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Full Length Research Paper

Field evidence of occurrence of groundwater in Gombe formation around Barambu and Gedawo, Northeastern Nigeria

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The study area lies within the Upper Benue Trough South of Gombe town. Field study was carried out by methods of compass traversing and traversing along stream courses. Gombe formation, exposing 3 sandstone lithofacies comprising the upper, middle and lower members, in this part of the Trough, has a thickness of about 63 m. 2 aquiferous zones occur in the formation. The upper aquifer is found towards the bottom of the upper member of the formation and sometimes at the top of the middle member where sandstone beds interbed with impervious layers of ironstone. The middle member of the formation is essentially an aquitard and overlies the lower member which is an aquifer. Both aquifers are low water yielding. Analysis of grain size of the lower aquifer shows that the sandstones are very fine-grained to fine- to medium-grained, poorly sorted to moderately sorted, and they are river or beach sediments. The intrinsic permeability of the sediments (aquifers) determined from the grain size varies from 1.215 x 10^{-4} to 3.840 x 10^{-4} cm/s. The aquifers can be developed for rural water supplies.

Key words: Groundwater, aquifer, Upper Benue Trough, Gombe formation, Nigeria.

INTRODUCTION

In the outcrop area of the Gombe formation water shor-tage is experienced soon after the rainy season, May – October, because the rivers are not only ephemeral but are also influent. Search for water in the formation is diffi-cult because of fluctuation in groundwater level within it. Although groundwater can be obtained in little quantities from hand dug wells and from holes dug in the alluvium of river channels especially at the southeast of Gombe Township and in other settlements, depths of boreholes within the town can vary from about 180 – 250 m and occassionally they are up to 300 m in other locations such as Kumo and environs (Bala, 1981) . Even then lithological logs for these boreholes tend to indicate that the boreholes were completed in the underlying Yolde or Bima formation. Whereas an earlier study (Thompson, 1956) indicates that the local groundwater conditions within Bima, Gombe and Kerri Kerri formations have not been fully explored, Carter et al. (1963) considered the Gombe sandstone formation generally to be a poor aqui-fer noting that only the Bima formation was the potential source of water supply in Gombe Township. Accordingly, provisions of groundwater to rural communities have focused on drilling of deep boreholes formation, with the aim of tapping water from the Bima or Yolde.

However, during a field work basaltic rocks, observed as syn-depositional flows/intrusions, within the Gombe formation were encountered at Barambu where contact between this formation and the underlying older one was also seen. This mode of occurrence of the basaltic rocks is not common as the rocks are found mostly as plugs of basalt and extrusions of trachyte and phonolite in this part of the Benue Trough. The underlying older Pindiga formation is seen here as an inlier, the overall thickness of the Gombe formation is reduced and the River Barambu becomes effluent downstream of Barambu village as water appears to be haboured in the alluvium and weathered shales and in the sandstone beds overlying the shales. The aim of this paper is to prove that, in deed, Gombe formation can be an aquifer locally due to geological history of the area of its occurrence and to emphasize that knowledge of the local geology is important for the success of rural groundwater development.

THE STUDY AREA

The study area is located within the Southern part of the Gongola arm of the Upper Benue Trough, 30 km on

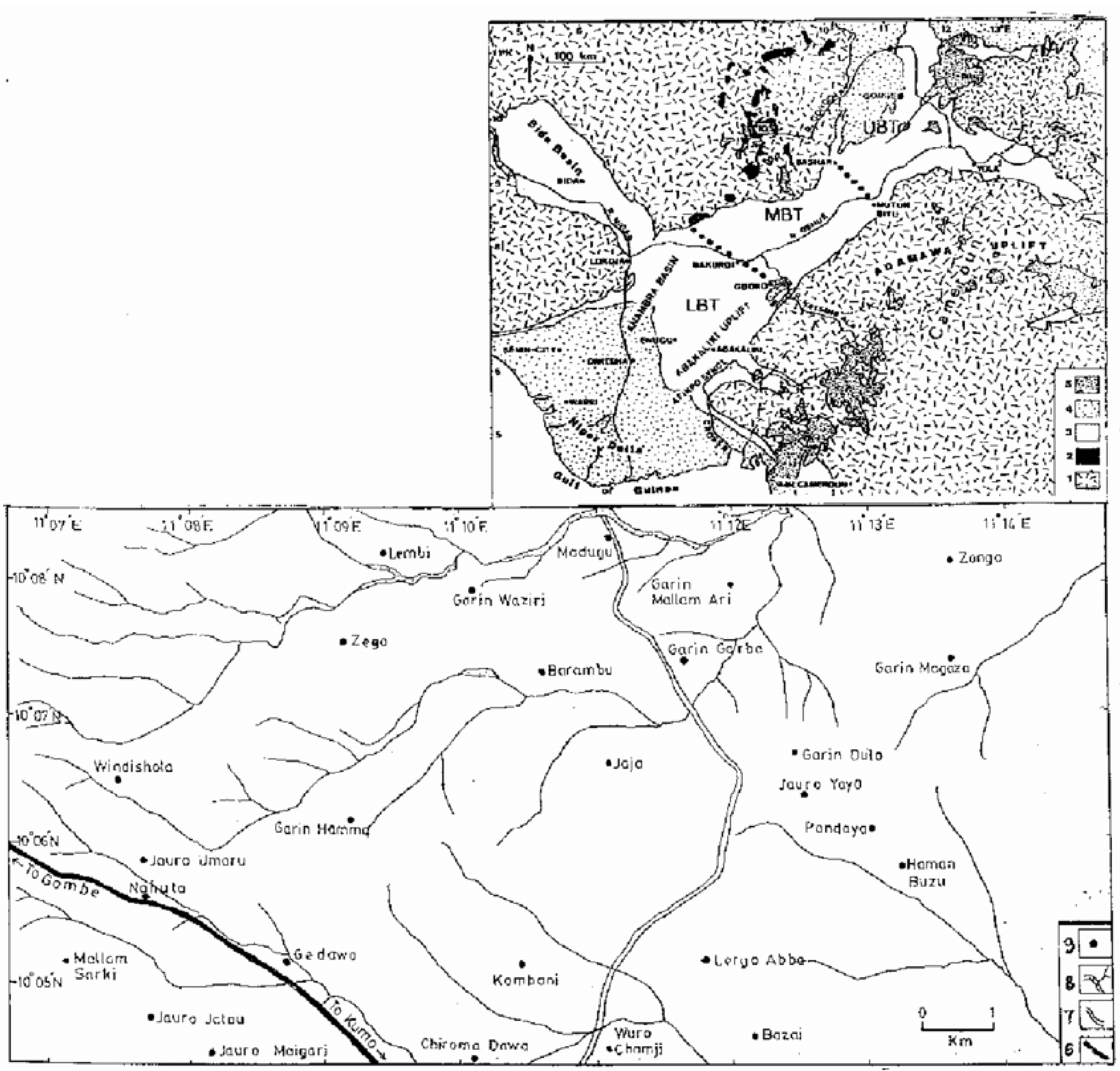

Figure 1. Location and drainage map of the study area. (Inset after Zaborski, 2003).

1. Precambrian. 2. Jurassic "Younger Granite". 3. Cretaceous. 4. Post- Cretaceous. 5. Cenozoic – Recent basalt (including those of the Cameroonline). 6. Main road. 7. Minor road. 8. Rivers. 9. Settlement.

Gombe – Kumo road. The Gongola arm is a N – S trending basin separated from the E – W Yola arm by the Zambuk ridge (an area of shallow basement rock). The area falls within Latitudinal range 10^{o} 04 34" – 10^{o} 08' 36" and Longitudinal range 11^{o} 06' 42" – 11^{o} 14' 40" (Figure 1). Mean annual rainfall is about 969 mm, and the mean annual temperature ranges from about 50 – 100° F (10 – 38°C). The topography is hilly and rugged. Elevation is highest in the western part, dominated by sandstones hills, where it is about 579 m and it falls to about 457 m in the Eastern part. The drainage system is generally dendritic and the vegetation is Sahel Savanna characterized by scattered trees and thorny shrubs.

GENERAL GEOLOGY AND TECTONISM AROUND THE STUDY AREA

Carter et al. (1963) recognized the various formations which Thompson (1956) described as a sedimentary sequence covering a considerable area around Gombe Township comprising the Bima formation, Yolde formation, Pindiga Shales, Gombe Sandstone and the Kerri Kerri formation. To the Southwest of Gombe Township, the sedimentary rocks overly the Basement Complex rocks.

Bima formation is an arkosic to feldspathic, cross-bedded sandstone at the base; thickly bedded and coarse-grained with intercalations of clay/shales in the middle part; and medium- to coarse- grained in the upper part. It has a thickness of about 300 m in the basin. The formation is overlain by the Yolde formation which is made up of a coarse- to fine-grained, cross bedded sandstone having a rapid alternation of well-bedded sandy siltstone with clay, grey to greenish shales and fine-grained sandstone. The sandstone becomes calcareous in the upper parts and may be overlain by limestone at the top. Its thickness varies from about 140 to 210 m. The overlying Pindiga formation consists of calcareous beds and clay/shales. Thin, dark grey to blue- black shales interbed with fossiliferous limetone beds in the formation. Zaborsiki et al. (1998) recognized five members belonging to this formation as Kanawa (blue-grey shales), Dumbulwa, Gulani and Deba Fulani (all sandy beds) and Fika (blue – grey shales). Total thickness is about 500 m. Pindiga formation is overlain by the Gombe formation. Gombe formation consists of a variable succession of well-bedded, fine- to medium-grained sandstones and sandy and silty micaceous shales with occasional mudstones. Three lithofacies have been recognized (Dike, 1995; Zarborski et al., 1998): a basal part of rapidly alternating thin beds of silty shales and fine- to medium-grained sandstone with some intercalations of thin ironstone (rhythmically bedded alternating layers of siltstones and shales) with broad channel filling sandstone bodies; a middle bedded facies consisting of fine- to medium-grained sandstones, carbonaceous siltstone or claystone with occasional coal seams and bioturbated ironstone horizons; and an upper part which consists of medium -coarse-grained thickly bedded sandstones which may be ferruginized and cross-bedded. The formation is about 300 m thick. Basal conglomerates consisting of cobbles, boulders of ferruginous sandstones and some-times rocks characteristically Bima sandstone indicates an erosional surface that separates it from the overlying Kerri Kerri formation. The Kerri Kerri formation is poorly consolidated, medium-coarse-grained arkosic sands and grits with interbedding of sandy gravels, minor clays, silt and fine-grained members (Thompson, 1956, Dike, 1995). It is about 210 m thick. Sedimentological features of these formations were described by Carter et al. (1963) and recently by Zaborski et al. (1998).

Sediments in the basin suffered tectonic deformation in the Santonian and later (Carter, 1963; Zaborski, 1998) towards the end of the Cretaceous (Carter, 1963) resulting into the folding and faulting of strata. Beds dip predominantly westwards or northwards.

MATERIALS AND METHODS

This account is based on field observations during a field training exercise organized for undergraduate students. Field equipment used were rock hammer, magnetic compass, GPS (Garmin GPSmap 76CSx) and a 30 m tape rule. Method of investigation was basic geological mapping of the area at a scale of 1:25,000 following pre-determined traverses that included stream courses. The base map was prepared by enlarging 1:50, 000 Sheet 152 SW Gombe (Federal Surveys of Nigeria, 1969) and production of new map to the appropriate scale. Measurement of depth to the water table in open wells and of bed thicknesses were made, where possible, with the tape rule. Four samples of the sandstone overlying Pindiga formation (Fika Shales) were collected for sieve analysis aimed at determining the texture and the co-efficient of permeability of the aquifer.

RESULTS

Field Geology

Within the study area the main outcropping formation is the Gombe (Figure 2). The 3 sections of the formation namely, the upper, middle and the lower sections are present. The upper part of the formation here is massively bedded, red or brownish in colour. Below the thick beds, fine-medium-grained micaceous sandstone 6– 10 cm thick sometimes intercalated with thin ironstone beds 2 – 5 cm thick may be found. The section is about 18 m thick. These are underlain by silty/clayey to clay sections interbedded with ironstone beds 5 – 8 cm thick in layers of silt. Within this unit, carbonaceous clays and sometimes lignite, up to 10 cm thick can be found. This is the middle section of the Gombe formation in the study area. It is about 30 m thick. Underlying this section is soft, massive and laminated fine-grained sandstone at the base, with 6 – 15 cm thick brownish or grayish beds intercalated with thin ironstone beds towards the top. This unit overlies the Fika shales of the Pindiga formation. It constitutes the lower member of the Gombe formation in the study area. It is about 15 m thick.

To the South of Barambu, is a volcano, Figure 3. Part of the extruded magma can be seen within the beds of sandstone of Gombe formation Figure 4. The rock is olivine basalt (Okpeyeaghan, 2004). Dips of strata as recorded from place to place vary from 4° to 10° generally westwards before the outcrop of Fika Shales and olivine basalt and eastwards after the outcrop, Figure 5, but they do not produce any definite geological structure, Figure 2.

Hydrogeology

Depth to the water table below the surface was measured in parts of the area, Table 1 and the locations of the wells are shown on Figure 2. The depths are shallower in the eastern part where Pindiga formation crops out and are deeper on the western where the Gombe formation dominates. No definite flow pattern could be established from the data on depth to water table.

The four samples of the aquifer overlying the Fika Shales were collected beneath the ironstone bed Figure 6 and were sieved. The distribution of the grain sizes is presented in Table 2. From the data, some parameters namely, mean grain size, inclusive standard deviation or sorting and skewness were analyzed according to procedures recommended by Folk and Ward (1957). The

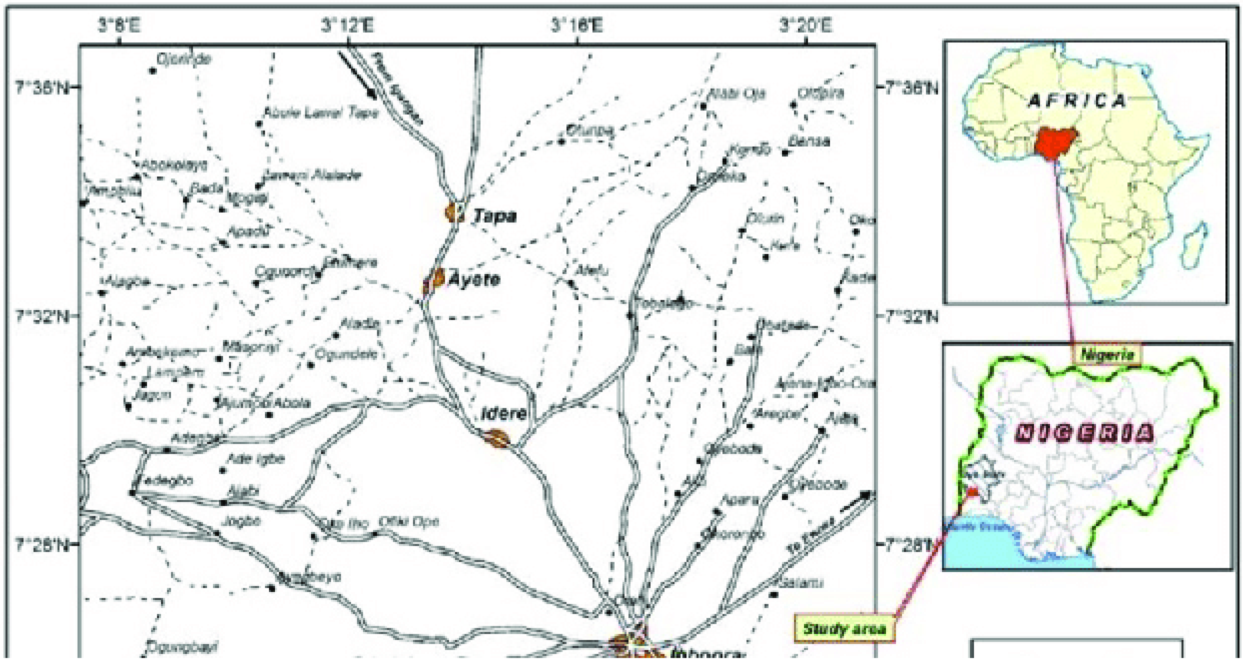

Figure 2. Geological map of the study area.
1. Pindiga formation (Fika Shales). 2. Gombe formation. 3. Olivine basalt. 4. Dip and strike. 5. Hand dug well.

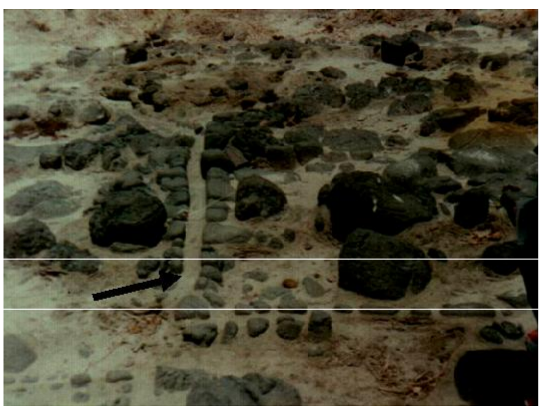

Figure 3. A volcano near Barambu.

Figure 5. Beds of Lower member of Gombe formation dipping eastwards downstream of the volcano.

Figure 4. Blocks of olivine basalt forming a "bed" within Gombe Sandstone.

sediments are very fine- grained to fine - grained, poorly sorted to moderately sorted and they are river or beach sediments.

Since no *in- situ* test was possible, the result from the sieve analysis provided data for the estimation of permeability of the aquifer using empirical relationship proposed by Uma et al. (1989) for poorly consolidated porous media as,

$$k = A(d_{10})^2$$

Where; k is permeability (cm/s), d_{10} is maximum particle size of smallest 10% of aquifer sample (mm) and A is a constant coefficient (6.0; for loosely cemented sandy aquifers and 3.8; for fairly consolidated sandy aquifer.

Figure 6. Lower member of Gombe formation overlying Pindiga formation, showing ironstone interbed

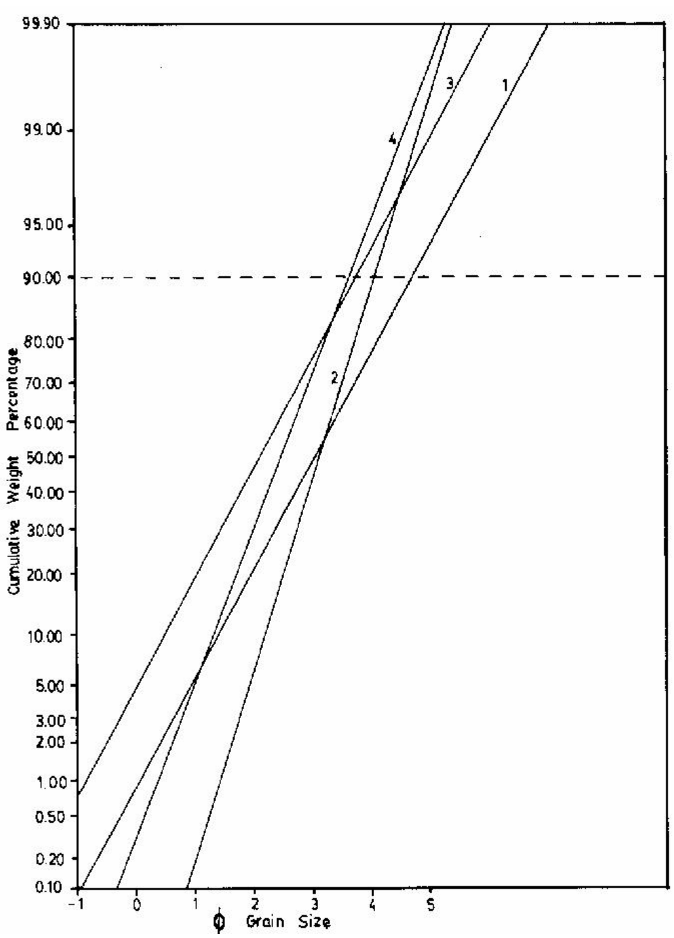

Figure 7. Probability plot based on results of sieve analysis of samples. Note position of d_{10} of samples.

Figure 7 was prepared from Table 2 following procedures outlined in Pettijohn (1975) and the value of d_{10} for each sample obtained from that figure is presented in Table 3. The average d_{10} value is 0.065 mm (= 4) indicating that the sediment varies between silt and fine- grained sands. The permeability of the aquifer varies from 1.215 x 10^{-4} to 3.80 x 10^{-4} cm/s.

DISCUSSION

The problem with accumulation of groundwater in the Gombe formation is related to the sedimentation character of the sediments and the stratigraphical sequence; an upper thickly bedded, medium- to coarse-grained section is separated from the lower very fine-to fine-grained section intercalated within thin beds of ironstone by a middle section which is mainly clay, mudstone and siltstone with intercalation of ironstone layers, 10 – 15 cm thick towards its top. This sequence favours accumulation of groundwater in the upper section of the Gombe formation and because this section is very pervious, water of meteoric source which infiltrates fairly easily into it is trapped/stopped at the top of the middle section and the water accumulates here and makes this part of the upper section an aquifer. Thus a stratigraphical control on the accumulation of groundwater in the upper section of Gombe formation is favoured.

At Gedawo, it is believed that the community water supply powered by Pedal Flo-Solar System comes from this aquifer. The borehole must have penetrated some ironstone beds in the upper part of the middle section; hence the surface of water in a container gets coated with iron film after some time upon exposure to air. Although ironstone beds would inhibit vertical migration of infiltrating water, infiltration into different beds of the sandstones is possible where they have been exposed through weathering and erosion.

Tokarski (1972) treats the formation at Gombe Township in detail. Along the Pantame ravine in Gombe, a 170 m lithostratigraphical sequence of shale-mudstone-sandstone occurring in cyclotherms of 5 “hard” and simultaneous “coarse” complexes with relative preponderance of sandstone or mudstone initial lower member of each cyclotherm and 5 complexes of mostly “soft” at top of each member of about 256 m thick overlying the Pindiga Shales is described. These sequences were typified as flysch-like sedimentation. Here, the shales, sandy shales and mudstone layers vary in thickness from about 3 – 10 cm and are intercalated.

However, Zaborski (2003) attributed the rapid changes in facies of Tokarski (1972) to synsedimentary movement along the Gombe Fault which, at Pantame, brings near vertical lower Gombe Sandstone into contact with the Bima Group, and just to the north, shales of the Pindiga formation are in contact with the Bima formation. Along River Pantame and its tributaries Southeast of Gombe Township, small quantities of water (usually cloudy be-

Table 1. Depth (metres below ground level) to the water table and elevation of water table above sea level) in parts of the study area.

Well No.	Locality	Elevation of ground surface (*m*. a. s. l.)	Depth to water table (*m*)	Elevation of Water table (*m*. a. s. l.)
1	Windishola	503	14.6	488.4
2	Nahuta	503	39.8	463.2
3	Mallam Sarki	518	21.0	497.0
4	Jauro Jatau	503	25.0	478.0
5	Jauro	503	31.0	472.0
6	Zego	472	24.0	448.0
7	Lembi	457	18.6	438.4
8	Garin Waziri	448	11.7	436.3
9	Barambu	436	10.6	425.4
10	Jaja	442	12.3	429.7
11	Kombani	472	10.6	425.4
12	Chiroma Dawa	472	7.9	464.1
13	Madugu	433	9.6	423.4
14	Garin Mallam Ari	433	9.6	423.4
15	Garin Garba	430	11.1	418.9
16	Chabbal / W. Chamji	463	8.9	454.1
17	Lergo Abba	457	13.9	443.1
18	Bazai	448	9.2	438.8
19	Zongo	479	6.5	472.5
20	Garin Magaza	436	9.4	426.4
21	Garin Dulo	448	12.2	435.8
22	Jauro Yaya	448	19.0	429.0
23	Pandaya	442	16.8	425.2
24	Haman Buzu	436	6.0	430.0

Table 2. Results of sieve analysis on samples of the aquifer materials.

Mesh size	Phi	Sample No. 1		Sample No. 2		Sample No. 3		Sample No. 4	
		Wt. %	Wt. Cum. %	Wt. %	Wt. cum.%	Wt.%	Cum. Wt. %	Wt. %	Cum Wt %
2.000	-1	0.00	0.00	0.31	0.31	0.00	0.00	0.00	0.00
1.000	0	1.20	1.20	2.02	2.33	6.83	6.83	0.00	0.00
0.500	1	3.27	4.47	2.64	4.97	13.23	20.06	0.17	0.17
0.250	2	16.23	19.50	2.10	7.07	27.46	47.52	0.16	0.33
0.125	3	32.77	52.27	28.65	35.72	27.38	74.90	3.00	3.33
0.063	4	44.77	97.04	53.79	89.51	18.51	93.41	67.32	0.65
<0.063	5	1.74	98.78	9.90	99.41	6.59	100.00	26.04	96.69

Table 3. Calculated permeability values based on d_{10} of samples.

Sample No.	at d_{10}	Grain size (mm)	K (cm/s)
1	4.63	0.045	1.215×10^{-4}
2	4.10	0.060	2.160×10^{-4}
3	3.65	0.075	3.375×10^{-4}
4	3.63	0.080	3.840×10^{-4}

cause of clay) can be obtained from holes dug in the alluvium. The available quantity is small and supply is unreliable. It is the nature of this cycle of sedimentation, in response to the Gombe Fault that precludes the occurrence of groundwater in large quantities here because the fine-grained sandy layers possess no significant thickness for accumulation of large quantities water. In and around Gombe Township, Gombe formation is not aquiferous.

Around Barambu, lithofacies of the lower, middle and upper members of the Gombe formation were observed on a traverse along River Barambu. The total thickness revealed along this traverse is only about 63 m. This thickness might have been controlled by syntectonic deposition during uplift accompanied by minor magmatism (olivine basalt) thus making the depositional environment to become shallow thereby attenuating the overall thickness of the sediments to about 63 m whereas it is up to 300 m elsewhere. Evidence of folding is seen near the volcano, Figure 5.

Weathering and erosion in the antiformal parts must have followed deposition and tectonism to remove the members of Gombe formation thereby exposing the Pindiga formation (Fika shales) as an inlier near Barambu. The underlying Pindiga formation is essentially impermeable and restricts downward movement of recharging water, which is mainly from rainfall, into the (Pindiga) formation. Recharge into the lower section of Gombe formation is therefore enhanced above and around the outcrop of the Fika Shales and accumulation of groundwater is therefore favoured in the lower member of the Gombe formation.

The middle member consisting mainly clays, carbonaceous clays and interbedding of ironstones (sometimes bioturbated) is essentially impervious and an aquitard and is capable of providing a confining condition on the lower section in some locations. At the same time it allows accumulation of water infiltrated into the upper section to be retained in the lower parts of the latter.

Although each section of Gombe formation may present itself as a homogeneous hydrogeological unit, anisotropic behaviour is evident judging by variation in values of the permeability and the presence of ironstone beds or clay beds within a member. Ironstone beds occur in different horizons and so depth to the water table is determined by the horizon at which the well was terminated. This is probably the reason why a consistent regional groundwater flow pattern could not be established from the few measurements of depth to the water table in parts of the study area.

Conclusion

Gombe formation contains two potential aquiferous layers, the upper and the lower members of the formation sandwiching an aquitard, the middle member. Within the upper member, groundwater is deeply located and occurs under water table condition. Abstraction from this aquifer will be by means of deep boreholes. Access to groundwater in the lower member of this formation is difficult because of depth to it, except in locations where thickness has been reduced due to tectonism, but the water will be under confined or semi confined condition and yield will be low because of its sedimentological characteristics.

The study shows the significance of tectonic and stratigraphical controls on the accumulation of groundwater within Gombe formation. Tectonism created different minor depocentres, some of which have enhanced the occurrence of groundwater in the granular layers of the lower member of the formation. A good knowledge of the local geology and geololgical history is essential in the exploration for groundwater in this and other thick permeable sedimentary rocks having similar geological controls. On the basis of the value of coefficient of permeability, the lower member of the Gombe formation is a low productivity aquifer and can therefore be suitable for small public water supplies. In deed, the borehole at Gedawo is stopped from supplying water to the community between 10:00 am and 4:00 pm daily. An aeromagnetic or gravity survey of the entire region is recommended in order to locate subsurface basic intrusions and faults that might influence groundwater accumulation.

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