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Full Length Research Paper

Borehole depth and regolith aquifer hydraulic characteristics of bedrock types in Kano area, Northern Nigeria

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In this study, the performance of regolith aquifers derived from the different bedrock types was examined using information on depth of borehole, depth to the static water level, yield of borehole and drawdown in 259 boreholes covering the different bedrock types. Results show that mean depth of wells varies from about 37 to 48 m in rocks of the Younger Granites and in the migmatite-gneiss complex and schists, respectively. Static water level ranges from about 9 to 18 m in regolith of the Younger Granites and that of the migmatite-gneiss complex and schists, respectively. Yield varies from about 28 to 44 L/min in the migmatite-gniess complex and schist and in the porphyritic granite, respectively. Drawdown varies from about 6 to 9 m in the regolith of the Younger Granite and in that of the migmatite-gneiss complex and schist, respectively. Mean values of specific capacity varies from about 9 to 11 m^2/d while transmissivity ranges from about 16 to 20 m^2/d. The least values are found with the regolith of the migmatite-gneiss complex and schists while the highest values are found in aquifers of the porphyritic granite. Results further indicate that aquifers derived from rocks of granitic composition tend to exhibit similar hydraulic characteristics. But the poor performance of regolith of the migmatite-gneiss complex and schists (Younger Metasediments) is ascribed to their texture and structure.

Key words: Kano, regolith aquifer, Younger Metasediments, groundwater, yield, transmissivity, basement complex.

INTRODUCTION

Kano area is underlain by rocks of the Nigerian Basement Complex comprising migmatite-gneiss complex, Younger Metasediments, Older and Younger Granites. The aquifers of the Basement Complex rocks are the regolith and the fractures in the fresh bedrock which are known to be interconnected at depth (Mohammed, 1984; Alagbe, 1987; Adanu, 1989; Uma and Kehinde, 1994). These previous works also suggest that the regolith aquifer is uniform in its hydraulic characteristics, properties which Uma and Kehinde (1994) highlights as more crucial than thickness or saturated thickness in determining regolith aquifer performance. In a recent hydrogeological study carried out in parts of Kano area, Bala (2008) has shown that regolith aquifer derived from schists and gneisses of sedimentary origin (orthogneisses) proved to be a difficult groundwater terrain contrary to the observations in the earlier works that not only indicated similarity in aquifer performance across the different bedrock types, but also that these aquifers compare with those in other parts of the African Shield. Using information on depth to the water table measured in hand dug wells, Bala (2008) sets an optimum borehole depth in the regolith aquifer for the area and also reveals that the larger the depth to the water table, the smaller is the borehole yield, and the deeper is the borehole, and that both drawdown and specific capacity are weakly and negatively correlated with depth to the water table. The study also revealed that depth to the water table in hand dug wells vary independently of

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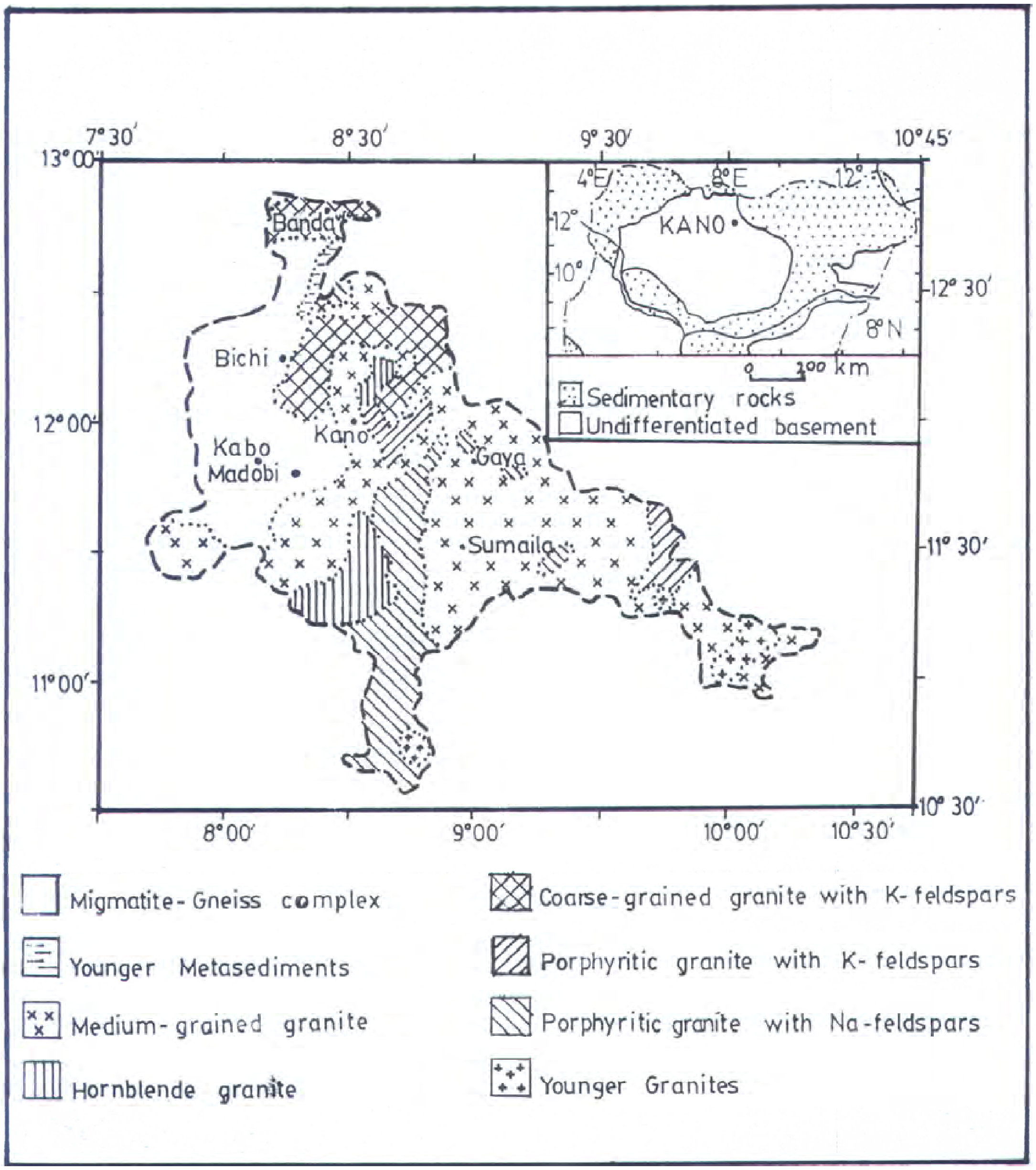


Figure 1. Location and geological map of the study area (Modified from KNARDA, 1989).

independently of rock types, but it is comparable from well to well in the same locality. It was also noted that wells located in areas underlain by schists and similar rocks were generally deep and the depth to the water table in them is larger than in those located in the other rock types.

The findings of Bala (2008) relating aquifer yield to depth to the water table and hence depth of the well is at variance with that of Uma and Kehinde (1994) that indicates a uniform yield of the regolith aquifer from all bedrock types. The aim of this paper is to examine the borehole and aquifer hydraulic characteristics of regolith derived from the different bedrock types of the crystalline basement in the study area.

LOCATION AND CLIMATE OF THE STUDY AREA

The area covered by this study is located approximately within latitudes 10° 40'N to 12° 48'N and longitudes 07° 43'E to 10° 20'E (Figure 1). The area experiences a tropical climate having a rainy and a dry season. Rainy season begins in April/May and ends in October while dry season prevails for the rest of the year. The mean annual rainfall estimated by means of simple arithmetic method for 23 stations is about 785 mm. Relative humidity at 10:00 h varies from about 20 to 70% (Federal Surveys, 1978). The least humidity value is recorded between January and February, and the highest, between July and September. Humidity at 16:00 h varies from about 20 to

60% and the highest values are recorded in July and August. Annual mean temperature ranges from about 70 to 80°F, (21 to 27°C). The lowest temperatures are recorded in the months of December and January while April and May are the hottest months. Although these weather conditions are old, there are no reliable records showing present changes being witnessed.

GEOLOGY OF THE STUDY AREA

The Northern Nigerian Basement Complex comprises three groups of rocks namely, migmatites and (high grade) gneisses derived from Birrimain sedimentary rocks through high grade metamorphism and granitization; the Younger Metasediemnts of Upper Proterozoic age which are low grade metamorphic rocks that were folded along with the migmatite and gneisses during the Pan-African orogeny; and the Older Granite series which were intruded during the Pan-African orogeny (McCurry, 1989). In the study area, Hazell et al. (1988) also reports the occurrence of rocks of the Younger Granites series (Falconer, 1911), so termed because they are Jurassic in age (Figure 1), as well as volcanics, and occasional younger dykes and flows. Kano Agricultural and Rural Development Authority, KNARDA (1989) identifies the individual members of the Older Granite suite, but rocks of the Younger Metasediments and those of the migmatite-gneiss complex were simply grouped as the migmatite-gneiss complex in some places (Figure 1).

GENERAL HYDROGEOLOGY OF THE STUDY AREA

Mohammed (1984) indicates that the aquifers of the Basement Complex area of Kano State are the weathered and fractured rocks in which groundwater exist under water table condition. Water table lies at a depth generally less than 20 m, and the maximum depth of boreholes rarely exceeds 60 m. The hydraulic conductivity of the aquifer ranges from 0.039 to 0.778 m/d with an average of 0.330 m/d; transmissivity varies from 3.756 to 36.600 m^2/d with an average of 12.320 m^2/d; and specific capacity is between 0.054 and 1.200 m^3/m/d with an average of 0.360 m^3/m/d. Muslim (1984) presents a composite hydrogeological section for the basement rocks having a general sequence as follows: Lateritic sand or laterite top layer, silty sand, sandy clay, clayey sand or clay, weathered rocks and fresh bedrock. The mean depth to water table was put at 8.4 m while the maximum depth is 18.5 m.

MATERIALS AND METHODS

The borehole data that were used for this work were from KNARDA(1989). The pieces of information from the data cover all the different rock types. For each borehole, information on location, borehole depth, depth to static water level, pumping rate and drawdown (from pumping test conducted for 60 min in the pumped well) were obtained. Fractures, where ever encountered were recorded and such a borehole was deselected in this work.

In order to enable comparison of borehole and aquifer parameters, the boreholes were studied in groups based on the bedrock types. Rocks of the Older Granite suite were separated into varieties on the basis of texture into medium-grained, coarse-grained, and porphyritic granite. From the information on borehole location, 63 boreholes (covering Shanono, Bagwai, Bichi and Tsanyawa Local Government Areas, LGA) were used for the migmatite-gneiss complex (Figure 2); 71 boreholes (covering Karaye, Gaya and Sumaila LGA) were used for medium-grained granite; 47 boreholes (covering Bebeji, Kumbotso and Gezawa LGA) were used for the coarse-grained granite; 62 boreholes (covering Tudun Wada, Rano and Dawakin Kudu LGA) were used for the porphyritic granite; and 16 boreholes (covering Gwaram LGA) were used for rocks of the Younger Granite suite. For the different bedrock types, the total number of boreholes used was determined by the available data.

The specific capacity of the aquifer was calculated using information on the discharge rate and drawdown in the well. Transmissivity was determined based on Logan (1964) estimation for phreatic aquifers as

$$T = a \times (Q/s)\ldots\ldots (1)$$

where T is the transmississvity of the aquifer (m^2/d), a is a dimensional constant = 1.22, Q is yield of well (m^3/d), and s is drawdown in the pumping well (m).

RESULTS

A summary of the results on borehole characteristics from the different bedrock types is presented in Table 1.

Mean depth of wells is highest in the migmatite-gneiss complex and schists and it is lowest in areas underlain by rocks of the Younger Granites; static water level in wells is deepest in the migmatite-gneiss complex and schists, and it is shallowest in areas underlain by rocks of the Younger Granites; yield is lowest in migmatitic-gniess and schist, and it is highest in the porphyritic granite and; drawdown is highest in the migmatitic-gneiss complex and schist while it is lowest in the regolith of the Younger Granite. From the results on aquifer hydraulic characteristics (Table 2), mean values of both specific capacity and transmissivity are highest in the regolith aquifer of the porphyritic granite, 15.55 and 19.61 m^2/d, respectively, and they are lowest for the regolith of the migmatite-gneiss complex and schist that has 8.73 and 10.65 m^2/d, respectively.

DISCUSSION

Boreholes located in the area designated as migmatite-gneiss complex (Figure 1) show characteristics that differ from those located elsewhere in the study area. Field evidence (Figure 3) shows that the area designated as migmatite-gneiss complex on Figure 1 also contains rocks of the Younger Metasediments which include quartzites (sometimes ferruginous), metapellites (mainly

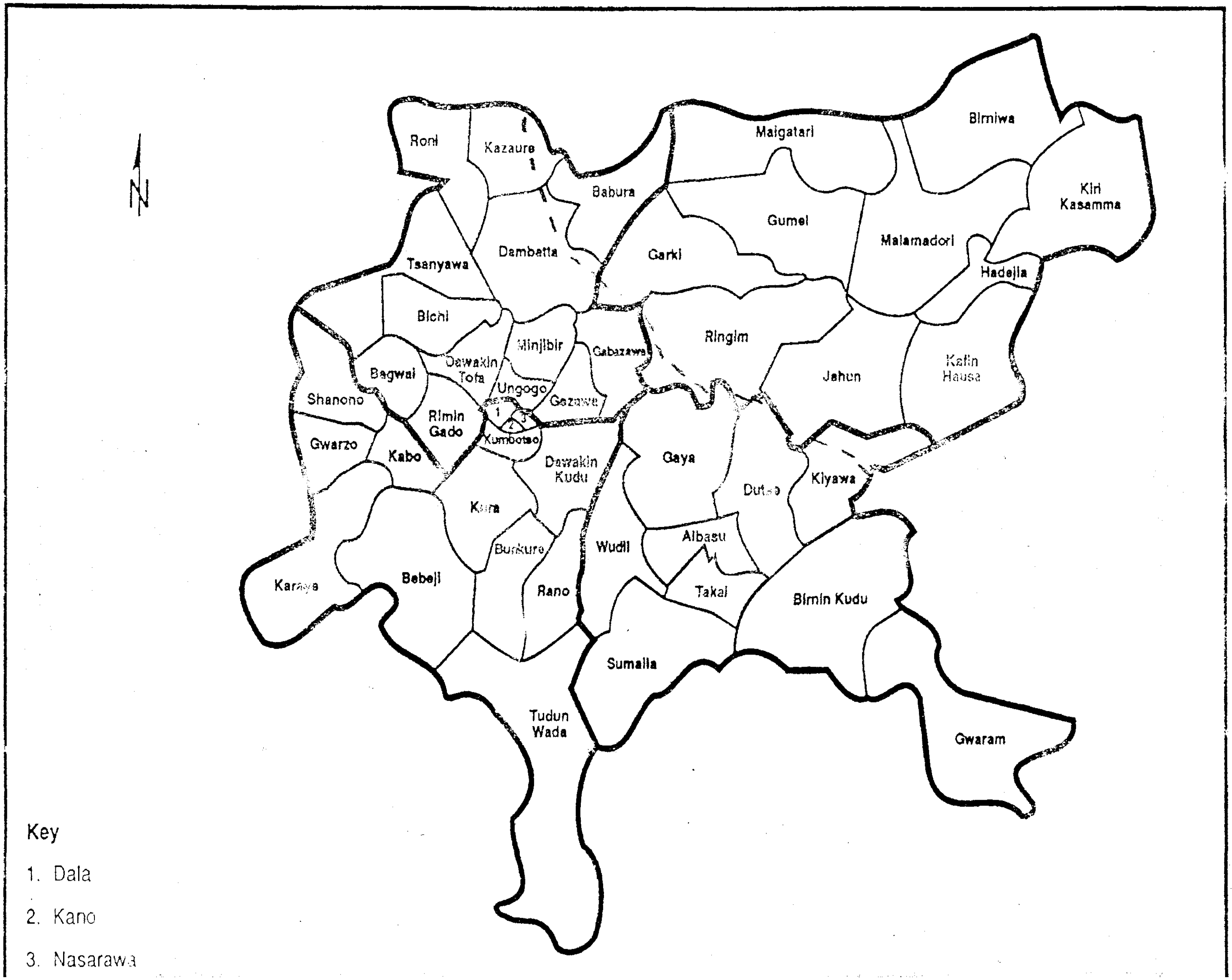


Figure 2. Location of local government areas of Kano.

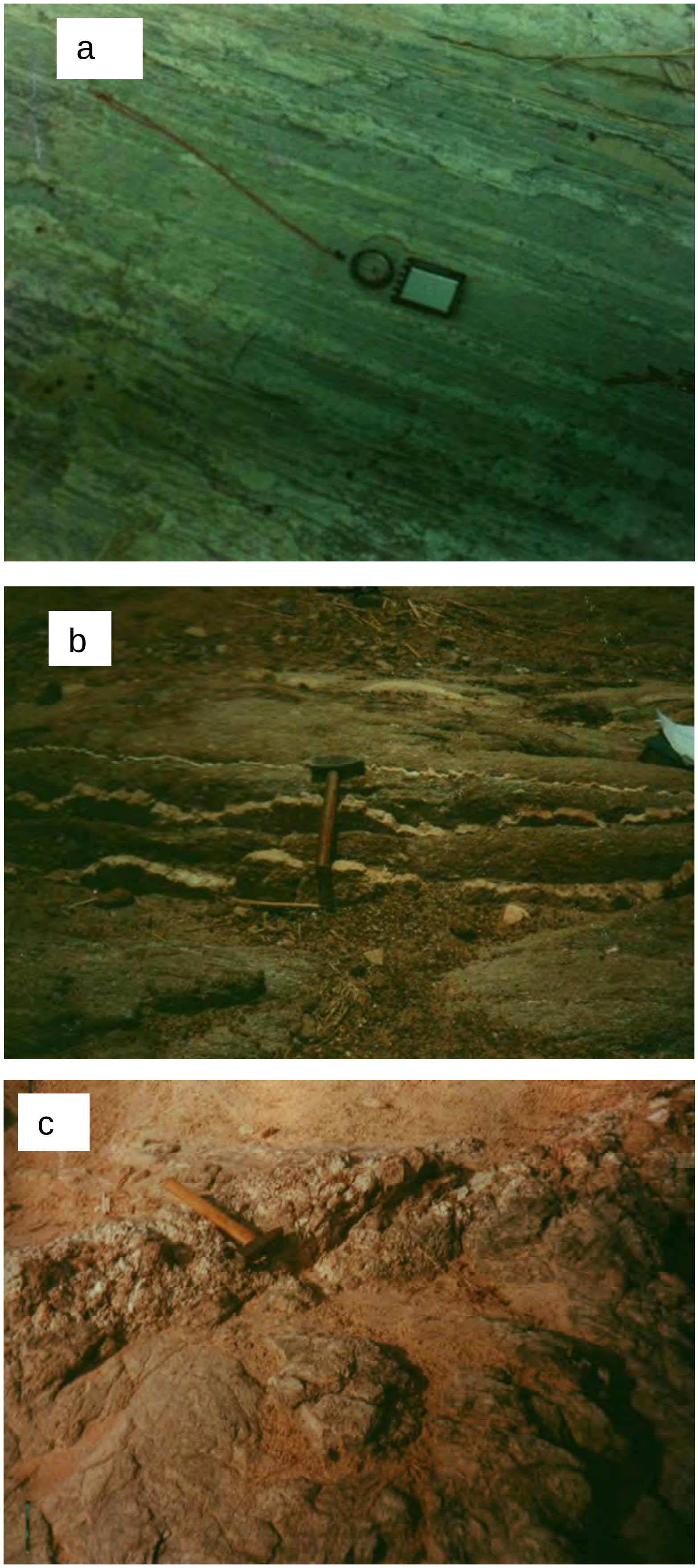
Table 1. General characteristics of boreholes located on different bedrock types in the studied area.

Parameter	Rock type				
	Older Granite				
	Migmatie- gneiss	Medium-graine	Coare-graine	Porphyritic	Younger Granites
Depth (m)					
Range	25.50 - 77.10	25.50 - 61.00	24.00 - 64.00	29.00 - 79.50	23.00 - 44.50
Mean	47.51	40.11	41.28	38.89	37.25
Std. Dev.	14.02	10.31	11.17	10.61	6.10
SWL (m)					
Range	2.70 – 30.76	2.70 - 28.65	4.82 – 27.72	2.10 - 27.87	4.30 – 13.60
Mean	18.48	12.79	14.13	10.96	8.76
Std. Dev.	7.17	5.74	6.16	6.31	3.72
Yield (l/min)					
Range	09.00 - 90.00	10.00 - 72.00	08.00 – 80.00	10.00 - 90.00	10.00 – 115.00
Mean	27.59	40.20	36.89	43.18	37.75
Std. Dev.	19.90	26.44	18.73	23.23.50	27.06
Drawdown (m)					
Range	1.30 – 28.34	1.66 – 32.51	0.26 – 19.85	0.79 - 25.53	1.13 – 12.91
Mean	9.35	7.80	7.55	8.71	6.44
Std. Dev.	7.13	5.23	5.25	6.50	2.54

Table 2. Hydraulic characteristics of regolith aquifers located on different bedrock types in the studied area.

Parameter	Rock type				
	Older Granite				
	Migmatie- gneiss	Medium-graine	Coare-graine	Porphyritic	Younger Granites
Specific capacity (m^3/m/d)					
Range	0.51- 41.23	0.53- 64.64	0.75- 56.84	0.48 -75.79	2.19 - 57.00
Mean	8.73	11.40	10.18	15.57	12.91
Std. Dev.	18.93	13.09	9.28	6.50	14.68
Transmissivity (m^2/d)					
Range	0.50 – 50.30	0.65 – 78.87	0.51 – 69.34	0.57 – 222.53	2.04 – 69.96
Mean	10.65	13.90	12.42	19.61	16.74
Std. Dev.	23.10	15.97	11.32	31.56	18.43

biotite and muscovite schists), and metasandstones. Although, ferruginous quartzites are sometimes found most of the area of metasediments is occupied by biotite or muscovite schists. In that area, the dynamic water level falls quite rapidly with pumping. This situation as well as the general low yield of boreholes in this terrain is a function of the general hydraulic characteristics of this very fine-grained aquifer where rate of flow into the well is at a slower rate than in the coarse-grained aquifers derived from rocks of granitic composition. Additionally, for phreatic aquifers, flow into the well and well recovery after pumping result from a combination of both horizontal and vertical flows (since area of influence of well increases with drawdown). Schist and similar rocks, from their original form of occurrence, may be homogeneous but they are anisotropic. Therefore, flow of water through their aquifers is slow, and specific discharge perpendicular to layering is smaller than that parallel to it because $\mathbf{k_z}$ is different from k_x and k_y which are also quite small because aquifer material is fine-grained. The effect of both structure and texture of this bedrock type is responsible for the low performance of regolith aquifer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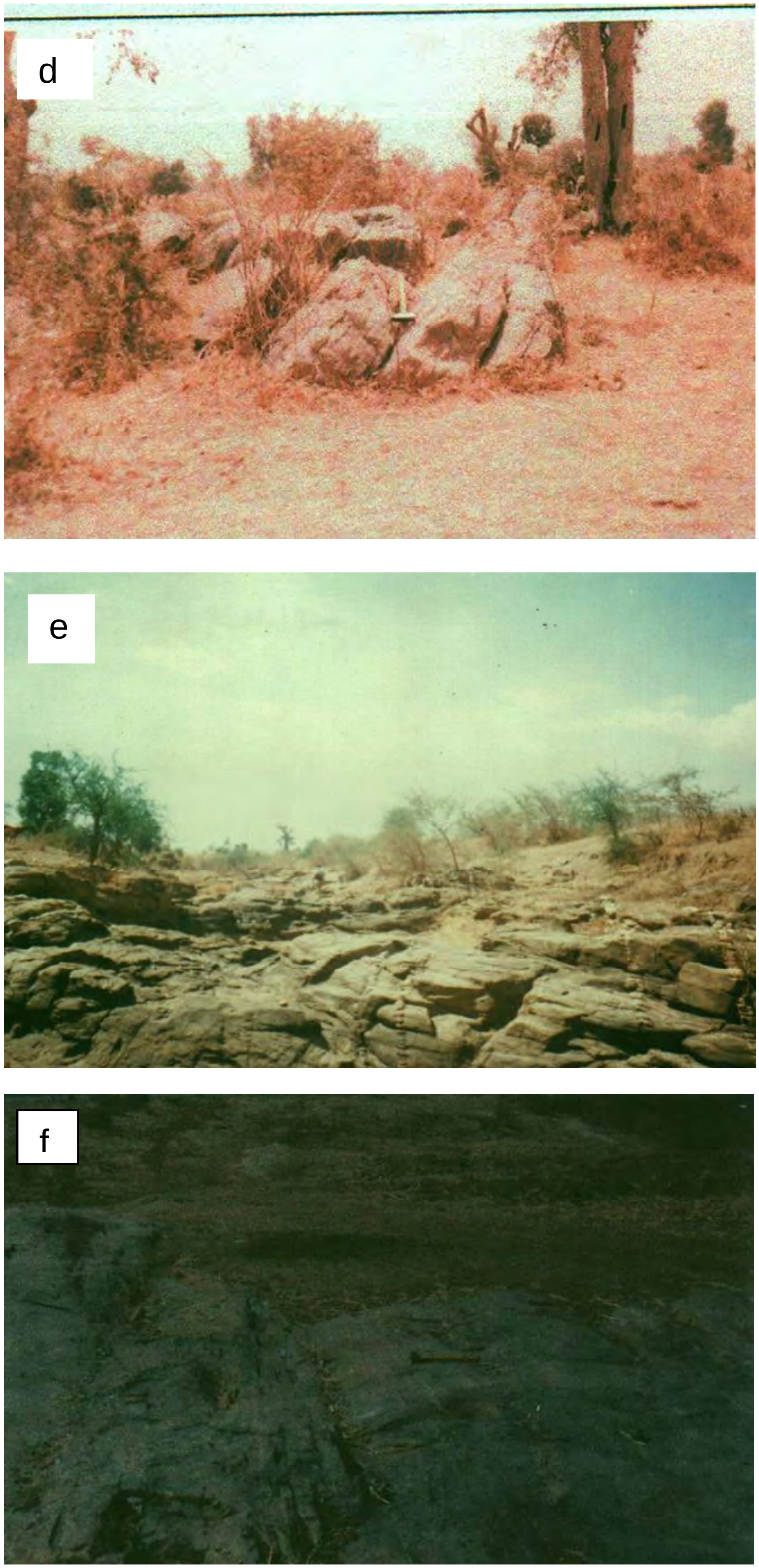
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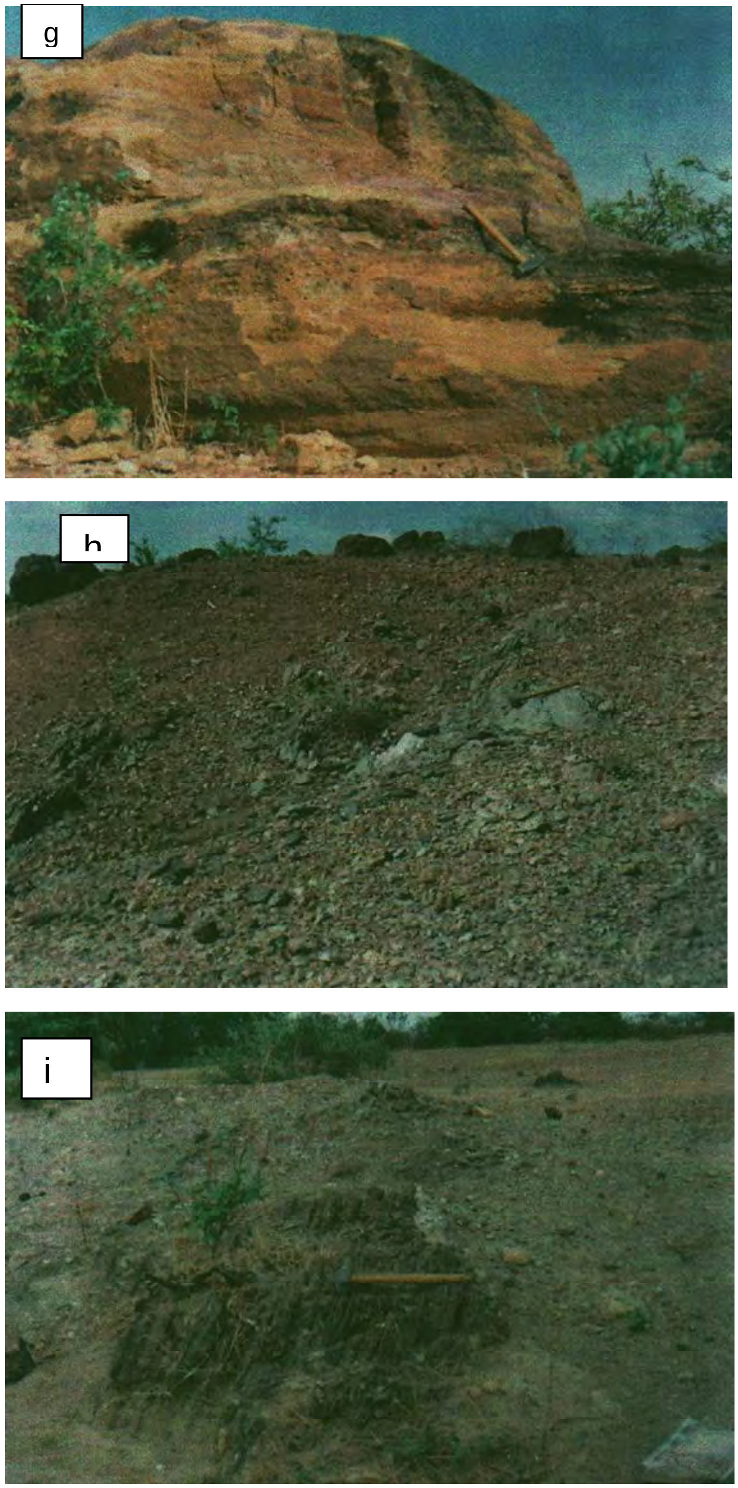

Figure 3. Outcrops of gneisses of sedimentary origin and other metasediments within the study area. (a) Biotite gneiss at Shanono. Light coloured layers are rich in quartz. (b) Biotite gneiss near Kabo showing layers that were originally rich is sand within the sediment as quartzite bands. (c) Biotite gneiss near Tsanyawa with quartz vein (at hammer) showing relic bedding parallel to handle of hammer. (d) Biotite gneiss at Bagwai showing relic bedding. (e) Outcrop of biotite gneiss by a stream channel at Bichi. (g) Outcrop of metasandstone at Ganji. (f) Migmatitic gneiss at stream channel near Karaye. (h) Outcrop of mucovite-biotite schist at Kunchi. (i) Outcrop of biotite schist near Kabo.

derived from it. It would appear that this bedrock rock type experiences deep weathering which is exploited by the borehole drillers. So the boreholes are deep and have deep static water level because of the slow rate of flow into the well after withdrawals.

The gneisses commonly associated with the migmatite may show relics of sedimentary rocks. Oyawoye (1964) refers to gneisses such as these as “ancient metasediments” in which layers rich in biotite “interbed” with those of fine- to medium-grained gneiss. In some localities, this rock may be mistaken for biotite schist. The regolith aquifer derived from these rocks of granitic composition contain potassic and/or sodic feldspars with quartz and lesser amounts of amphiboles and micas. Within the regolith, weathering is more thorough at the top than towards the base as has been shown by Muslim (1984), Jones (1985) and Uma and Kehinde (1994). The most important end products of chemical weathering of rocks of granitic composition (the granites and gneisses) are clay minerals and hydrated sesquioxides of aluminum and iron. On the basis of physical and chemical properties and internal structure, the main types of clay are illite, montmorillonite and kaolinite. Illite will first form, then kaolinite, from potassic feldspar although potassic and plagioclase feldspars may alter to halloysite, a product more common with plagioclase feldspars. Loughnan (1969) expresses this decomposition as follows;

$3KAlSi_3O_8 + 2H_2O$ ---> $KAl_2(AlSi_3)O_{10}(OH)_2 + 6H_2SiO_3 + 2KOH$ ... (2)
Orthoclase Illite

Illite will form if some potash is retained in the reaction, or

$2KAl_2(AlSi_3)O_{10}(OH)_2 + 5H_2O$ ----->$3Al_2Si_2O_5(OH)_4 + 2KOH$ ... (3)

Kaolinite

and

$2KAlSi_3O_8 + 3H_2O$ ------>$Al_2Si_2O_5(OH)_4 + 4SiO_2 + 2KOH$ ... (4)
Halloysite

when all the potash is lost in the reaction in the presence of surplus water. Similarly,

$2NaAlSi_3O_8 + 9H_2O$ ---> $Al_2Si_2O_5(OH)_4.2H_2O + 2H_2SiO_3$ $2NaOH$ ... (5)
Albite

In the study area, kaolinite or kaolin mineral (halloysite) is the clay derived from weathering of the feldspars because rainfall is enough (700 to 800 mm per annum is required), Loughman (1969) to allow a total chemical decomposition of the feldspars and the removal of other products of weathering. Although kaolinite is a non-expanding clay, but occurring dispersed in the regolith, it is capable of lowering permeability of the aquifer in which found because of heterogeneity of aquifer materials due to varying grain sizes. This explains the closeness in performance of regolith of rocks of granitic composition, but fine-grained varieties show lower yields compared to the coarse-grained (Table 2) as amply revealed by yield from the porphyritic granite or the medium,-grained granite in which there is equigranularity of grains. Even though Uma and Kehinde (1994) states that rock type and mineralogy are not as important as aquifer hydraulic characteristics with regard to aquifer yields, it can be seen that both mineralogy and texture affect the hydraulic conductivity of regolith aquifers.

The composition of the regolith was not professionally described in the borehole log presented in KNARDA (1989) because cuttings were variously described as pink granite, black-and-white granite, pink-, black-and-white granite, white granite, pink-and-white granite, and pink-and-black granite. Observations on the field enabled the bed rock type to be appropriately distinguished as gneiss (sometimes migmatitic), Younger Metasediments (essentially schist), granite (Older Granite series), and granites of the Younger Granite suite. The rocks described as “black-and-white granite” in the borehole logs were identified as biotite gneiss on the field (Figure 3) This rock type is a member of the migmatite-gneiss complex. It is fine- to medium-grained in texture and decomposes to produce an aquifer of fine- to medium-grained clayey sands or sandy clay. Grain size analysis on three samples of aquifer materials obtained from this variety of gneisses showed that more than 50% of the samples consist of silt and clay. The largest effective grain size was found to be 0.18 mm and more than 50% of the aquifer material is smaller than 0.075 mm. Therefore, water yield from wells is low in regolith aquifers derived from this type of rock due to texture.

The pair of values of specific capacity and transmissivity in the different bedrock types is close and comparable. This is expected because both properties express the yield of the aquifer per unit decline of a parameter (head or water level). The values obtained are low and they indicate generally a low hydraulic property of the regolith aquifers. The mean values of borehole parameters represent generalizations for the different bedrock types for each parameter tested and the spread around the mean is an indication that some individual wells may be distinct based perhaps on location.

Conclusion

Regolith aquifer performance is affected by the mineralogical composition, texture and structure of the parent bedrock. These in turn, account for the variability of yield from the different bedrock types. The areas underlain by migmatite-gneiss complex and schists of the Younger Metasediments represent generally a poor groundwater terrain due to their lithological and structural characteristics. Choice of screen for boreholes located in such area is therefore very critical to yield. Based on information from the grain size analysis and following Johnson (1975), a conservative choice of screen slot for the aquifers will be 0.5 mm.

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