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Geological Controls for Groundwater Distribution in the Basement Rocks of Kanke, Central Nigeria from Geophysical and Remotely Sensed Data

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Abstract: The Kanke area which forms part of the Basement Complex Nigeria was studied by integrating geophysical and remotely sensed data to evaluate the general geological controls that govern the distribution of groundwater basins in the poorly weathered and fractured rocks. Interpreted resistivity depth sounding reveals a depth to basement values in meters to range from 15 to 35 while depth to water table measured from wells in the area range from 7 to 24. The relationship between the shallow and most yielding aquifers are found to be inconsistent with the greatest depth to basement areas signifying that the aquifers are not sourced from weathered rocks but rather concentrated in fractured zones. Lineaments generated from Landsat_5 TM shows that highest concentration are located around areas of least measured resistivity and follow the pattern of distribution given by geophysical studies. Major NE-SW and minor NW-SE fractures do not yield any water especially around the far western flanks but the most yielding areas are those areas with high fracture densities. Groundwater targeting therefore in the Kanke area should be focused on mapping fractures rather than weathered overburden.

Key words: Basement · Geological control · Groundwater · Geophysics · Remote sensing

INTRODUCTION

The exploration for water has continued to remain a critical factor in rural communities in crystalline basement terrain of the central plateau and especially in sub-saharan Africa. The rocky terrains underlain by undifferentiated Basement Complex rocks stretching from the highly fractured southern limits of the ring complexes of the Central Jos Plateau and the sedimentary contact of the Lower Plateau (Fig. 1) bordered by the Upper fringes of the Middle Benue Trough where the basins provided the structural convenience for the surface water storage has continued to defy provision of sustainable groundwater resources. Most hydrogeological explorations here are aimed at either targeting fractured Precambrian crystalline rocks or areas where the level of weathering is deep enough.

In the Kanke terrain, percolation of water and its accumulation is essentially controlled by fractures and rock discontinuities. Developing a conceptual model that would support water prospecting in such formations will include an understanding of the fracture geometry as well as the crustal level of brittle deformation [1]. While the level of weathering from drill data available on the area is low, with most aquifers yielding about 0.2-1.0 litres per second, crustal ductile and neotectonic brittle deformation accompanying the Pan-African and possibly earlier events played an important role in resetting the structural configuration leaving mainly NE-SW, N-S and NW-SE fracture systems on the Precambrian migmatite gneisses, granites and associated volcanics [2-7]. The interconnectivity of such fracture systems evidently will promote groundwater flow and storage either laterally or vertically from surface percolation.

The approach of this work is to assess both such parameters as surface recharge channel ways through remote sensing and underground water basins through geophysics. Technically sound approaches to ground water prospecting give emphasis on mapping regional and local fracture patterns in relation to their hydric potential [1] which is a function of interconnectivity of the fractures and level of weathering which may widen the fractures

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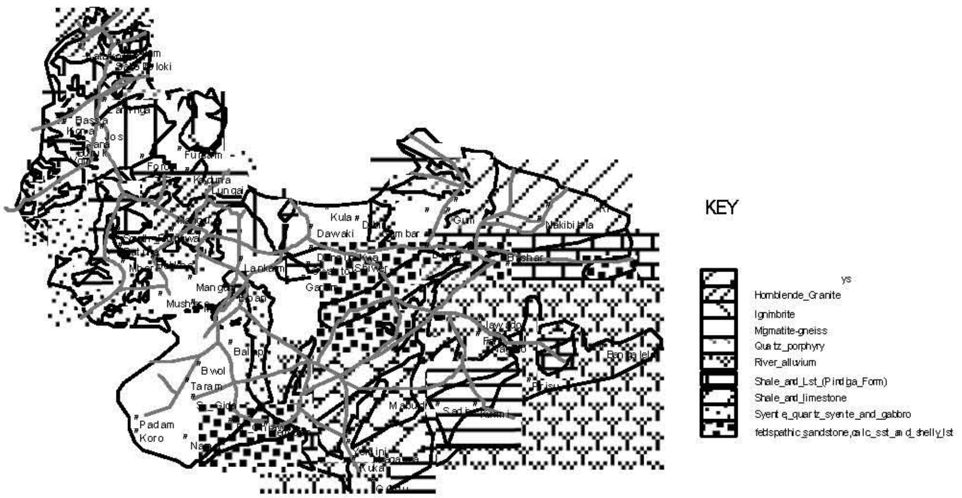


Fig. 1: Geological map of Plateau state showing the study area

such as foliation planes and using ground resistivity survey to establish the geoelectric sections and hence delineate the different geological layers (in this case fractured layers, weathered layers and fresh basement).

Lineament intersections and/or density map normally would accentuate hydrological characteristics of the basement terrain [8] but may differ from a closer structural evaluation through mapping and vertical electrical sounding (VES). This work aim at closely comparing both structural and geological data and there from provide an exploration guide for ground water exploration in the Kanke area.

Method of Study: Exploring for groundwater in this paper involve field geological and geophysical data acquisition and remote sensing. The geological mapping of the area was concurrently carried out. At least three VES points were sounded in twenty-three communities using ABEM Terrameter SAS 3000 with the Sclumberger electrode array across strike of lithologies and maximum electrode spread of 130m in most sounding points except in terrains where obstructions were encountered. This is because expected depth of weathered mantle hardly exceeds 50m. In each community, depths of hand-dug wells were measured and recorded in meters. The automatic curve-matching Zohdy programme after the procedure of [9] was used for geoelectric modeling of the calculated apparent resistivity to match the field curves. The interpretations of selected suitable VES point curves produce estimated depth to basement value for each of the twenty-six areas selected. The depth to basement values for the area and depth to water table measured from wells were then contoured at 1m intervals using SURFER 8.0. Approximate ground water basins were then delineated.

Landsat 5 TM scene acquired 12th December 1986, (*P187, R54*) of the study area was subset and digitally enhanced using Ilwis 3.1Academic in order to accentuate structural features represented by lineaments and displayed in RGB 432 after filtering. Lineaments were then digitized and saved as vector layers. Lineament analysis was done visually and onscreen and major intersection density areas were mapped out and compared with the other maps for interpretation. The Programme used for digitization automatically produces the rose plot of the orientations of the lineaments.

Geologic Setting: The Kanke area forms part of the Precambrian to Lower Paleozoic Basement Complex that lies in the mobile belt sandwiched between the West African Craton to the west and the Congo Craton to the east and southeast [2]. This Pan-African domain that have been reworked by polydeformational events since the Archaean and early Proterozoic involved migmatization, granitization and intrusion of large volumes of granitoids [10], [5] and [11-13]. This resulted in the basement exposure in Nigeria to be an ensemble of undifferentiated rocks called the migmatite-gneiss complex (MGC), N-S trending enclaves of metasediments called the schist belt restricted to western Nigeria [13] and a suite of Pan-African granitoids called the Older Granites including undeformed acid and basic dykes.

The basement exposure in Nigeria is characterized by widespread fracturing leaving a dominant N-S / NE-SW structural grain (folds, foliation, schistocity and

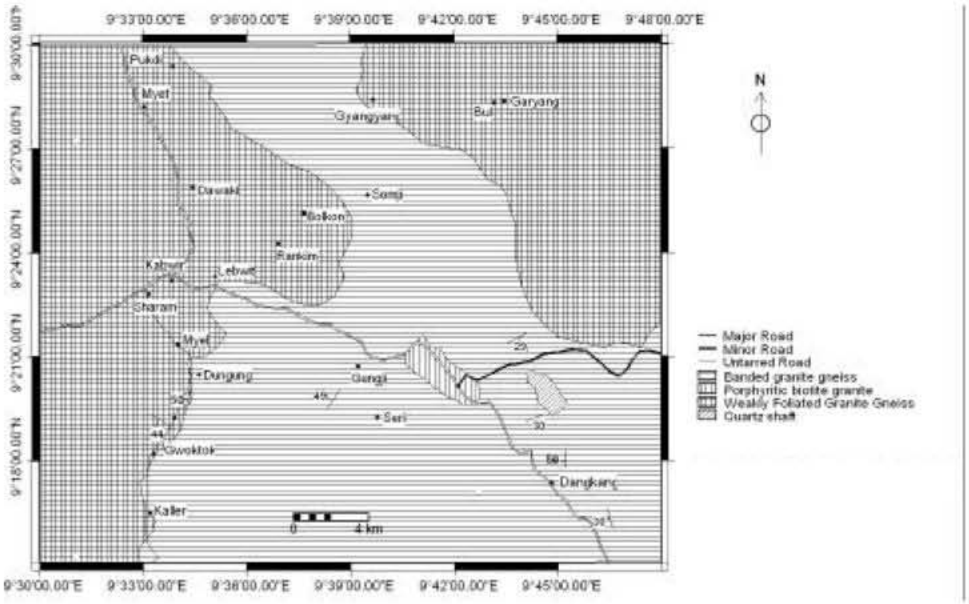


Fig. 2: Geological map of the Kanke study area

lineaments) [14], [11] and brittle failure structures indicating neotectonic [15] mapable structural units on field and lineaments that can easily be read-off on spatially enhanced satellite imagery.

Geology of Kanke Area: Kanke area consists predominantly of banded gneisses that stretches from the south and covers the central belt from Dangkang through north of Gungji (Fig. 2). The Pan-African undeformed older granites intrude the basement and have a gradational contact around the western flanks while the weakly foliated granite gneisses appear to be undifferentiated from the banded gneisses. Predominantly the banded gneisses are gray and medium grained while the granites are coarse porphyritic. Pegmatite veins, dolerite dykes and quartz veins have intruded the gneisses variously.

The effect of the tectonics that occurred possibly during the Pan-African appear to be more pronounced on the granitic intrusions than on the older basement signifying that brittle failure was more dominant on the granites. Foliation planes generally strike N-S, NE-SW and a few are NW-SE and dip between 30-50 degrees on the gneisses

RESULTS

Geoelectric models produced by curve-matching of the apparent Resistivity to match the field curves with the

Table 1:

No	Village	Depth to Basement (m)	Depth to Water Table (m)	Estimated Depth Of water bearing Formation (m)
1	Garyang	30	20	10
2	Gungji	35	15	20
3	Pukdi	26	12	14
4	Bolkon	30	6	24
5	Leplek	28	13	15
6	Lebwit	30	20	10
7	Jemut	35	7	28
8	Bul	35	20	15
9	Kopging	31	15	16
10	Myet	32	22	10
11	Somji	-	-	-
12	Yinang	35	24	11
13	Dangkang	30	20	10
14	Gamu	30	20	10
15	Mwel	35	16	19
16	Gochom	30	20	10
17	Gyangyang	32	10	22
18	Ban	28	6	22
19	Sharam	22	10	12
20	Lur	32	15	17
21	Kudum	30	20	10
22	Seri	30	20	10
23	Myalche	30	20	10

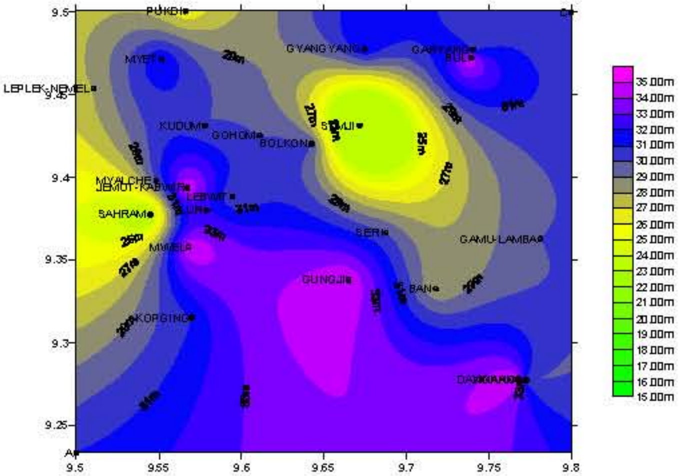


Fig. 3a: Depth to basement interpreted from resistivity measurements contoured at 1m interval for the Kanke area

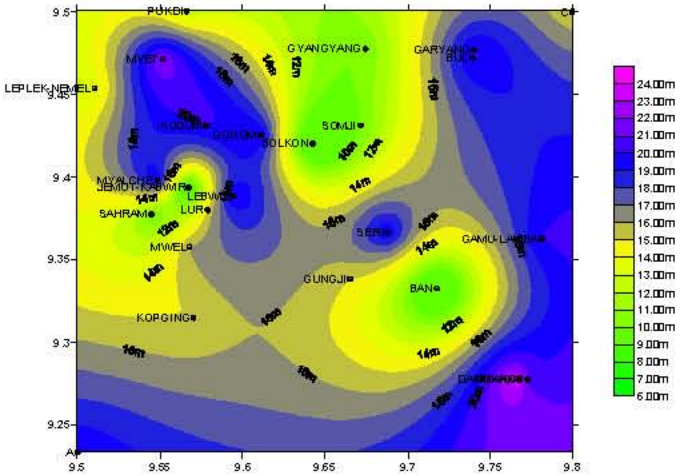
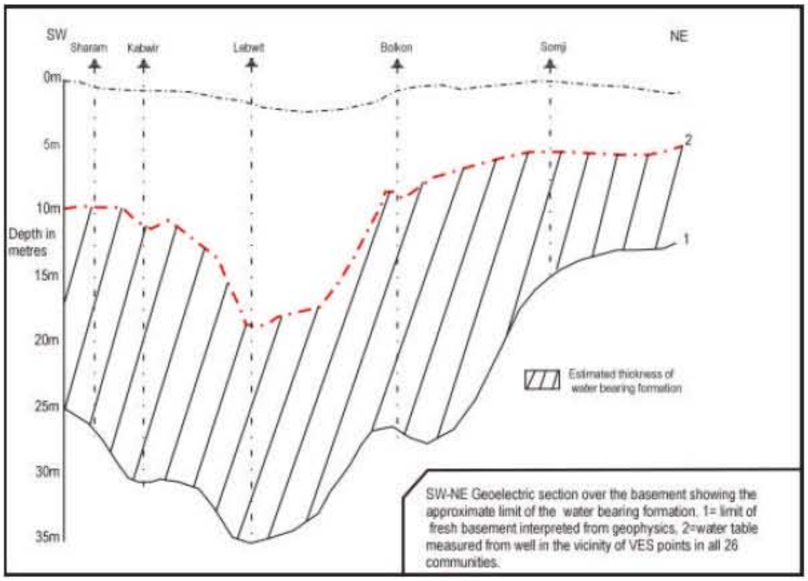


Fig. 3b: Water measurements from wells contoured at 1meter interval for the Kanke area



SW-NE Geoelectric section over the basement showing the approximate limit of the water bearing formation. 1= limit of fresh basement interpreted from geophysics. 2=water table measured from well in the vicinity of VES points in all 26 communities.

Fig. 3c: SW-NE Geo-electric section over the basement in the Kanke area

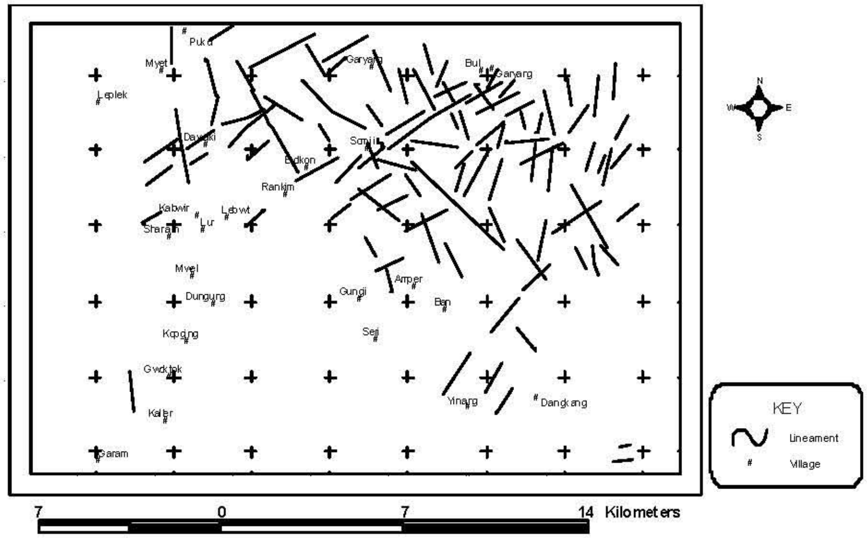


Fig. 4a: Lineament Map generated from Landsat_5 TM for the Kanke area

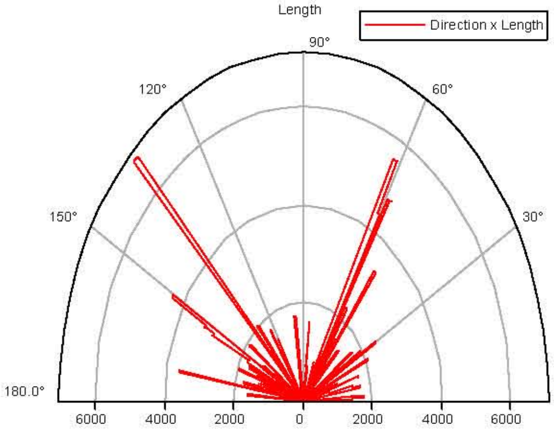


Fig. 4b: Rose plot for lineaments generated from Landsat5 TM data for the Kanke area

use of log-log paper representing apparent resistivity against AB/2 was produced using Zordy programme. Layers were automatically determined corresponding to apparent resistivity of various values. Mostly the H-type curves (4-layer) were plotted. For the purpose of this interpretation and volume of data involved, it is practically impossible to present the geoelectric sections. Results that are of interest include the average depth to basement (solid bedrock) as shown in Table 1 for the whole area. Depth to basement ranges from 15m (shallowest) around Somji and Sharam, to 35m (deepest) around Myet, Kabwir, Lur and Dangkang. Intermediate depths fall around Gungji, Pukdi etc. Fig.3a shows the spatial distribution of subsurface geology, while Fig.3b shows water measurements contoured at 1meter interval to give a distribution of groundwater accumulation. Average thickness of the water bearing Formation is obtained by subtracting column B from column A and plotted into a geo-electric section as in Fig 3c) Areas of hydric potential are chosen for areas with good intersections and the rose plot Figure 6 gave a major NE-SW, NW-SE pattern. Jointing patterns is predominantly NW-SE and NE-SW.

DISCUSSION

The detailed geological control in groundwater distribution in the crystalline rocks of the Kanke area is not well understood. There has been persistent borehole failure in the area and wells dry out during dry seasons. These have prompted the keen interest by NGOs such as WaterAid, COWAN etc and geophysical / geological data acquisition in this terrain becomes imperative. Resistivity surveys reveal depth to which solid hard basement is encountered. If the depth to basement is deep enough and the level of weathering is intense, then it can store enough water and can serve as a potential aquifer. Where these conditions do not hold true, fracturation is normally sought and where the fractures are adequately interconnected, then permeability is enhanced. The rocks in this area (Fig. 2) shows that the older granites and gneisses can be weathered to become aquifers or may be fractured enough. In this study, a comparative analysis of the depth to hard rock and the brittle deformation is carefully considered to assess which is the dominant factor.

The approximate limits of the water prospective zones are shown by the Figure 3a based on areas of deeper levels of fresh basement. The areas between Myet, Dawaki, Gochom and Lebwit theoretically should be more productive. The same applies to Seri and the far eastern flanks covering Garyang, Somji, Sharam and Ban. The basement high that stretches between Pukdi, Somji and Gamu-lamba and around Sharam at the west seems to coincide with the approximate limits of the ground water basins. From the aforementioned, the areas that show deeper hard rock should be the areas of high interest and should potentially be the ground water basins. But a critical look at the distribution of wells that are producing and the water table level show that the areas with higher water levels signifying that the water bearing formation is deep enough is not in consonance with levels where the depth to hard basement is deepest. For instance, the areas around Lur, Sharam show a basement high yet the hydric potential is low. Stretching from Myet, Kudum, Lebwit to Gungji represent a basinal trough with a high hydric potential (Fig. 3a) also gives a low hydric potential if Figure 3a is considered. It therefore means that the basins as inferred from geophysical survey coincide with deeper water levels while the basement highs around Somji, Gamu-Lamba and Sharam coincide with shallower water levels.

Most of these areas with basement highs are underlain by undeformed granitoids that are not highly fractured. On the other hand, the banded gneisses coincide with deeper levels of solid basement. It is most likely that they are more susceptible to weathering as a result of zones of weaknesses accentuated by foliations. Also, the effect of the Pan-African on the older basement is more intense than the slightly weathered granitoids, which in essence are a consequence of the tectonics. Field mapping also reveal more intense structural discontinuities and brittle failures on these basement.

The field structures and TM generated structures were carefully compared. The lineaments mapped (Fig. 4a) and the rose plot Fig. 4b also gave general comparable orientations and distribution restricted almost exclusively to the areas of interest.

CONCLUSION

Groundwater distribution in the Kanke area appears to be controlled by both weathering and structures but the fractures seem to be predominant. The major fractures that govern permeability are a product of NE-SW, NW-SE brittle failure and deformation and not ductile deformation. The level of weathering in the granite rocks is more intense than the banded gneisses and hence stores more water. Exploration for groundwater in the area should therefore lay more emphasis on mapping fractures.

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