out of which 80% is lost through surface runoff and evapotranspiration while about 20% goes to recharge the groundwater system. Groundwater in the area is hosted in three aquifer systems all tapping from three geologic formations- the Bima Formation, the Yolde Formation and the Quaternary river course alluvium. Handdug wells tap their water from mainly the upper unconfined aquifer whose depth ranges from 0- 40m and the boreholes are completed in either the middle semi confined aquifer 40 -75m or the lower confined aquifer 75-240m (depth range of 0-240m). The computed aquifer parameters gave a mean hydraulic conductivity of 5.6 x10 $^{-1}$m/day, a Transmissivity of 65.67m^2/day groundwater velocity of 2.43m/yr, groundwater discharge of 612.69m^3/yr, a groundwater reserve of 1.01x10^{10}m^3 which is capable of supporting a population of 1.4m for one year on an average of 220/l/day/head and a mean borehole yield of 20 m^3/hr. Results of the hydrochemical analysis indicate that most of the water samples agreed with both the WHO 2006 and the NIS 2007 drinking water quality standards. However isolated samples especially from the upper unconfined aquifer tested moderately hard to very hard (106-421mg/L). Few cases of high NO_3^- (88-132mg/L) in HW6 HW10 HW11, high Fe^{2+} (1-2mg/L) in HW1 and HW2, were recorded. Two dominant water types were recorded; Ca^{2+}-HCO_3^- (from four boreholes and seven handdug wells) and Na^++K^+-HCO_3^- (from three boreholes and three handdug wells). This study suggests that Numan and environs could be considered as a potential source of sustainable groundwater supply as a good alternative to the existing sources of supply. It would however require an improved waste management system and proper well completion methods to check the encroachment of surface generated pollution.

KEY WORDS: Groundwater, potential, Numan and environs, aquifer parameters and hydrochemistry

INTRODUCTION

Groundwater potential of an area is determined by the ability of the area to supply adequate quantity of groundwater of potable quality to satisfy the demands of that area (Callist, 2006) it is now recognized that groundwater development via shallow hand dug wells and deep boreholes is common source of water supply to most rural-semi urban communities in the developing countries. The understanding of the geometry and configuration of this subsurface resource is still a major challenge to most groundwater resources development and management agencies. A vital and most crucial aspect to be addressed prior to embarking on any groundwater development project is to ascertain the potential of the available resource within the area. It is in line with this objective that this investigation was carried out to establish the groundwater potential of Numan and environs with the view of providing a data base on the available resources and the possibilities of sustainable development to meet the demands of the people in the area.

Using available borehole data complemented with field sampling and analysis, this research aims at: determining the occurrence and distribution of groundwater in the study area, providing information on the quantity and quality of groundwater in the area and suggesting options for a more sustainable development and management of groundwater in the area.

Study area

Numan is situated along the banks of rivers Benue and Gongola. The area of this investigation lies between latitudes 9º 25ᴵ N and 9º 35ᴵ N and longitudes 12 º 00ᴵ E and 12^0 10^0 E covering a land area of 3422.5km^2 fig 1. The area receives an annual rainfall of 800mm which falls between the months of March to October with August as the peak. The rainfall data used for this study was obtained from UBRBDA Yola for the period of ten hydrological years (1986-1996). The temperature ranges from 13ºC during the Harmattan (December to January) to a maximum of 44ºC during the months of March to May. The mean monthly temperature is 37.2 º C. The measured relative humidity for the area is within the range of 25.6% in February and 78.9% in August with a mean monthly value of 64.6 %.(UBRBDA Yola 1996). The total runoff of river Benue for a period from 1988/89 -1992/93 is about 15435.74x10^6 m^3/year out of which only 6.8% goes to recharge the adjacent aquifers as baseflow while the remaining 93.2% is considered as direct runoff as obtained from hydrograph separation.

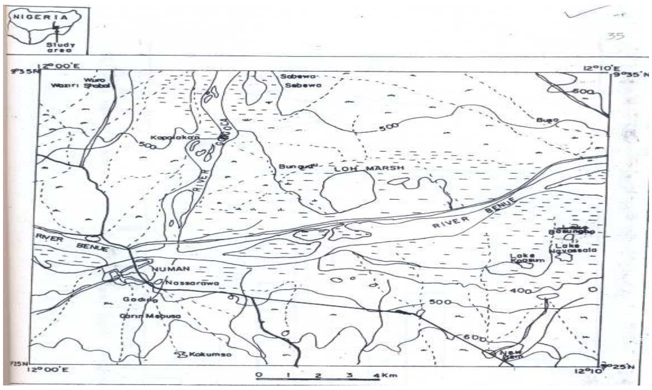

Fig. 1 Location map of Numan and Environs in Nigeria (inset), showing access roads.

Geology

The study area forms part of the Yola arm of the upper Benue Trough. The geology of the area is defined by the Precambrian Basement Complex rocks, the Cretaceous Bima Sandstone and the Yolde Formation while river course alluvium constitutes the Quaternary deposits. The Bima Sandstone consists of a thick sequence of feldspathic sandstones, grits, pebble beds and shale-clay intercalations (Offodile, 1992). It is a highly cemented and indurated sequence that varies from laminated sandstone to coarse grained cross bedded sandstone (Carter *et al* 1963, Allix 1983) The Yolde Formation forms a series of transition from continental to marine sedimentation. It is diachronous, made up of calcareous sandstones and shales and shows lateral variation in thickness (Barber *et al*, 1954, Reyment, 1955). It represents sedimentation in a high to moderate near shore littoral environment (Mode 1993). Its estimated thickness at the type locality (Yolde) is about 150m and consists of fine grained sandstone and thin bedded siltstone at the base with layers of shaly limestone (Carter *et al*, 1963). The Quaternary river course alluvium occurs along the flood plains of rivers Benue and Gongola and consists of loose sands, moderately sorted and highly permeable (Obiefuna *et al*, 1999). The geology of the area is summerised in Fig. 2

Hydrogeology

Groundwater plays an important rule in domestic and public water supply as an alternative to the supply from the surface water treatment plant. Development of groundwater in Numan area is commonly through shallow dug wells and deep boreholes. (Fig. 3) Groundwater in the area is under water table conditions and confined conditions. Groundwater under water table conditions occurs within weathered overburden and Quaternary river course alluvium whose thickness varies from place to place (2-10m). It is phreatic in nature and consists of gravely sands of the river course alluvium. Recharge into this aquifer is from direct rainfall and the depth of occurrence ranges from 0 -40m and is subject to seasonal fluctuations. Groundwater from this source is

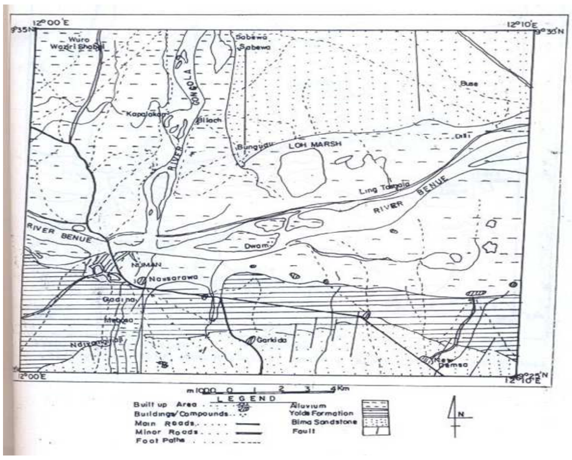

Fig.2 Geologic map of the study area.

harnessed through handdug wells and surface impoundments like ponds and is used for domestic and agricultural needs. Correlation of existing borehole logs from SW-NE reveals that groundwater under confined conditions is hosted in two aquifer systems thus the middle semi confined aquifer system and the lower confined aquifer system. (Fig.4) The middle semi confined aquifer system forms part of the underlying material beneath the upper water table aquifer system and is separated from it by a semi confined layer of shale /clay material of varied thickness. It is composed of sandstone, medium to coarse grained whitish, grey and poorly cemented sands. It occurs at depth below 40m and is exploited by most boreholes (BH1, BH2, BH3, BH4, BH5, and BH6). The measured maximum thickness is about 77m. An artesian condition with a positive hydraulic head was reported in a borehole in Numan town believed to be tapping from this aquifer system (GSN, 1965). The pressure built up in this system depends on the thickness of the overlying shale/clay units which varies laterally across the area with the highest thickness of 30m in BH6 and the least 10m in BH5. The lower confined aquifer system occurs at depth below 75m and has an average thickness of 50.6m. Two out of the seven boreholes used for this study have their base in this aquifer (BH8 & BH9). This aquifer consists of coarse grained, whitish grey and poorly cemented sandstones with dark shale intercalations. It is confined in nature with the shale intercalation acting as the confining layer. The average measured saturated thickness within the depth of investigation is 99.4m. A summary of the characteristics of the groundwater systems is presented in Table 1

MATERIALS AND METHODS

Lithologic logs used for this study were obtained from Adamawa State Water Board Yola, Rural Water Supply and Sanitation Agency (RUWASSA) Yola, stream flow and meteorological data were provided by the Upper Benue River Basin Development Authority (UBRBDA) Yola, while the hydrochemical data used was generated from field sampling and laboratory analysis of water samples from 7 boreholes and 10 handdug wells.

In this study, six (6) major parameters were considered; hydraulic conductivity (K), Transmissivity (T), groundwater velocity (V), groundwater discharge (Q), groundwater reserve (Qa) and aquifer thickness (b). Groundwater velocity was calculated using Todd (1980) equation while the groundwater discharge was obtained using Guisti 1978 relation (Q =10kit where k is hydraulic conductivity, I the hydraulic gradient and t the aquifer thickness). An estimate of the groundwater reserve was determined from Brassington 1990 formula (Qa= b x sy x area; where b=average saturated thickness of the aquifer, sy =the specific yield). The available driller's record is incomplete so Storativity and specific yield could not be evaluated. Available pumping test

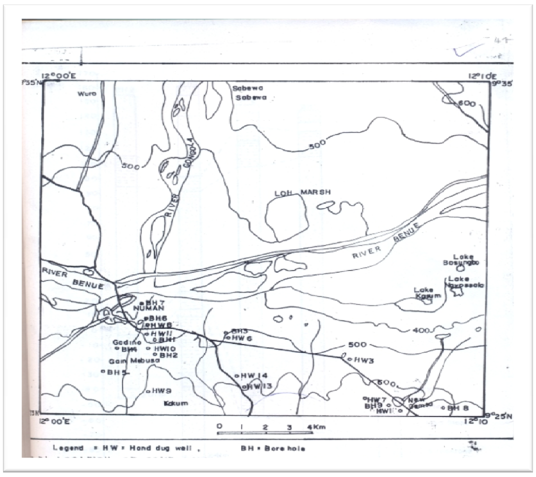

Fig. 3 location map of sample points.

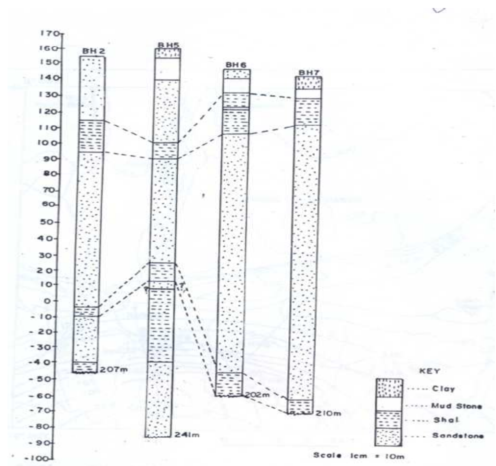

Fig. 4 correlation of some borehole logs along SW-NE line showing the three aquifer systems in the study area.

data for six boreholes was used in computing aquifer parameters. A summary of the computed results are presented in Table 2.

Hydrochemistry and groundwater quality

Water samples were collected from all the available groundwater sources in the area for analysis. Using field measuring kits pH reading, hydraulic head for hand dug wells, temperature and TDS were measured right in the field. A total of seven deep boreholes and ten hand dug wells were sampled for analysis. The ten (10) handdug wells include HW1, 3, 4, 6, 8, 9, 10, 11, 13, and HW 14The collected samples were analysed in the soil science and chemistry laboratories of the Federal University of Technology Yola, Adamawa state northeastern Nigeria. The cations were analysed using adsorption flame photometer and atomic absorption spectrophotometer (AAS) Spectronic 20D while the anions were analysed using general volumetric titrimetric methods with EDTA and Phenolphthalein as the indicators. Results of the chemical analysis were interpreted using the hydrochem computer software and are presented in the piper 1944 trilinear diagram(fig 5) Water quality is commonly defined by a multitude of chemical, physical and biological properties which determine the suitability of the water for domestic, industrial or agricultural use (Bachmat *et al*, 1980.) Groundwater quality generally depends on the quality of water recharging the source, the length of the flow path, mineralogy of the soils and aquifer materials, the residence time in the groundwater flow system and human activities (Thomas *et al*, 1993). In order to establish the quality of groundwater in the study area four parameters were considered and the results were compared with WHO (2006) standards and Nigerian industrial standard for drinking water, (NIS, 2007), (Table 3). The parameters chosen are Cl^-, NO_3- , $HCO_3^-$and hardness. These parameters in addition to being used as pollution indicators can also be used as indices to check on- site sanitation (Mike *et al*, 1999). The results of the hydrochemical analysis are presented in Table 4

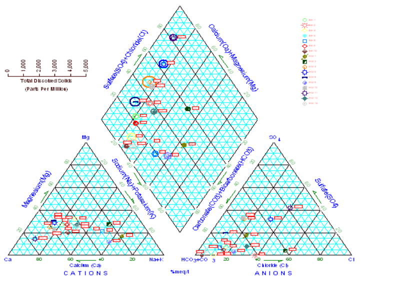

Fig: 5 piper diagram for water samples from the study area

major cations &anions from water samples in the study area

RESULTS

Groundwater Systems

A correlation of borehole log s across the area in a SW-NE direction shows that there are three groundwater systems-the upper unconfined, the middle semi confined and the lower confined groundwater systems. (Table 1)

The analysis of the stream flow data and other meteorological data for the river Benue shows that there is effluent hydraulic connectivity between the river and the adjoining groundwater system. The mean annual discharge of river Benue is about 1.67x $10^{10}m^3$/year the mean runoff in the river is about 1.54 $x10^{10}$ m^3 per annum. The baseflow from the adjoining aquifers into the river is $1.12x10^{10}$ $m^3$and this represents about 6.8% of the total flow. Numan receives about 800mm (5.12 x10 $^{8}m^3$/yr) of rainfall per year about 65% (3.3 x10 ^{8} m) of this is lost through evapotranspiration while 15% ($7.7x10^7m^3$) constitutes runoff and the remaining 20% is considered to be the main recharge into the groundwater systems.

Aquifer Parameters

Granulometric analysis of available lithologic logs from six boreholes (BH2, BH4, BH6, BH7, and BH8) and driller's data from pumping test were used in computing aquifer thickness and hydraulic conductivity while Cooper-Jacobs (1946) method was used to determine the transmissivity for the 6 boreholes in the study area. The method relates (T,Kand b): T=Kb where T= transmissivity , K = hydraulic conductivity and b= aquifer thickness or the screen length.

Table 1: Summary of groundwater systems in the study area from borehole logs

Groundwater system	Depth range (m)	Thickness (m)	Source of recharge	Lithology
Water table or phreatic system Unconfined	0-40	2-10	Direct precipitation	Gravely sands/weathered overburden
Semi confined system	40-75	77	Percolation from the overlying semi permeable shale/clay units and baseflow from the river bed	Whitish, grey sandstone medium –coarse grained, poorly cemented
Confined system	75-241	50.6	Baseflow /regional flow from adjoining basins	Whitish –grey Coarse grained sandstone

Table2: Summary of aquifer parameters from the study area using pumping test data from single wells

Borehole number	Saturated aquifer thickness (m)	Drawdown (m)	Transmissivity (m^2/day)(T)	Hydraulic conductivity (k)(m/day)
BH2	63.5	21.5	26.09	$4.11x10^{-1}$
BH 4	75.0	16.5	17.25	$2.3x10^{-1}$
BH 5	57.0	7.0	37.05	$6.5x10^{-1}$
BH 6	150.0	26.0	4.95	$3.3x10^{-2}$
BH 7	173.0	21.0	276.8	1.60
BH 8	78.0	10.15	32.76	$4.2\ x10^{-1}$
Mean	99.4	17.0	65.8	$5.6\ x10^{-1}$

DISCUSSION

The area receives a moderate amount of rainfall (800mm) annually 65% 0f this is lost through evapotranspiration , 15% constitute direct surface runoff while 20% goes to recharge the groundwater system. The high percent evapotranspiration is probably due to high maximum daily temperature experienced in the area for most part of the year as well as poor vegetation cover. While the surface runoff is favoured by urban development through pavement of roads and other drainage systems, the recharge into the groundwater system is supported by highly permeable loose sand of the Quaternary river course alluvium (Obiefuna *et al* 1999). Correlation of bore logs in a SW-NE directions reveal that there are three aquifer systems- the upper unconfined (0-40m) mostly tapped by handdug wells, the middle semi confined aquifer (40-75m) that serves some boreholes (BH3, 4, 5, 6&7) and the lower confined aquifer (75-241m) The borehole yields range from 9.0 m^3/hr to 31.7 m^3 /hr with an average of 20 m^3 /hr. The mean hydraulic conductivity (K) determined from the available pumping test data is 5.6 x10 $^{-1}$m/day and a Transmissivity of 67.8m^2/day, these results agree with Brassington 1990 moderate yielding aquifers. The calculated groundwater velocity of 2.42m/yr is moderate to allow sustainable infiltration /percolation into the groundwater regime. The groundwater reserve of $1.01x10^{10}m^3$ is capable of supporting a population of 1.4m for one year on an average of 220/l/day/head and a mean borehole yield of 20 m^3/hr is sufficient for sustainable development of groundwater.

The hydrochemical results show that most samples are within maximum permissible limits for drinking water quality of WHO (2006) and the NIS (2007). Hardness of 150 mg/L and above was recorded in Hw 3, 6, 8, 10 & 11. NO_3^- concentration of 50mg/L and above was recorded in 3 samples (Hw6, 10, 11), these same samples also recorded high concentrations of TDS, electrical conductivity (EC) and are among those samples with Fe^{2+} concentration of 0.6 and above. For hardness, NO_3^-,TDS and EC in high concentration it is most likely to be due to input from domestic effluents into wells closer to waste disposal sites. A plot of the major cations and anions in the piper 1944 trilinear diagram (fig. 5) reveals that there are two dominant water types in the study area; Ca^{2+}- HCO_3^- type and Na^+ +K^+ – HCO_3^- type, (table 6). The Ca^{2+}- HCO_3^- type according to Arthur (1995) is associated with areas with temporary hardness which agrees with results in table 5 (hardness of 106-136 mg/L). This was recorded in four out of the seven boreholes sampled. The second water type recorded in seven out of the ten handdug wells is mostly associated with influx of domestic effluents rich in sodium and bicarbonate which gives the water similar characteristics as those originating from alkali carbonate rocks (Arthur, 1995). Additional bicarbonate could also be released from the break down of weak carbonic acid formed by rainwater and carbon dioxide recharging these aquifers.

Table3. WHO and NIS standards for drinking water quality

Parameter	Units	WHO (2006) drinking water quality standards maximum permissible limits	Nigerian industrial standards for drinking water quality(NIS 2007) maximum permissible limits
Aluminum(Al^{3+})	mg/L	0.2	0.2
Chloride (Cl^{-})	mg/L	250	250
Color	TCU	15	15
Odor	Threshold numbers	3	NA
Copper (Cu^{2+})	mg/L	1.0	1.0
Corrosivity		Non corrosive	NA
Fluoride(F^{-})	mg/L	2.0	1.5
Iron (Fe^{2+})	mg/L	0.3	0.3
Magnesium(Mg^{2+})	mg/L	0.05	0.2
Mercury(Hg^{+})	mg/L	0.002	0.001
pH		6.5-8.5	6.5-8.5
Arsenic(As^{2+})	mg/L	NA	0.01
Barium($Ba^{2+)}$	mg/L	NA	0.7
Chromium(Cr^{6+})	mg/L	NA	0.05
Cyanide(CN^{-})	mg/L	0.2	0.01
Conductivity	µS/Cm	NA	1000
Hardness(as $CaCO_3$)	mg/L	NA	150
Lead(Pb^{+2})	mg/L	0.015	0.01
Nickel(Ni^{2+})	mg/L	NA	0.02
Nitrate(NO_3^{-})	mg/L	10	50
Sodium(Na^{+})taste threshold	mg/L	30-60	200
Silver	mg/L	0.1	NA
Sulphate (SO_4^{2-})	mg/L	250	100
Total dissolved solids (TDS)	mg/L	500	500
Zinc (Zn^{2+})	mg/L	5.0	3.0

Table 4: Results of chemical analysis of groundwater samples from the study area.

s/no	Water source	Location	Temp ^0C	Conductivity µs/cm	TDS mg/L	pH	Ca^{2+} mg/L	Mg^{2+} mg/L	Na^+ mg/L	K^+ mg/L	SO_4^{2+} mg/L	Cl^- mg/L	HCO_3^- mg/L	NO_3^- mg/L	Fe^{2+} mg/L	Hardness mg/L
1.0	BH1	Nu 1	33.0	350	224	6.5	36	11.2	13	6.0	10	16	133	13.7	0.6	136
2.0	BH2	Nu 4	33.0	340	218	6.5	32	11.4	15	6.0	0	40	112	0	0.6	127
3.0	BH4	Nu 6	35.0	210	135	6.0	28	13.4	18	6.0	0	16	212	0	0.5	125
4.0	BH5	Nu7	31.9	370	237	6.5	16	6.0	17	6.0	10	8.0	100	8.8	1.6	67
5.0	BH8	Dem 1	30.0	70	45	6.5	6	2.7	9	5.0	12	16	180	17.6	0	26
6.0	BH9	Dem 2	33.8	300	192	6.5	27.2	9.2	12	6.0	5	12	106	4.4	0.6	106
7.0	BH 10	DEM	35.0	260	167	6.5	32.8	7.8	17	6.0	0	2.0	80	4.4	0.65	144
8.0	HW1	ITALIYA	32.2	60	38	6.3	4	2.2	13	5.0	20	20	84	13.2	2.0	19
9.0	HW3	FARAI 1	33.0	220	141	6.7	12	9.3	29	6.0	5	48	60	8.8	1.0	68
10	HW 3	FARAI 2	32.4	1320	846	6.9	120	30	29	6.0	80	28	168	17.6	0	421
11	HW6	DAKANTA	32.9	880	564	7.1	54	17	15	3.4	70	52	100	88	0.06	199
12	HW 8	SABON PEGI	34.4	1070	686	6.9	60	20	15	4.0	45	16	204	44	0.1	231
13	HW 9	KUKUMTO	33.8	110	71	6.8	8.0	2.0	16	4.0	7.0	36	200	35.2	0.7	28
14	HW 10	GADINA 1	32.4	334	214	6.3	72	17	22	6.0	26	8.0	53	88.0	0.1	250
15	HW11	GADINA 2	-	1400	897	6.0	140	16	18	6.0	40	28	22	132	0	415
16	HW 13	SABOGARI MISSIONARY	31.8	300	192	6.3	26	10	18	6.0	12	32	120	22.0	0.1	105
17	HW 14	SABONGARI PALMAS	30.3	220	141	6.0	28	10	20	6.0	10	8	260	22.0	0.1	109

Table 5: Hardness of individual groundwater sources from the study area

Location	Well no	Hardness mg/L	Water type
Gindin kuka	BH1	136	Slightly hard
Gwaidamala	BH2	127	Slightly hard
Opp. Sakato	BH4	125	Slightly hard
Unguwan Maizakara	BH5	67	Slightly soft
Demsa L.G. Secretariat	BH8	26	Soft
GSS Numan	BH9	106	Slightly hard
Bakatsalle	BH 10	144	Slightly hard
Italiya	Hw 1	19	Soft
Farai 1	Hw 3	68	Moderately soft
Farai 2	Hw 4	421	Hard
Dakata	Hw 6	199	Moderately hard
Sabon pegi	Hw 8	231	Moderately hard
Kukomto	Hw 9	28	Soft
Gadina 1	Hw 10	250	Moderately hard
Gadina 2	Hw 11	421	Hard
Sabon gari missionary	Hw 13	105	Slightly hard
Sabon gari palmas	Hw 14	109	Slightly hard

CONCLUSION

The study has identified three aquifer systems in the area within the depth bracket of 0-240m. The upper unconfined aquifer receives recharge from direct rainfall and is tapped mainly by the handdug wells (0-40m total depth). This aquifer is presently under the treat of surface generated pollution mostly associated with domestic/household waste. The middle semi confined aquifer occurs at depth below 40m and is a source of supply to boreholes completed within 40-75m. The quality of water from this aquifer is still within the limits for drinking water quality of WHO (2006) And NIS (2007). The lower confined aquifer is tapped by very few boreholes 75-241m. Groundwater chemistry suggests that the upper aquifer has isolated cases of high concentrations of NO_3^-, (88-132mg/L), high TDS (546-897 mg/L) Fe^{2+} (.5-2 mg/L), moderately hard to very hard (144 -421 mg/L). The quality of the water from the middle and the lower aquifers is generally acceptable as it falls within the maximum permissible limits of WHO (2006) and NIS (2007). Two dominant water types are identified from the piper diagram – Na^+ +K^+ -$HCO_3^-$and the Ca^{2+} - HCO_3^- water types. The study area therefore has high potentials for sustainable groundwater development to meet the needs of the populace. It is however suggested that development of groundwater through handdug wells should ensure high protective aprons and well points should be sited at good safety distances from waste disposal sites.

TABLE 6: Summary of water chemistry data

Sample	Na^+ mg/L, meq/L	K^+ mg/L meq/L	Ca^{2+} mg/L meq/L	Mg^{2+} mg/L meq/L	Cl^- mg/L meq/L	HCO_3^- mg/L meq/L	SO_4^{2-}: mg/L meq/L	TDS (mg/L)	(Cations/ Anions	Comments
BH1	13.0 0.57	6.0 0.15	36.0 1.80	11.20.92	16.0 0.45	133.0 2.18	10.0 0.21	225.2	1.2	Ca^{2+}-HCO_3^-
BH 2	15.0 0.65	6.0 0.15	32.0 1.60	11.40.94	40.0 1.13	112.0 1.84	0.0 0.00	216.4	1.1	Ca^{2+}-Cl^-
BH 4	18.00.7 8	6.0 0.15	28.0 1.40	13.4 1.10	16.00.45	212.0 3.47	0.0 0.00	293.4	0.9	Ca^{2+}-$HC0_3^-$
BH 5	17.00.7 4	6.0 0.15	16.0 0.80	6.0 0.49	8.0 0.23	100.0 1.64	10.0 0.21	163	1.1	Ca^{2+}-$HC0_3^-$
BH 8	9.0 0.39	5.0 0.13	6.0 0.30	2.7 0.22	16.0 0.45	180.0 2.95	12.0 0.25	230.7	0.3	Na^+ +K^+-$HC0_3^-$
BH 9	12.00.5 2	6.0 0.15	27.2 1.36	9.2 0.76	12.0 0.34	106.0 1.74	5.0 0.10	177.4	1.3	Na^++K^+ -$HC0_3^-$
BH 10	17.0 0.74	6.0 0.15	32.8 1.64	7.8 0.64	2.0 0.06	80.0 1.31	0.0 0.00	145.6	2.3	Ca^{2+}-$HC0_3^-$
HW 1	13.0 0.57	5.0 0.13	4.0 0.20	2.2 0.18	20.0 0.56	84.0 1.38	20.0 0.42	148.2	0.5	Na^++K^+ -$HC0_3^-$
HW 3	29.0 1.26	6.0 0.15	12.0 0.60	9.3 0.77	48.0 1.35	60.0 0.98	5.0 0.10	169.3	1.1	Na^++K^+ -$HC0_3^-$
HW 4	29.0 1.26	6.0 0.15	120.0 5.99	30.0 2.47	28.0 0.79	168.0 2.75	80.0 1.67	461	1.9	Ca^{2+}-$HC0_3^-$
HW 6	15.0 0.65	3.4 0.09	54.0 2.69	17.0 1.40	52.0 1.47	100.0 1.64	70.0 1.46	311.4	1.1	Ca^{2+}-$HC0_3^-$
HW 8	15.0 0.65	4.0 0.10	60.0 2.99	20.0 1.65	16.0 0.45	204.0 3.34	45.0 0.94	364	1.1	Ca-$^{2+}$$HC0_3^-$
HW 9	16.0 0.70	4.0 0.10	8.0 0.40	2.0 0.16	36.0 1.02	200.0 3.28	7.0 0.15	273	0.3	Na^+ +K^+ -$HC0_3^-$
HW 10	22.0 0.96	6.0 0.15	72.0 3.59	17.0 1.40	8.0 0.23	53.0 0.87	26.0 0.54	204	3.7	Ca^{2+}-$HC0_3^-$
HW 11	18.0 0.78	6.0 0.15	140.0 6.99	16.0 1.32	28.0 0.79	22.0 0.36	40.0 0.83	270	4.7	Ca^{2+}-$HC0_3^-$
HW 13	18.0 0.78	6.0 0.15	26.0 1.30	10.0 0.82	32.0 0.90	120.0 1.97	12.0 0.25	224	1	Ca-$^{2+}$$HC0_3^-$
HW 14	20.0 0.87	6.0 0.15	28.0 1.40	10.0 0.82	8.0 0.23	260.0 4.26	10.0 0.21	342	0.7	Ca^{2+}-$HC0_3^-$

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REFERENCES

Allix, P. (1983): Environment Mesozoiques de la Partie Nord Oriental du Fosse de laBenoue(Nigeria),Stratigraphique Sedimentologic Evolution Geodynamique Thesies 2eme cycle trav. Lab. Sc. de Terre Marseille St Jerome (B) 21 200p

Arthur W.H., (1995): Water quality data: analysis and interpretation CRS press, Boca Raton/New York/London/Tokyo pp 88-93

Bachmat Y, Gredehhoeft J, Barbara H, Hohz D, and Scoh S, (1980): Groundwater Management: The Use of Numerical Models in Water Resources Monograph 5 Amer.Geoph. Union Washington D C P 12

Barber W.M., Tait E.A., and Thompson J.H, (1954): Ann Rep. Geol. Surv. of Nigeria: 18-20

Brassington R,(1990): Field Hydrogeology Geol. Soc. of Prof. Handbook, Open University Press Million Keynes/Halted Press. New York/Toronto Pp48-62.

Callist T. (2006) Groundwater mapping and its implications for rural water supply in Uganda in *forum for groundwater issue three* December 2006 p1-2

Carter J.D., Barbar W., Tait E A. and Jones J.P. (1963): The Geology of Parts of Adamawa, Bauchi Bornu Provinces in North Eastern Nigeria. *Bull Geol. Surv. of Nigeria* 30 1-109.

Cooper H.H. Jr and Jacob C.E. (1946): A Generalized Graphical Method for Evaluating Formation of Constants and Summerising Well Field History, *Trans.Amer. Geophysical Union,*V 27 Pp 526-534.

Dike E.F.C (1994): Geology And Hydrogeology of Misau and environs in *Water Resources Jour of the Nigerian Association of Hydrogeologists* Vol 4 Nos 1&2 P57-63

Guisti E.V.(1978): Hydrogeology of the Kerst of Pnerto Rico. US Geol.Surv.Prof.Paper 1012 Pp 68.

Mike B., Mai N. and Pedley S. (1999): On-Site Sanitation and Urban Aquifer Systems in Uganda,*Water Lines International Jour. of Appropriate Technologies for Water Supply and Sanitation vol 17 No 4 P10.*

Mode W.A. (1993): Ethology and paleo-environment significance of trace fossils from Cenomanian-Turonian sediments in the Upper Benue Trough *Jour. of Min and Geol. Vol 29 Pp 111-117.*

NIS (2007): Nigerian Industrial Standard for Drinking Water Quality, NIS 554

Obiefuna G.I., Nur A. Baba A U and Bassey N.E. (1999): Geological and geotechnical assessment of selected gully sites in Yola area, North East Nigeria, *Jour of Environmental Hydrology* No, 6 Vol 7. 13

Offodile M.E. (1992): An approach to groundwater study and development in Nigeria Mecon Services Ltd ,Jos

Piper A. M., (1944) A graphical procedure in the geochemical interpretation of water analysis, *Amer. Geophys. Union trans* vol. 25 pp 914-923

Reyment R.A.(1955): The Cretaceous Ammonoidea of southern Nigeria and southern Cameroon, *Bull. Geol. Surv. Nigeria*, 25 1-112.

Thomas E. Reilly and David W.P.(1993): Factors affecting areas contributing recharge to wells in shallow aquifers,U.S Geol.Surv. Water Supply Paper 2412

Todd D.K. (1980): Groundwater Hydrology 2nd ed. John Wiley&Sons, New York/London/Sydney p 535.

UBRBDA (1986-1996): Upper Benue River Basin Development Authority Year Book.

WHO (2006): 2006 edition of the Drinking Water Standards and Health Advisories EPA 822-R-06-013

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