Journal of Mining and Geology Vol. 36(1) 2000, pp. 85 - 92 1116-2775


# USING LANDSAT 5 IMAGERY IN THE ASSESSMENT OF GROUNDWATER RESOURCES IN THE CRYSTALLINE ROCKS AROUND DUTSIN-MA, NORTHWESTERN NIGERIA

*** A. E. Bala, ** O. Batelaan and ** F. De Smedt**
* Department of Geology, Ahmadu Bello University, Zaria Nigeria
** Laboratory of Hydrology, Vrije Universiteit Brussels, Belgium

*Received 17 July 1998, Revision accepted 8 February, 1999*

## ABSTRACT

Landsats TM imagery of January 1986 covering Dutsin-Ma and the surrounding areas in northwestern Nigeria was used for the assessment of groundwater resources in the crystalline rocks (Basement Complex) terrian.

Employing ER Mapper (5.2), surface indicator for the occurrence of groundwater such as thriving vegetation in non-irrigated lands, and fracture were identified. These were interpreted vis-a-vis the tectonic development of the area. Lineaments interpreted as fractures show two prominent strike maxima that lie between 000° and 030°, with the more common lying between 000° and 010°. These strike maxima correspond to the stress axis of the Pan African orogeny. The lushness of vegetation along these strikes is higher than in the neighbouring areas and indicate the presence of groundwater. On the basis of lineament density and relative lushness of the vegetal cover, the area was divided into three main hydrogeological zones namely, the zones with the highest, intermediate, and least groundwater potential, for which ground truthing is recommended for their confirmation. Geophysical surveys for the siting of boreholes are also recommended parallel to strikes between 270° and 300°.

It is judged that the groundwater resource for this area is low because of the general lack of moist or seepage areas, the low threshold value (0.12) of Normalized Difference Vegetation Index (NDVI), and the generally dispersed nature of the vegetation.

## INTRODUCTION

Dustin-Ma and its surrounding areas are underlain by Precambrian crystalline rocks of both metamorphic, and igneous origins. These rocks lack primary porosity, but secondary porosity could have resulted from the weathering, and fracturing. The distribution of the fractures, or depth of weathering varies from location to location. Therefore, the occurrence of groundwater in these rocks is erratic and bore hole siting in this geological terrain is often difficult, expensive and time consuming. JICA (1984), in their investigation for supply of groundwater to rural communities in Sokoto State drilled several bore holes in a catchment (river Gagere catchment) adjacent to that of River Bunsuru, which is part of the study area. Both catchments have a similar geology. Most of the bore holes were unsuccessful, and the need for thorough geophysical study prior to their siting was stressed. Fortunately, remote sensing provides information on remote areas of the Earth where otherwise no measurements would have been taken (Schultz, 1988). Relevant information thus derived help to direct geophysical or geological operations on the field.

Unlike for vegetation, land use and surface hydrology, for which remote sensed image can be interpreted directly (more or less), interpretation for groundwater using remote sensed images is accomplished through inference from the surface indicators for the occurrence or favourable locations for the presence of the groundwater. Such surface indicators include thriving vegetation in non-irrigated lands, seepage areas, and fractures (Schultz, 1988; Batelaan and De Smedt, 1994). The identification of areas with such indicators on the image helps to direct and limit the bounds for geophysical prospecting for groundwater in the field and therefore cuts down the cost of investigation while improving the chances of properly siting a bore hole. The aim of this study therefore is to locate possible areas favourable for the occurrence of groundwater within the area under investigation. It is these areas that would be targeted for ground truthing proceeding the siting of bore holes.

## THE STUDY AREA

The study area and the surrounding areas are located within longitudes 006:53.20E - 008:00.00E and latitudes 12:20.00N - 12:53.30N. It covers an area of about 473 km$^2$, and forms part of River Bunsuru drainage basin (Fig. 1). The vegetation is typical Sudan Savanna, characterized by *Isoberlinia doka*, and *Acacia sp.* The area is subjected to two seasons - the rainy and the dry seasons. The rainy season lasts from about late April or May through October. The average annual

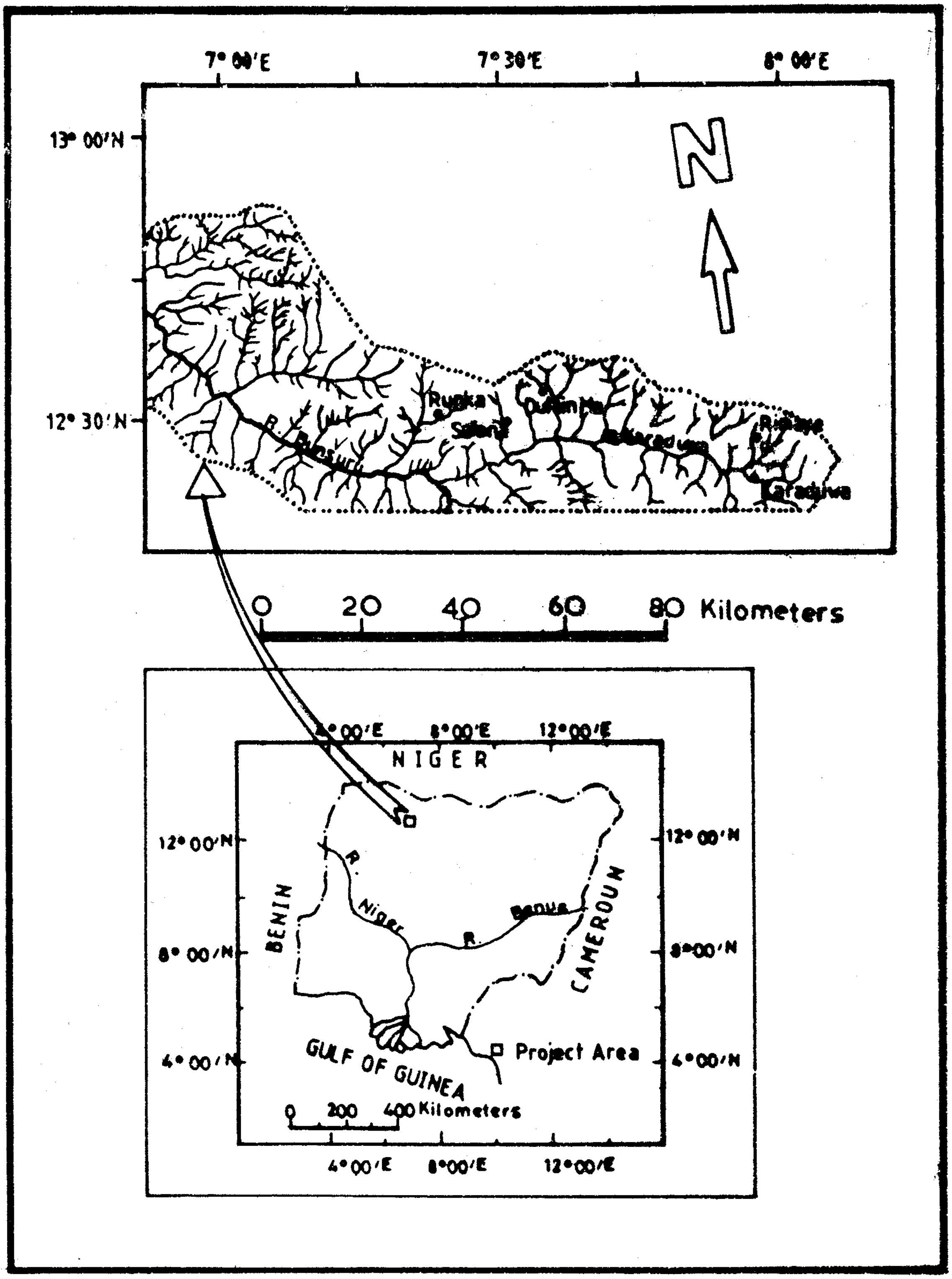


Fig. 1. Location map of the study area showing drainage

rainfall is about 873 mm. Field studies revealed that the crystalline rocks present in the area are gneisses, schists (Younger metasediments) and the Older granites. All these are rocks of the Basement Complex of Nigeria, (Russ, 1957).

The gneisses are leucocratic, massive, and medium, to coarse-grained. They occur commonly as whale back outcrops. Sometimes they appear migmatitic and show foliation. The schists are members of the so called Younger metasediments. They are dark grey in colour, have a general north-south strike and occur in deeply dissected valleys. Rocks of the Older granites found here have porphyritic textures. On some outcrops, the pinkish feldspar phenocrysts show a prominent north-south alignment within the groundmass of quartz and mafic minerals. They outcrop as massive bodies and sometimes they appear as massive blocks which have resulted from weathering along the joints. An outline geology of the area is presented as Fig. 2.

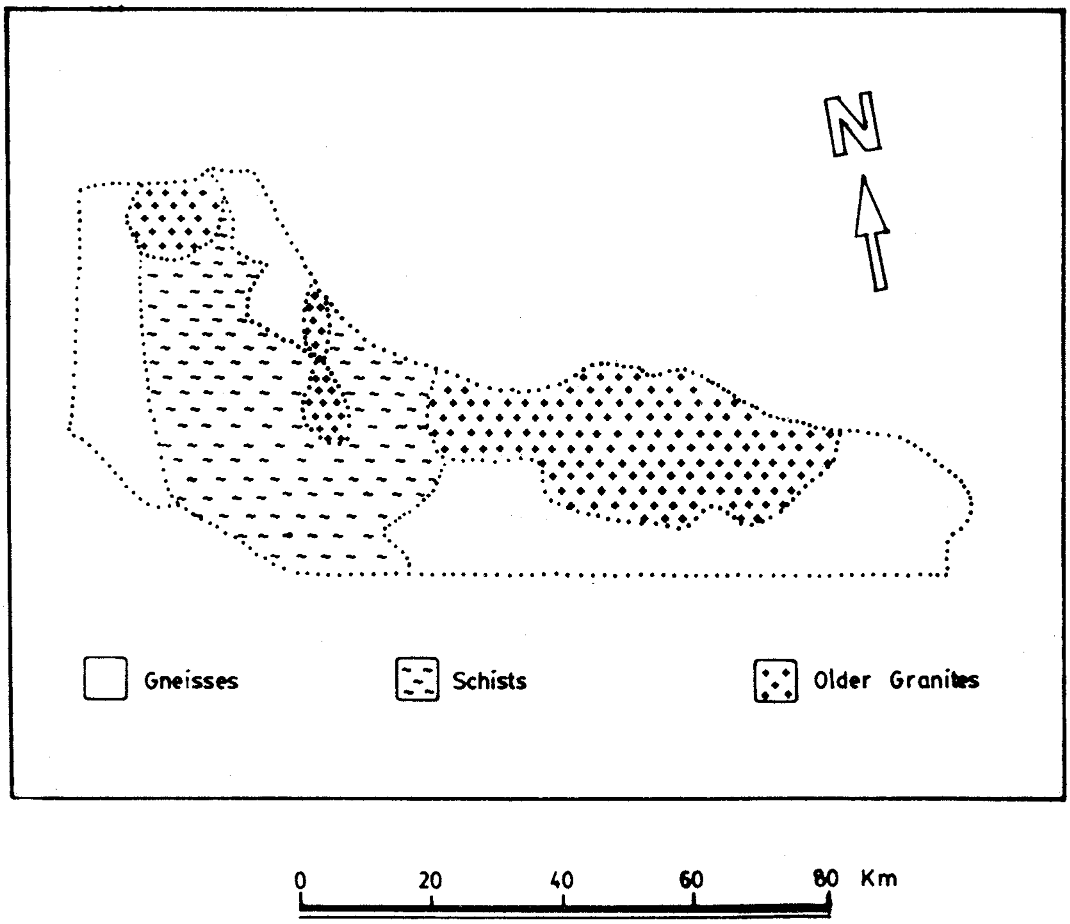


Fig. 2. Generalized geological map of study area

## METHOD OF INVESTIGATION

The study was carried out using a Landsat 5-TM imagery acquired on 8th January, 1986. Image processing, feature identification and interpretation were done using a raster-based image processing and integrated mapping software package, the ER Mapper (5.2), supplied by Earth Resources Mapping PTY Limited, U.S.A., which was run on a UNIX computer.

The dataset as supplied by EROS Data Center (EDC), Sioux Palls, U. S. A., was prepared in the new National Landsat Archive Production System (NLAPS), the National Data Format (NDF). It consists of the image data, and the processing information. No digital elevation model (DEM) was supplied. The scene data (image data) consists of 7 bands of Landsat5-TM. In addition, a header, a work order, and a history file were also provided. These three files contained the useful pieces of information on the imagery and those needed to import the data into the ER Mapper environment.

The image is at least 90% cloud-free, (Bala, 1997). The data was geometrically and radiometrically corrected during processing in the NDF. It was also rotated and aligned at 8.7°, and resampled by the cubic convolution kernel technique. However, after merging all the bands to produce a single file in the ER Mapper environment, the dataset was resampled by the nearest neighbour kernel technique. This was done mainly to allow accurate cross band operations. Then using the annotation tool of the ER Mapper, a raster overlay of the study area was demarcated and created.

Contrast enhancement was carried out only on the study area to improve the visual presentation of the information content of the image. The enhancement was done using the ER Mapper Transform editor. Such as an image would have intensities of pixels well distributed over the range from 0 - 255 giving a broad histogram (Cracknell and Hayes, 1991). This enhancement was carried out on the basis of layer or band in the pseudocolour mode, and for the Red Green Blue (RGB) algorithm, but the bands of the data were later saved together as an image in the latter case.

## RESULTS

Further processing continued for the information content of the imagery. Information on vegetation location and abundance was obtained from RGB 321 (natural vegetation) and RGB 432 (false colour), and the Normalized Difference Vegetation Index (NDVI). NDVI uses information in band 3 (red) and band 4 (near infrared) of the Landsat imagery to highlight vegetation location. It uses the formula;

$$(TM4 - TM3) / (TM3 + TM4) \quad \ldots\ldots\ldots\ldots\ldots (1)$$

where TM3 and TM4 represent Landsat band 3 and band 4 respectively, and the empirical relations between them. Perry and Lautenschlager (1984) noted that the NDVI is a means of reducing multispectral scanner measurements to a single value for predicting and assessing vegetation characteristics such as species, leaf area, and biomass. By applying a threshold formula, such as;

IF (I1-I2) / (I1+I2) >=THRESHOLD VALUE
INPUT1 ELSE NULL ........ (2)

where I1 and I2 represent the TM Bands as written in equation(1), and inputting several values of NDVI, evidence of vegetation clearly showed at the value of 0.12. This value falls within the range for urban areas, dead vegetation and shallow groundwater, (Gathumbi, 1996), and simply indicates the presence of poor vegetation in the area.

A tasseled cap transformation of the area was done. It represents soil, vegetation and wetness (related to canopy and soil moisture) corresponding to dimension defining planes of soil, vegetation, and a transition between them (Crist and Cicone, 1984). The bright areas represent sand or barren land. More than 50% of the area is barren. The lakes and ponds are bright blue while the green/cyan areas represent vegetation/moist soil. Again vegetation is prominent in areas occupied predominantly by the metasediments, and along stream/linear courses.

Using the result of the tasseled cap transformation as a guide, six classes were selected for an unsupervised land use classification of the area. The area coverage of each class is presented in Table 1. Again, the distribution of vegetation follows a similar trend as already observed.

Table 1. Areal coverage of land use classes in the study area.

| Land use name | Area (km2) | Percentage coverage |
|---|---|---|
| Reservoirs/Ponds | 32 | 6.77 |
| Urban and moist areas | 30 | 6.34 |
| Natural vegetation | 93 | 19.66 |
| Cultivated I | 144 | 30.44 |
| Cultivated II | 127 | 26.85 |
| Open dry lands | 47 | 9.94 |

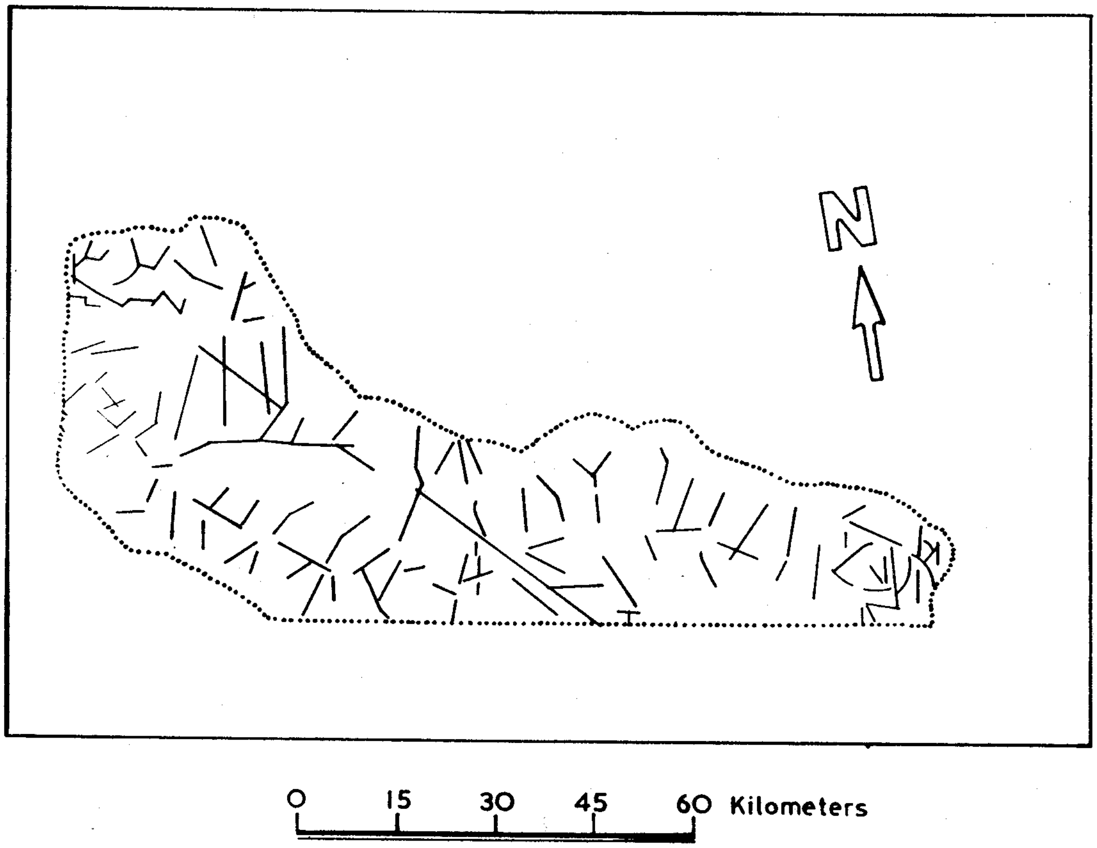


Fig. 3. Lineaments map of the study area

Lineaments in the area were mapped using band 5 which was contrast stretched and appended with a histogram equalize, (Fig. 3). These are represented by linear or curvilinear, continuous or discontinuous over their entire length. They may appear as ridges or depressions or drainage lines, (Dainelli, 1986), and differ distinctly from patterns of adjacent features and are an expression of the subsurface geology (O' Leary *et. al.,* 1976). The strikes of the lineaments were determined, and the rosette diagram based on them is presented in Figure 4. This figure revealed that the commonest strikes of lineaments in the area fall within 000° and 060°, and a dominant between 000° and 030°.

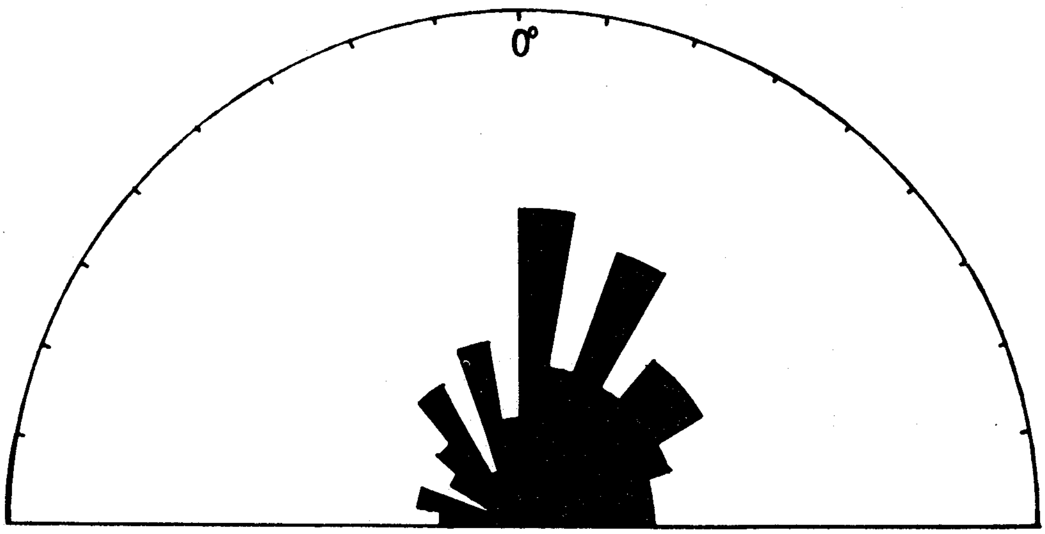


Fig. 4. Rosette diagram of the lineaments (x5)

**DISCUSSION**

There were no areas of seepage seen, therefore, the hydrogeological interpretation was based on the cover analysis and lineaments with respect to the local geology. The distribution of vegetation, (Batelaan and smedt 1994, Dainelli 1986 and Musick and Pelletier 1986) as observed from their studies, is influenced by the distribution of moisture. During the image processing the algorithms Band5/band1, band5/Band7 and NDVI were carefully examined and compared. These algorithms agree well and show grey areas that correspond to those where vegetation has been observed. The tasseled cap transformation image shows that vegetation is commonly found in the areas occupied predominantly by metasediments, and along some lineaments where the signature of the third plane helps their recognizability. The unsupervised land use classification shows the general distribution of natural vegetation. Vegetation appears in a highly dispersed manner, but is more concentrated in the areas occupied by metasediments and along some lineaments.

Lineaments are one type of geological structure whose presence is favourable for the occurrence of groundwater especially in crystalline terrains where they control groundwater recharge, transmission and discharge. Many lineaments were mapped; and the analysis of their strikes showed two major maxima, (Fig. 4). The view has been expressed by Travaglia (1983) that not every lineament is related to fracture or to groundwater. Lineaments important for the occurrence of groundwater were identified by Caponella (1989), to be tensional fractures which are related to the main direction of tectonic stress, enlarged by brecciation, and weathering. This view is also supported by Dainelli (1989).

The last major tectonic event in this area was the Pan African orogeny (650 ± 150 Ma). It produced geological structures trending essentially north-south. Some of the lineaments bear this strike while others shows a deviation from it (Fig. 4). Important hydrogeological lineament (fractures) therefore fall within the range of strikes exhibited by these maxima. Many of the lineaments are drainage lines, meaning that the drainage is structurally controlled. In the dry season, the dry sandy river beds are often dug for water by villagers. The availability of water confirms that groundwater is present in some fractures identified as lineaments on the Landsat5_Tm imagery. Lineaments inferred from the alignment of vegetation are not common, but are found in the eastern and southern portions of the central parts of the study area. Similarly, lineaments criss-crossing are rare. The ğlobal picture provided by these lineaments is that the presence of groundwater in areas far from river courses is rather limited and restricted, and regional aquifers are lacking.

On the basis of cover analysis and lineament density, the area has been divided into three broad hydrogeological zones, namely; Zone A, Zone B and Zone C, (Fig. 5). Zone A is considered to have the highest groundwater potential while Zone C has the least. This interpretation is subject to confirmation through ground truthing and so should be considered as such with caution. This is especially so because the zone designated B shows better vegetal cover on the tasseled cap transformation and Land use classification maps and also has many lineaments. It has been given an intermediate position hydrogeologically because its lithology consists of fine-grained metasediments. At the moment, it is neither certain whether the lineaments go beneath the metasediments that overly the gneisses nor the vegetation found here is supported by water which is retained for a comparatively longer period of time in this type of lithology than in the others on account of low permeability.

On the basis of the strike maxima, geophysical sounding traverses are recommended along strikes ortogonal to them, that is, between 270° and 300°.

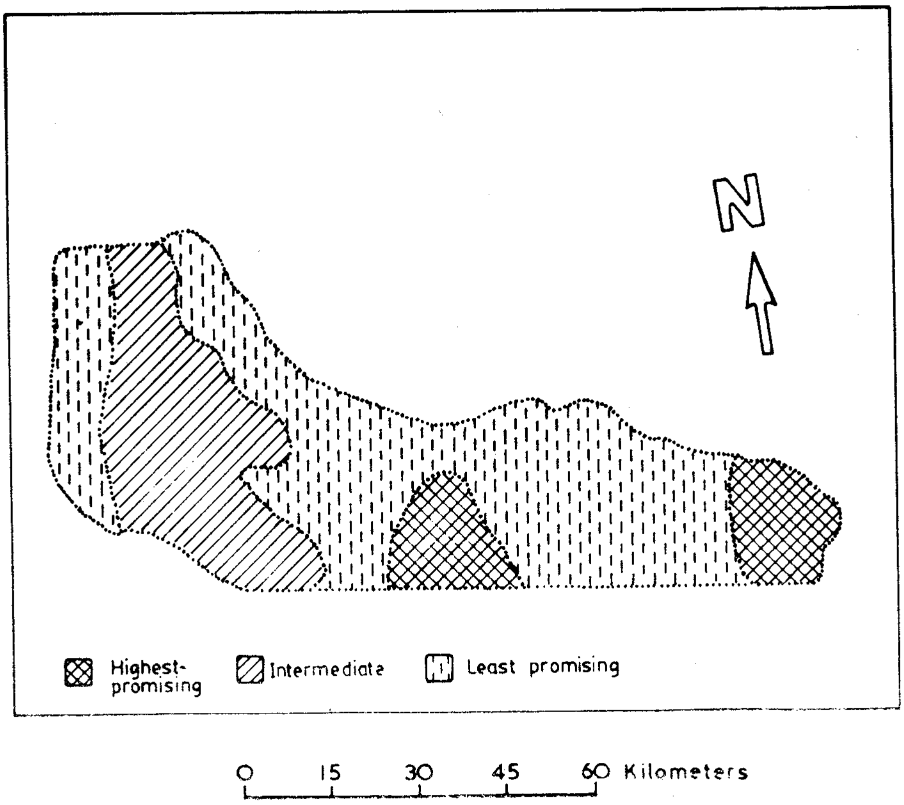


Fig. 5. Hydrogeological zones of the study area

## CONCLUSIONS

This work demonstrates the use of Landsat5_TM remote sensing in groundwater exploration. Additionally, the geological history of the area on which the investigation is being carried out should be well known. It is only then that the imagery can be interpreted for groundwater in the correct perspective.


## ACKNOWLEDGEMENT

This work was funded by the World Bank through the National Universities Commission (NUC) under the staff-in-training scheme for Nigerian Universities. Material support was also provided by the Laboratory of Hydrology, Vrije Universiteit, Brussels. Special thanks are due to Prof. A. Van der Beken, Prof. Dr. Ir. F. De Smedt, and Dr. Okke Batellan for their interest in the work.


## REFERENCES


BALA, A.E. 1997. Remote Sensed Groundwater Potential of the Basement Complex Around Dutsin-Ma, Katsina State, Nigeria Unpublished M. Sc. Thesis IUPWARE, V.U. Brussels, 70p.

BATELAAN, O. and DE SMEDT, F. 1994. Use of Landsat Tm in the analysis of groundwater flow systems. Space Scientific Research in Belgium. Vol. III Earth Observation, part 2. Federal Office for Scientific Research in Brussels, Belgium, pp. 215-233.

CAPONELLA, F. 1989. Remote sensing image interpretation for groundwater surveying. In: Remote sensing application to water Resources: Report of the 13th UN/FAO/UNESCO International Training course; RSC Series 50, pp. 281-292.

CRACKNELL, A.P. and HAYES, L.W.B. 1991. Introduction to remote sensing. Taylor and Francis, United Kingdom, 293p.

CRIST, E.P. and CICONE, R.C. 1984. Application of Tasseled Cap Concept to simulated Thematic m apper data, Photogrammetric Engineering and Remote Sensing Vol. 50, No. 3, pp. 343-352. In: T. M. Lillesand, R.W. Kiefer Remote sensing and Image interpretation. Third edition. John Willey and Sons, Inc. New York, 750p.

CRIST, E.P. LAURIN, R. and CICONE, R.C. 1986. Vegetation and soils information contained in transformed Thematic Mapper Data. Proceedings of IGARSS, ESA SP-254, pp. 1465-1470.

DAINELLI, E.P. 1986. Satellite data analysis for water resources. In: E.C. Barret, Molner and Podhorsky (eds): Remote Sensing application in hydrology and water resources. UNESCO, Technical documents in hydrology, pp. 107-122.

DAINELLI, E.P. 1989. Airborne photographic methods. Remote sensing application to water resources. Report of the 13th UN/FAO/UNESCO International Training Course; RSC Series 50, pp. 11-31.

GATHUMBI, S.M. 1996. Remote Sensing and Image Processing: A Dender Catchment Case study. M. Sc. Thesis, IUPWARE, V.U. Brussels, 65p.

JICA. 1984. The Study for Groundwater Development in Sokoto State. 5 volumes.

MUSICK, H.B. and PELLETIER, R.E. 1986. Response of some thematic band ratios to variation in soil water content. Photogrammetric Engineering and Remote Sensing, 52 (10), pp. 1661-1668.

O'LEARY, D.W., FRIEDMAN, J.D. and PHN, H.A. 1976. Lineament, Linear, lineation: some proposed new standards for old terms. Geol. Soc. Amer. Bull., Vol. 87, pp. 1463-1469.

PERRY, C.R. and LAUTENSCHLAGER, L.F. 1984. Functional equivalence of spectral vegetation indices. Remote Sensing of Environment, (14), pp. 169-182.

RUSS, W. 1957. The geology of parts of Niger and Sokoto Provinces with special reference to the occurrence of Gold. Bull. Geol. Surv. Nig., 27.

SCHULTZ, G.A. 1988. Remote sensing in hydrology. J. Hydrol. (100), pp. 239-265.

TRAVAGLIA, C. 1983. Groundwater assessment in hard rocks, Case histories: Upper Volta and the People's Democratic Republic of Yemen. Report of the 8th International Training Course on application of satellite remote sensing to water resources. FAO, 158p.


Best Wishes