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ASSESSMENT OF THE HYDROGEOLOGIC PROPERTIES OF THE BASEMENT AQUIFERS OF WESTERN PART OF BAUCHI, NIGERIA.

E. M. SHEMANG and K. T. JIBA

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ABSTRACT

An analysis of existing borehole data from the Bauchi State Water Board (BSWB) and Bauchi State Agricultural Development Project (BSADP) was carried out with the aim of defining areas with high potentials for groundwater in the western part of Bauchi. It was also aimed at determining any relationship between rock type and yield of aquifer within the area, as the existence of such a relationship will go along way in minimizing the problems of exploration for suitable aquifers in the area. The methodology involved analyzing all pumping test data available for the area and determining the properties of the aquifers such as yield, specific capacity, transmissivity and hydraulic conductivity.

The results show that yields of aquifers in the area range from as low as 1.8 litres per minute (lpm) to over 400 lpm with and average of 50 lpm. Specific capacities range from 0.4 – 100 lpm/m with over 63 percent of the area having specific capacities between 0.5 – 10 lpm/m. Transmissivities of the aquifers range from 0.8 – 5.0 x 10^{-4} m^2/s with over 73 percent of the area having transmissivities ranging between 0.8 – 1.0 x 10^{-4}; and only 12 percent of the area having transmissivities above 4.0 x 10^{-4} m^2/s. Hydraulic conductivities in the area range generally from about 9.88 x 10^{-7} to 4.77 x 10-5 m/s, with over 73 percent of the area having hydraulic conductivities of less than 8 x 10^{-6} and only about 7 percent of the area having hydraulic conductivities of more than 5.0 x 10^{-5} m/s.

An attempt to correlate the above results with the rock types in the area showed that the fractured coarse grained granites hold better promise for groundwater because it gives higher yield and higher specific capacity than the other rock types. The granite gneiss is next in terms of yield and specific capacity. All the other rock types, Biotite granite gneiss, Hornblende granite and Undifferentiated gneisses, have very little promise for groundwater.

KEYWORDS : Groundwater, Pumping test data, Aquifers, Transmissivities, conductivities.

INTRODUCTION.

Basement aquifers are of particular importance in tropical and sub-tropical regions because of their widespread extent and accessibility and also because there is no readily available alternative source of water supply, particularly to the rural populace (Wright 1992).

Basement aquifers are developed within the weathered overburden and fractured bedrock of crystalline rocks of intrusive and/or metamorphic origin, which are mainly of Precambrian age.

In the Western Part of Bauchi, water supply to the rural populace is obtained mainly from hand-dug wells, boreholes that extract water from the overburden and fractured bedrocks, and from small earth dams and streams.

This study is therefore an attempt at assessing critically the characteristics of the Basement aquifers in the western part of Bauchi State with a view to identifying the most productive ones for exploitation for rural water supply.

For this study, data from Bauchi State Agricultural Development Project (BSADP); Bauchi State Water Board (BSWB) were obtained and analyzed. Data from Edok-Eter Mandilas Nig. Ltd (1976-1979), Water Surveys Nig. Limited (1976). Conred Nig. Limited (1978), Consulint Co. Nig. Ltd (1976) and Wardrop Engineering Incorporated (1989) were also analyzed. All of these firms have produced unpublished reports and they form the basis of this study.

Data analysis involved a critical assessment of the data on yield of aquifers and pumping test results with the aim of determining the characteristics of the aquifers.

The area of study lies between Latitudes 9^0 30' and 10^0 48' 30" North and Longitudes $8^0$41'11" and 10^0 13' 38" East (Fig. 1) and is situated in the Northeastern part of Nigeria.

Two distinct seasons; wet and dry seasons are found in the area. The wet (rainy) season starts from mid-April and last to early October, while the dry season (harmattan) is between October and March.

Climatological records from meteorological section of the Bauchi Airfield over a period of 10 years (1986-1996) show that the mean annual rainfall for a 10 (ten) year period is about 932.24 mm. Temperatures range from about 11.5^0 C during the harmattan period to 38^0 C in April and May. Humidity is very low particularly in the dry season.

Evaporation ranges from about 5.28 mm in July to about 14.20 mm in May (Duze *et al.* 1977). Drainage in mainly by surface streams which are dendritic in pattern.

Vegetation of the area is the Sudan type, generally devoid of thick forest, but consist of grasses, shrubs, and scattered trees. Shrubs, however, form the dominant vegetation (Duze and Afolabi, 1977).

Geological Setting of the Area.

The area of study lies within the Pre-Cambrian Basement Complex area of Nigeria. The Basement Complex consists essentially of rocks that are granitic in composition; and in different stages of metamorphism as gneisses, migmatites, quartzites, phyllite, schists and pegmatities (Fig.2). The gneisses and metasediments are believed to be oldest rocks in the area and are of Birmian age (Oyawoye 1970; McCurry 1976). They are emplaced into the Basement during or just after the Pan-African deformation. These rocks range in size

E. M. SHEMANG, Department of Geology, University of Botswana, Gaborone, Botswana.
K. T. JIBA, Geology Programme, Abubakar Tafawa University, Bauchi, Nigeria.

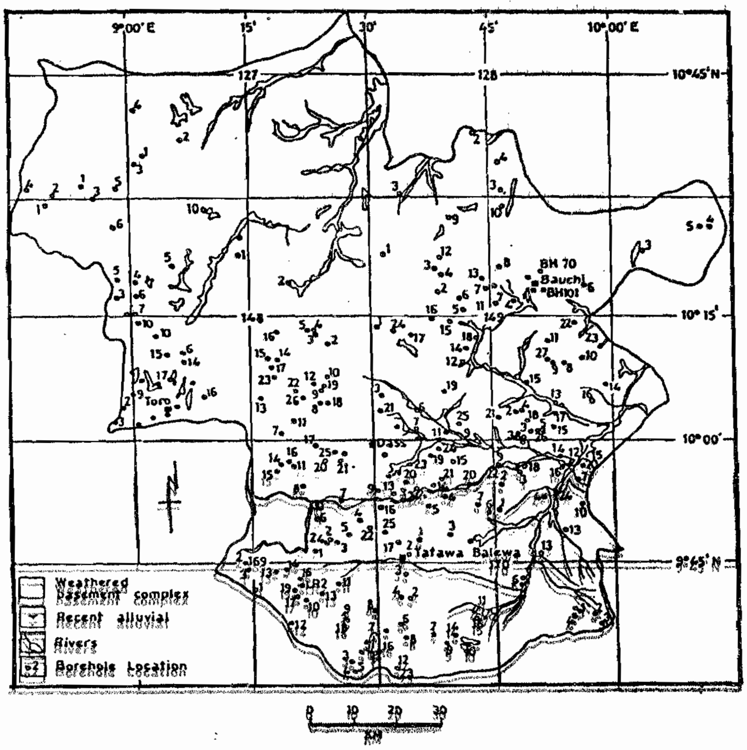

Fig: 1 Hydrogeological map of Western Part of Bauchi showing borehole Locations (After BASDP, 1986)

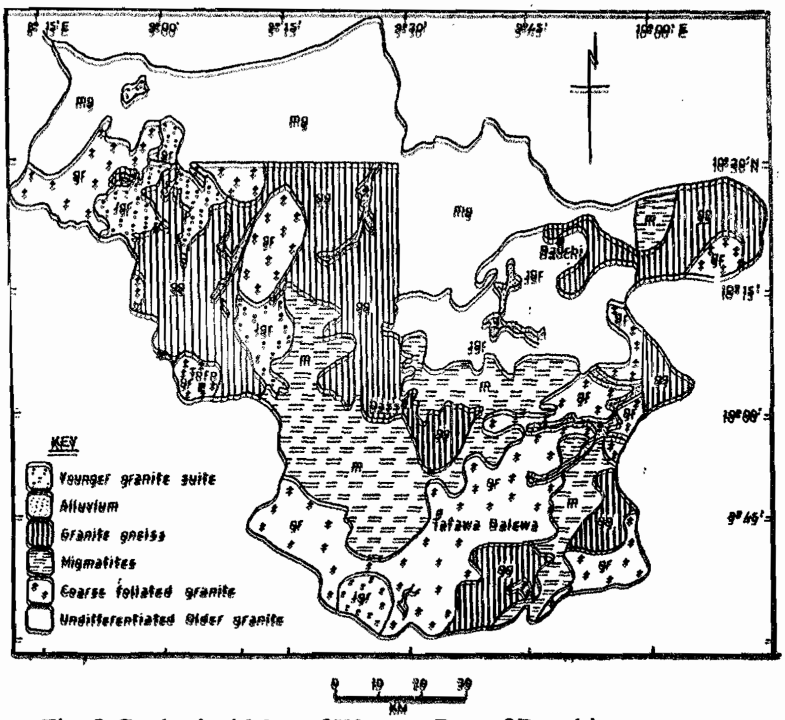

Fig. 2 Geological Map of Western Part of Bauchi.

from small sub circular crosscutting stocks to large elongate concordant batholitic bodies predominantly of granodioritic composition (Oyawoye 1970).

The study are is underlain by the following rock types:

i) Coarse foliated granite, diorite, charnockite, and bauchite. All these belong to the older granite suite and are of palaeozoic age.

ii) Granite gneiss, migmatites, migmatitic gneisses, banded gneisses, schist, and some undifferentiated igneous and metamorphic rocks that belong to the basement complex; these are Palaeozoic-Precambrian in age.

iii) Rhyolites, acid volcanics, biotite granites, porphyrritic biotite granite, gabbros, dolerite,

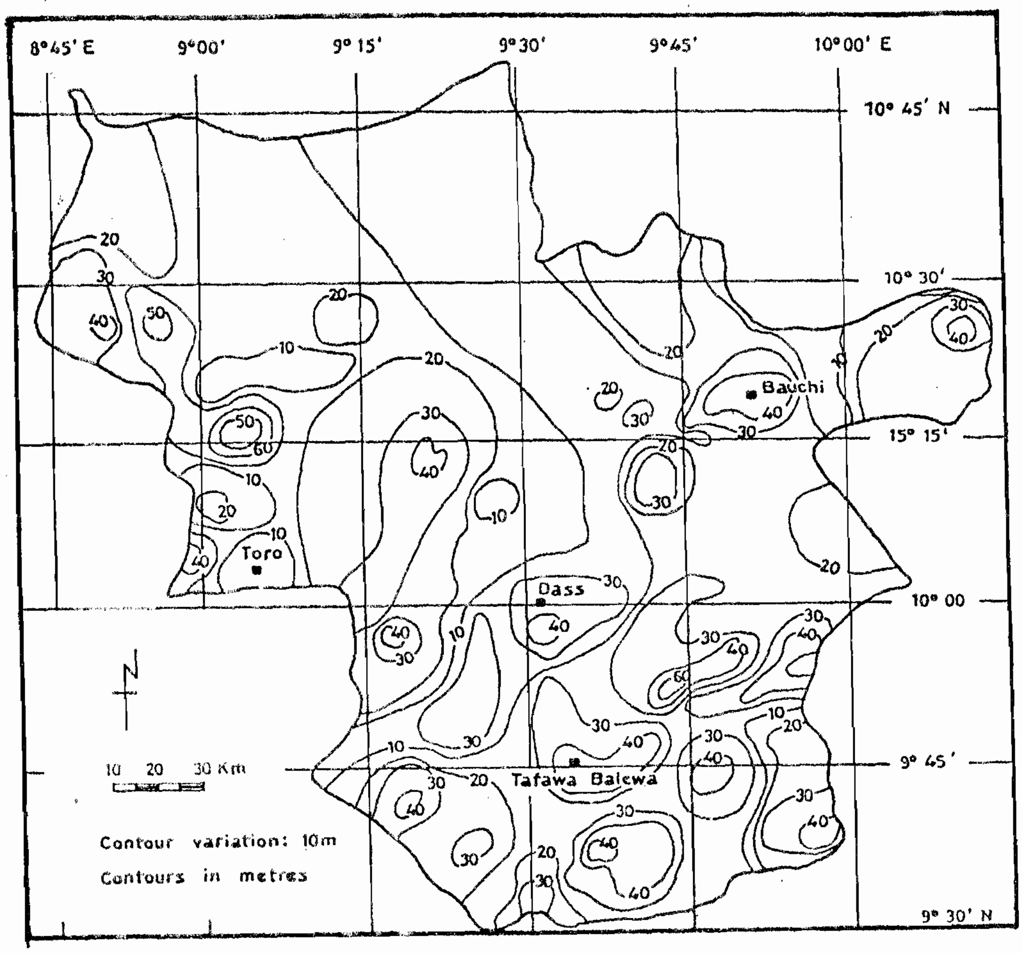

Fig 3. Depth to Basement (overburden thickness) map of the area of study

biotite-muscovite granite, nebulitic granite, granite porphyries and some younger granite suite (undifferentiated), belonging to the younger granite suite and are Jurassic in age. These rocks are hard with low permeability and generally not water bearing except when fractured.

iv) Recent alluvium resulting from the weathering and erosion of hills and decomposed in-situ rock cover a large part of the crystalline Basement Complex.

Aquifer Types

There are two basic types of aquifers in the area, fractured crystalline rocks and weathered crystalline rocks that overlie the former. Both may be found to occur in the same borehole.

a) Fractured Crystalline Aquifer.

Most of the crystalline rocks that underlie all parts of the area of study are fractured and a greater part of them are buried under overburden material. These fractured rocks are sometimes encountered in boreholes at variable depths.

The capacity of the crystalline rocks to store, transmit and yield water depends mainly on the extent, size, degree of openness and continuity of the fractures and also on the degree to which the fractures are hydraulically connected.

Most of the fracture zones are buried beneath the overburden material through which it receives recharge; these fractured zones therefore requires more detailed methods of geological/geophysical investigation to delineate them (Hazell *et al.* 1992).

b) Overburden (Regolith) Aquifer

This aquifer consists essentially of decomposed rocks. These decomposed rocks are characteristically clayey, concretionary, brown to reddish brown, ferruginous and lateritic. Occasionally, they show desiccation cracks when exposed at outcrops. At most places the decomposed rocks are covered by a thin blanket of alluvium consisting mainly of silt, clays, gravels, and local intermixes of these materials.

The overburden thickness in the area ranges from about 10 m to 70 m (Fig.3), and generally forms small groundwater basins (reservoirs) that are separated by underground domes and ridges.

The overburden forms the main source of groundwater that occurs under water table (unconfined) conditions. The water in this layer occurs in the granular pores of the alluvial material, pores of the moderately weathered coarse-grained igneous and metamorphic rocks and in the fractures of the poorly decomposed rocks.

The yields of boreholes completed within the area of

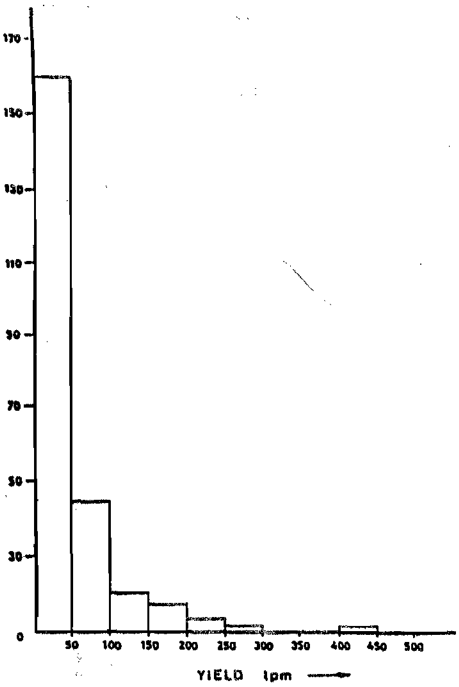

Fig. 4 Histogram of Number of Boreholes Vs Yield of Boreholes

study range widely from 1.8 lpm to over 400 lpm with and average yield of about 50 lpm (Fig. 4). The draw down in the boreholes vary greatly from as low as 1 to as great as 40 metres, with most of the draw down of boreholes ranging between 4 and 6 metres. The recovery rate is very slow owing to the clayey nature of the aquifers.

Depth-to-Water Table

Measurements from hand-dug wells and from boreholes show that the water table is generally shallow and ranges from less than 1 metre at the peak of the rainy season to about 24 metres in the dry season. Fig. 5 is a map of the variation of the water table. This map is based mostly on measurements from hand-dug wells.

From the figure it can be seen that some of the contour lines are concave suggesting that they are areas of discharge. The few convex contours seen in the area also suggest areas of recharge. The parallel contours indicate areas of uniform flow of groundwater and also indicate gentle to flat gradient.

Yield of Aquifers

The yield of an aquifer can be defined as the maximum rate of withdrawal that can be sustained by an aquifer without causing an unacceptable decline in head in the aquifer (Freeze and Cherry 1979).

The yields of over 309 boreholes were available for this study. The yields vary widely from as little as 1.8 to over 400 litres per minute. Over 73 percent of the boreholes yield between 1.8 and 50 litres per minute; 17 percent yield between 51 and 100 litres per minute; 5 percent yield between 101 and 150 litres per minute; 4 percent yield between 151 and 300 litres per minute; 2.6 percent yield between 301 and 400 litres per minute; while only 0.4 percent of the boreholes yield more than 400 litres per minute. The average yield for the area is 50 litres per minute.

Aquifer Characteristics.

Figure 4 is a histogram showing the distribution of the yields of the boreholes in the area. The histogram is skewed to the right indicating that most of the aquifers yield low amounts of water.

The yields obtained from the boreholes in the area can be considered alright for the communities since most of the water requirements in the area are for domestic and livestock purposes of the inhabitants who live in sparsely populated villages.

An attempt at correlating the yields of boreholes with rock types showed that fractured coarse granite granites has the highest verage yield of about 74 litres per minute; gneiss and biotite gneisses have average yields of about 35.5 litres per minute and 30.0 litres per minute respectively; while the hornblende granite and the gneiss (undifferentiated) have average yields of about 42.3 litres per minute and 21 litres per minute respectively.

The high yield associated with the weathered/fractured coarse-grained granites results from weathering of quartz and other minerals that disintegrate into porous and permeable aquifer units.

Specific Capacity.

This is defined as the volume of water that a unit volume of aquifer release from storage under a unit decline in head. The specific capacity of a well depends on transmissivity of the aquifer and well diameter, degree of aquifer penetration and completeness of well development.

The specific capacities of wells in the study area were computed and the results show that they vary between 0.4 and 100 litres per minute per metre (lpm/m). 63 percent of the boreholes have specific capacities between 0.5 and 10 lpm/m, suggesting that transmissivities of those boreholes are very low. Fig. 6 is a map showing the distribution of specific capacities of the aquifers in the area of study.

Table 1 shows the Correlation between the average specific capacities with the various rock types (aquifers) in the area of study.

Table 1. Table showing the different rock types and their specific capacities

Rock Type	Specific Capacities
Coarse-grained granites	31.1 litres/minute/metre
Granites gneisses	13.9 litres/minute/metre
Biotite granite gneisses	9.53 litres/minute/metre
Hornblende granites	6.6 litres/minute/metre
Gneiss (Undifferentiated)	6.5 litres/minute/metre

Transmissivities

This is the rate at which water flows through a vertical strip of the aquifer of unit width and extending to full saturated thickness under hydraulic gradient 1.00.

Mathematically, transmissivity (T) can be expressed as

$$T = kb \text{ in } m^2/s$$

where T = Transmissivity

k = Coefficient of conductivity (m/s)

b = aquifer thickness (m)

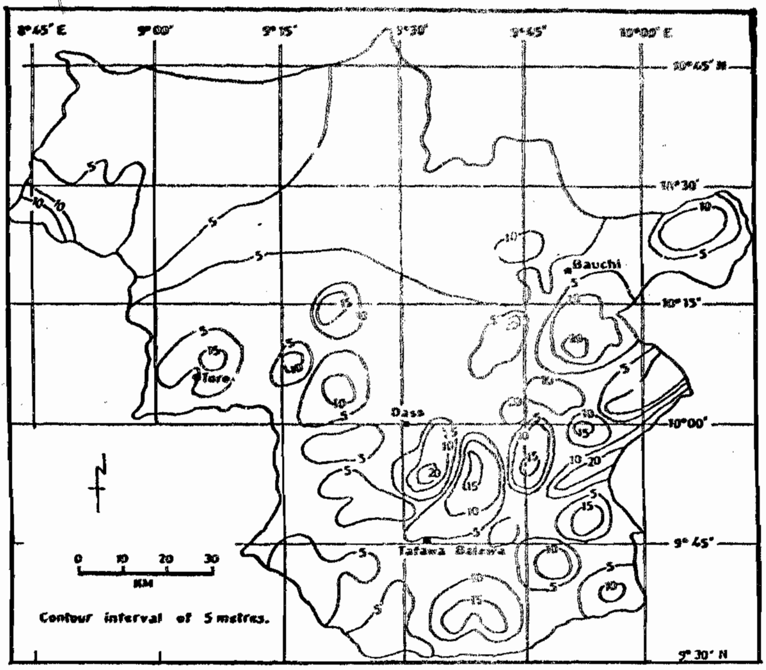

Fig. 5 Depth to Water table map of the area of Study

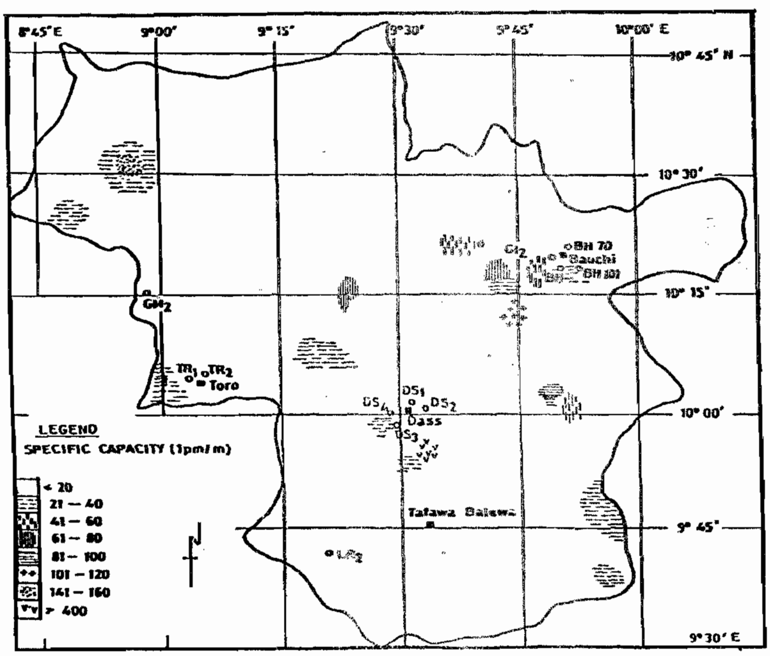

Fig. 6 Specific Capacity Map of the area of Study

For the calculation of transmissivities, the Jacob's modified non-equilibrium method was used, represented mathematically as

$$S' = \frac{2.303Q}{2\pi T}\log\frac{t+t'}{t'}$$

where S' = residual draw down (m)

Q = yield in m^3/s

T = Transmissivity (m^2/s)

t = time for pumping test

t' = recovery time (s)

Estimates of transmissivities obtained from this method in the area show that transmissivities (T) range from 0.80 to 5.4 x 10^{-4} m^2/s, with over 73 percent of the area having transmissivity of the aquifers ranging from 0.8 to 10 x 10^{-4} m^2/s, and only about 14 percent having transmissivities above 4.0 x 10^{-4} m^2/s.

Tables 2 shows the percentages of number of wells and their transmissivities (T) for 45 selected wells.

Table 2. Number of boreholes with their Transmissivities.

S/N	Transmissivity T (m^2/s)	No of Wells	Percentage No. of wells
1.	0-1.0 x 10^{-4}	33	73
2.	1.0 x 10^{-4} – 2.0 x 10^{-4}	6	13
3.	2.0 x 10^{-4} – 4.0 x 10^{-4}	0	0
4.	4.0 x 10^{-4} – 5.0 x 10^{-4}	3	7
5.	5.0 x 10^{-4} – 6.0 x 10^{-4}	3	7

Hydraulic Conductivity

This is the ratio between the discharge velocity and the corresponding hydraulic gradient.

Mathematically this can be expressed as

$$K = T/b$$

where k = hydraulic conductivity (m/s)

T = transmissivity (m^2/s)

b = aquifer thickness (m)

The thicker the aquifer, the smaller the value of hydraulic conductivity.

Using the above relation, hydraulic conductivities were obtained for about 45 selected boreholes and the results are shown in Table 3. The conductivities varied from aquifer to aquifer and range generally from as low as 9.88 x 10^{-7} to about 4.77 x 10^{-5} m/s, with over 73 percent of the wells having hydraulic conductivities ranging between 9.88 x 10^{-7} and 8.0 x 10^{-6} m/s. These low values of hydraulic conductivity could be attributed to the clay content in the aquifers, and the fact that the degree of hydraulic connectivity between the fractures is low.

Table 3. Number of Boreholes with their hydraulic conductivities

S/N	Hydraulic Conductivity	No of Wells	percentage No of Wells
1.	<8.0 x 10^{-6}	33	73
2.	8.0 x 10^{-6} – 1.6 x 10^{-5}	3	7
3.	1.6 x 10^{-5} – 2.4 x 10^{-5}	3	7
4.	2.4 x 10^{-5} – 3.2 x 10^{-5}	3	7
5.	3.2 x 10^{-5} – 4.0 x 10^{-5}	0	0
6.	4.0 x 10^{-5} – 4.8 x 10^{-5}	3	7

CONCLUSIONS

Two main aquifer types are recognized in the area of study – the weathered basement rocks which constitute the over burden (regolith) and the fractured crystalline rocks. The major water-bearing unit in the are of study is the regolith, derived mostly from in-situ weathering and crystalline rocks. These aquifers have poor and non-uniform hydraulic properties that can be attributed to the fact that clay is the main constituent of the product of decomposition of the parent rock.

The geometry of the aquifers is complex, thus making the evaluation of the aquifer properties from test results only rough estimates. Also because of the complex configuration of the aquifer, selection of borehole sites, efficient well design and construction is highly demanding.

Though the aquifers in the area have very poor yields, the best rock types that hold better promise for groundwater in the are is the coarse grained granite, and the granite gneiss. Therefore, any exploration for groundwater in the area should be directed at these two rock types. The presence of any fractures within these rocks will further improve the yield of the aquifer.

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REFERENCES

Bauchi State Agricultural Development Projects, 1989. Phase II. Rural Borehole Project: 2: 92-127

Bauchi State Water Board file, 1976. Completed Borehole Records, Bauchi Province, BSWB Headquarters, Bauchi.

Consulint (Nig) Ltd., 1976. Water Survey of Northeastern State. General Report. Vol. 1 Summary and Conclusions pp 31-33

Conred Nig, Ltd. , 1977-78. Report on Construction of productive and piezometric Boreholes, Unpublished Report.

Duze, M and Afolabi, O.M.A , 1977. Senior School Atlas Macmillan publ. Pp 18-21.

Edok-Eter Mandillas (Nig. Ltd) 1976. Hydrogeology and Geophysical Investigation for Groundwater in Bauchi State; Unpubl. Report.

Freeze, R.A and Cherry, J. A., 1979. Groundwater, Prentice-Hall, pp304-306

Hazell J.R.T. Cratchley, C.R. and Jones, C.R.C., 1992. The hydrogeology of crystalline aquifers in northern Nigeria and geophysical techniques used in their exploration: In Wright E.P and Burgess W.G (eds) Hydrogeology of Crystalline Basement Aquifers in Africa. Geological Society of London Special Publication, 66: 155-182

McCurry, P., 1976. The Geology of Precambrian to lower Palaeozoic rocks of Northern Nigeria – a review. In: Kogbe C.A (Ed). Geology of Nigeria. Elizabeth Publ. Co. Ibadan, Nigeria, pp 15-38.

Oyawoye, M.O., 1970. The basement Complex of Nigeria IN: Dessauvagie, T.F.J and Whiteman A.J. (Ed.). African Geology, University Press Ibadan, Nigeria. Pp 91-97.

Wardrop Engineering Inc., 1989. Bauchi State Agricultural Development Project/Bauchi State Integrated Rural Development Authority: Phase II Rural Borehole Project. Vol.2 – Hydrogeology and Borehole data. Pp 92-127

Water Surveys (Nig.) Ltd., 1978. A limited Investigation for Rural Water Supplies and had-use in Bauchi State; Vol. 1, Unpubl. Report.

Wright, E. P., 1992. The Hydrogeology of crystalline basement aquifers in Africa. In Wright E.P and Burgess W.G (eds) Hydrogeology of Crystalline Basement Aquifers in Africa. Geological Society of London Special Publication, 66: 1 - 27.