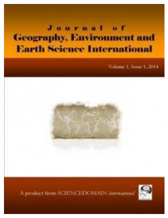

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Identification of Groundwater Potential Zones Using Lineament Analysis in Parts of Ilesa Metropolis, Southwestern Nigeria

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Authors' contributions

This work was carried out in collaboration between both authors. Author OAO designed the study, performed the statistical analysis (in conjunction with the technical contact) and wrote the first draft of the manuscript. Author ROB managed the literature searches. Both authors read and approved the final manuscript.

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ABSTRACT

This paper is focused on mapping of lineaments within the Schist Belt of Ilesa using Geographic Information System (GIS) and Remote Sensing (RS) tools. An approach which involved studies of lithology and lineaments were useful for a proper assessment of groundwater bearing potential zones in the study area. The study area is within Ilesa metropolis, which lies within the Precambrian Basement Complex, hosting fracture zone aquifers which are promising sites for groundwater exploration.

The rock types within the study area can be grouped into migmatite-gneiss complex, mafic-ultramafic suite (or amphibolite complex), metasedimentary assemblages and an intrusive suite of granitic rocks. The mapped structural lineaments were analysed using lineament density and lineament frequency analyses on ILWIS 3.1 Academic and ArcGIS 10.1.

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The lineament density values ranged from 0.00003 to 0.001 km/km^2. These indicate areas of poor water-bearing potential to areas of high water-bearing potential. Presentation of the detected lineaments shows two possible orientations in the directions of NE and SW which are also principal directions of the regional structures in basement complex of Nigeria.
Conclusively, axial directions present the direction of groundwater flow in the area.

Keywords: Basement complex; lineament; GIS; groundwater; remote sensing.

1. INTRODUCTION

The study area, which is underlain by crystalline rocks, is one-tenth of the total area covered by the southwestern Nigeria Basement Complex (Fig. 1). A classification of the Basement Complex based on observations presents the rock units into a chronological order [1,2]. The first group is the most widespread occupying about 35% of the total surface area of Nigeria. It is called the Migmatite-Gneiss-Quartzite Complex. It is a heterogeneous rock group comprising granite gneiss, quartzite and quartz schist and small lens of calc-silicate rocks. The second group show lithologic similarities to schist belts from other parts of the world which are known to contain economic mineral deposits [1]. The charnockitic, gabbroic and dioritic rocks are another distinctive group which occur in the core of aureoles of granitic rocks. They are closely related to the older granite which was distinguished from the Jos Plateau tin-bearing Younger Granite [3]. The youngest members are the unmetamorphosed dolerite and syenite dykes.

The amphibole and hornblende gneiss of the earliest group occur as low lying outcrops which are mostly seen around the river beds in Ilesa area.

Majority of the people living in the vicinity of the metropolis depend on groundwater and even at times, rainwater for domestic and industrial uses. Hence, it becomes necessary to identify and explore potential sources of groundwater - within this section of the Basement Complex - for drinking, irrigation and other uses. In this case, there is a need to, first of all, detect the structural trends within the metropolis. With the advent of photogeology, lineament analysis has been used extensively.

Research work has been carried out to investigate groundwater potentials of particular areas using lineament analysis. An applicable one was carried out in Kano city [4] to investigate regions favourable for groundwater development. The study revealed that the boreholes might not be tapping the suspected deep-fractures, as their exploration potential is poor.

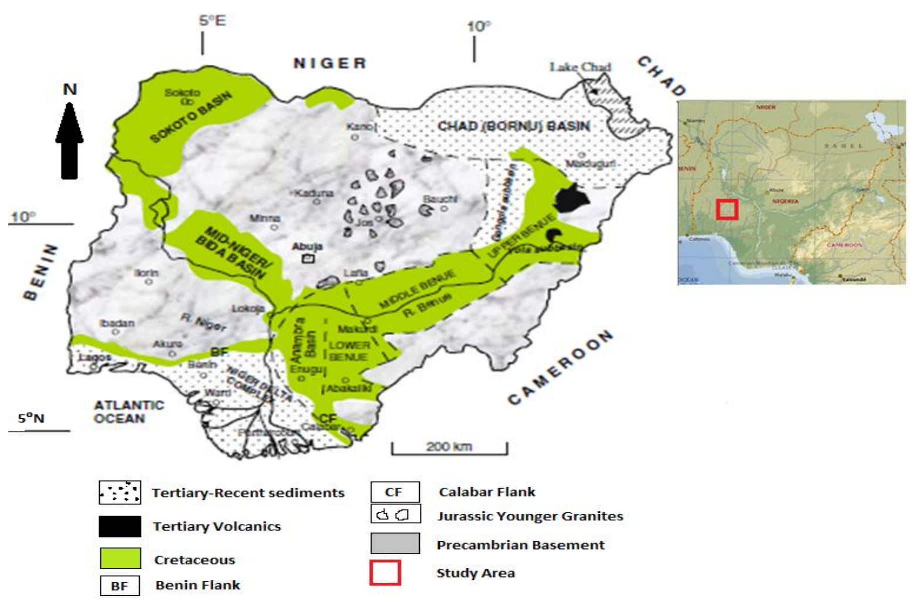

Fig. 1. Map of Nigeria showing the study area and rock types

Also, according to [5], yield of wells on lineament is about 14 times that of wells which are away from lineaments in the case of Gondwanas, Warangal district in India. Wells located on lineaments in the Lower Paleozoic carbonate-bearing rocks had also been shown to yield about ten to hundred times more than wells located in similar condition but away from fracture traces [6].

According to [7], the most promising water-bearing directions originate from brittle deformation caused by tensional stress which in turn is related to faulting and strike-slip faulting. Furthermore, lineaments which are reflections of such underlying geologic structures are assumed to be features with secondary permeability.

A combination of thematic maps such as geology, geomorphology, lineament and density, when combined using GIS software will produce a composite map. The resulting map will depict the possible zones of groundwater occurrence [8].

2. STUDY AREA

The study area lies within latitudes 7°25'19.51"N to 7°45'46.82"N and longitudes 4°38'43.17"E to 4°55'36.61"E (Fig. 2). It covers an area extent of about 302.59 km^2. The area has good road network of tarred and untarred roads which link different towns such as Iloko-Ijesa, Ijebu-Ijesa, Ibala and Ibode.

The area has a gentle topography and well-drained with many rivers, some of which are seasonal. The climatic condition of Ilesa area follows the pattern of southwestern Nigeria where the climate is influenced mainly by the rain-bearing southwest trade winds from the Atlantic Ocean and the dry northeast winds from the Sahara Desert. High temperatures and high humidity also characterise the climate. There are two distinct seasons, the rainy and dry seasons.

The significant rocks associated with Ilesa area are summarized in Fig. 2. The amphibolite hornblende, gneiss, pegmatite and the quartzite/quartz schist appear to be the most dominant. The schist belt around here is one of the over 20 schist belts which have been identified throughout the country.

The amphibolites occur as low-lying outcrops which are seen in riverbeds. The hornblende gneiss occur at several locations across Igangan, Ayetoro and Ifewara area. The gneiss is highly foliated, folded and faulted. According to [1,9], the rocks of the Ilesa district may be broadly grouped into Gneiss-Migmatite Complex, mafic-ultramafic suite (or amphibolite complex), meta-sedimentary assemblages and an intrusive suite of granitic rocks. A variety of minor rock types are also related to these units. The Gneiss-Migmatite Complex comprises migmatitic and granitic, calcereous and granulitic rocks. The mafic-ultramafic suite is composed mainly of amphibolites, amphibole schist and minor meta-ultramafites, made up of anthophillite-tremolite-chlorite and talc schist. The meta-sedimentary assemblages, chiefly metapelites and psammitic units are found as quartzites and quartz schist. The intrusive suite consists essentially of Pan

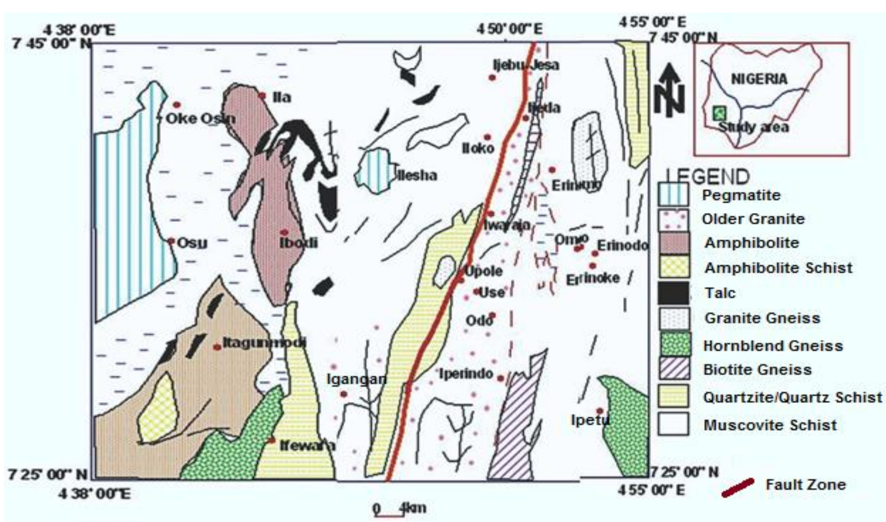

Fig. 2. Study area showing the Geology of Ilesa Schist Belt, SW Nigeria [10]

African (c.600 Ma.) Granitic units. The minor rocks include garnet-quartz-chlorite bodies, biotite-garnet rock, syenitic bodies, and dolerites.

In terms of the structural features, rocks in this area are divided into two main segments by the two major fracture zones often called the Iwaraja Faults in the eastern part and the Ifewara Faults in the western part [9].

3. MATERIALS AND METHODS

For this study, the method of spatial analysis involved two complementary approaches (see also [11,12,13,14,15,16] for discussions of geospatial concepts and methodologies). The first was based on GIS, where thematic maps were used to derive the most promising sites for groundwater exploration. The second approach was based on Digital Image Processing (DIP) of remote sensing data to identify the spectral class that was highly correlated with the sites identified by the GIS tools. The first approach was necessary in this work because lineaments and drainage patterns are some of the most important factors for evaluating the potential concentration of water in a fracture zone aquifer.

Although Remote Sensing (RS) data do not directly detect deeper subsurface resources, it has been effectively used in groundwater exploration as RS data aid in drawing inferences on groundwater potentiality of regions indirectly [4,17,18]. The satellite image used was originally downloaded at the National Centre for Remote Sensing, Jos, Nigeria. The image organization, which was in Band Sequential (BSQ) and raster format, was presented in seven (7) bands. It is to be noted that Landsat measures different ranges of frequencies along the electromagnetic spectrum (colours which may or may not be visible to human eye). Each range is called a band. Landsat 5, typically, has 7 bands (Table 1). It numbers its red, green and blue sensors as 3, 2 and 1 respectively.

Table 1. Bands of a Landsat 5 satellite image

Band number	μm	Resolution
1	0.45-0.53	30 m
2	0.52-0.60	30 m
3	0.63-0.69	30 m
4	0.76-0.90	30 m
5	1.55-1.75	30 m
6	10.40-12.50	120 m
7	2.08-2.35	30 m

The satellite image used in this study is a part of path 190 row 55 scene of 2nd March, 2002. Ground Control Points (GCPs) and satellite orbit information were used to rectify the imagery. Thus, image rectification was to existing geo-coded Landsat MSS and SPOT Multispectral data, utilizing the WGS (Word Geodetic System) coordinate system, Clarke 1880 Spheroid. The data was further processed using Integrated Land and Water Information System (ILWIS 3.1) academic and ArcGIS 10.1 software. ILWIS software was used for creating several themes or layers from the satellite image. This software has the capabilities for various image enhancement routines such as linear enhancement, statistical analysis and principal component analysis.

Foremost, image analysis involved contrast stretching on the acquired Landsat data. Edge enhancement filtering process was applied to the band 7 imagery (using ILWIS 3.1 academic filter module). This was done to increase the spatial frequency of the imagery so as to enhance high frequency features, which may include fractures. Lineaments were digitized on screen using the mouse.

The resulting lineament vector layer was then rasterized by using the segment density module in ILWIS 3.1 academic. The resulting raster image had a pixel size of 0.25 × 0.25 km. Furthermore, the lineament map was densified using the spatial analyst tool in ArcGIS 10.1. This was done to further bring out, clearly, areas of water potential. In addition, a rose diagram was made to know the dominant direction of lineaments, using ILWIS 3.1 academic software.

4. RESULTS AND DISCUSSION

4.1 Analysis of Data

The mapped structural lineaments were analyzed using lineament density analysis and Lineament frequency analysis on ILWIS 3.1 and also on ArcGIS 10.1. The results were presented as lineament density map and Rose Diagram (Figs. 3, 4 and 6).

The lineament density map shows the lineament numbers to be of the ranges varying between 0.00003 and 0.001. These indicate areas of poor water bearing potential to area of high water bearing potentials. From Fig. 4, zones in the range of 0.00003 to 0.0003 are poor zones (i.e. little or no ground water can be found in those areas. Those with the range of 0.00031 to 0.00060 are moderate zones. These are areas where we can find ground water but not in economic quantities. Areas with lineament density values of 0.00060 to 0.00090 are high zones, while zones >0.00091 are very high zones. The high and very high zones are areas where we can get water in high and economic quantities. These provide interpretation of hidden subsurface tectonic configuration in the form of linear feature intersection / cross cutting geological structures, which are indicators of deep seated fracture / fault medium and are known geologically to behave as reservoirs for ground water. The zones of high lineament density are zones of high lineament intersection over the study area and are feasible zones for groundwater targeting in the study area (Fig. 3) [19].

To further correlate the different zones of lineament densities with groundwater potentials, a comparison has been identified [8] with a work focused on potentials of Osun Basin in general (Ilesa inclusive). The model produced predicted poor to highly rated potentials (Fig. 5). Spatially, the very high and high groundwater potential areas coincided with areas with high lineament densities. So was it for this work where good groundwater potential areas coincided with areas with high and very high lineament densities (Figs. 4 and 5).

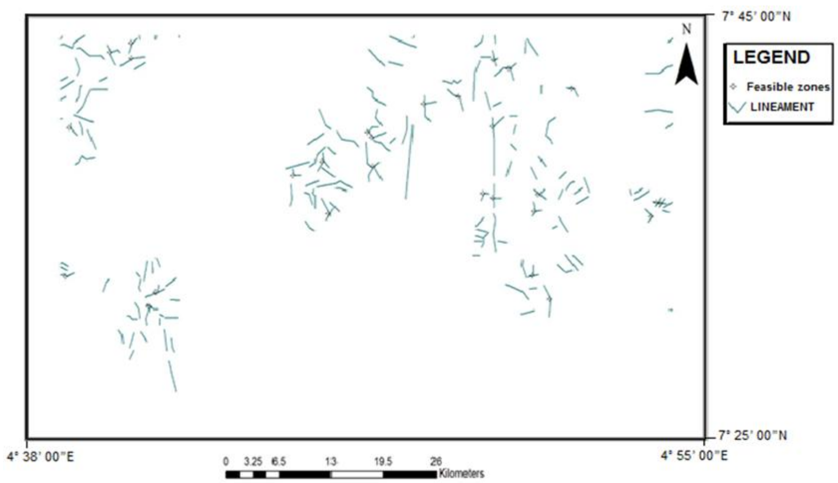

Fig. 3. Digitized lineament map showing feasible zones for groundwater prospecting

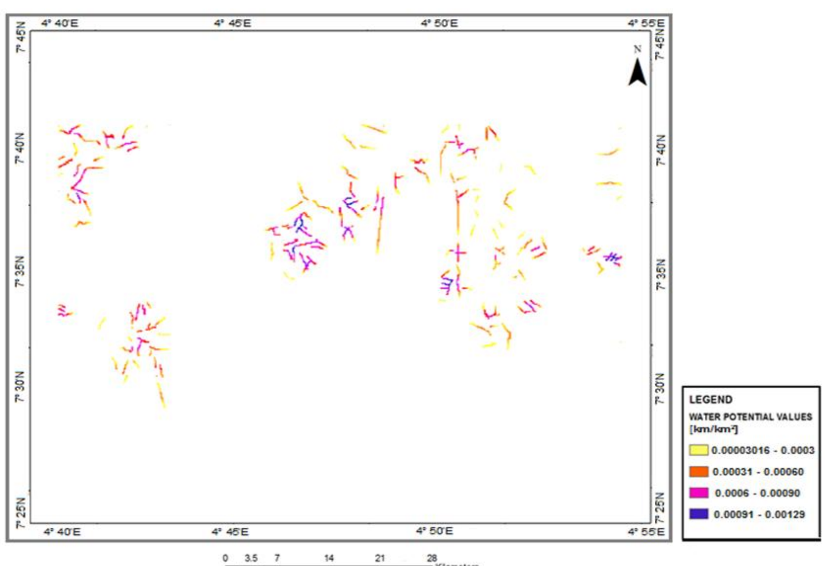

Fig. 4. Lineament density interpretation map of the study area

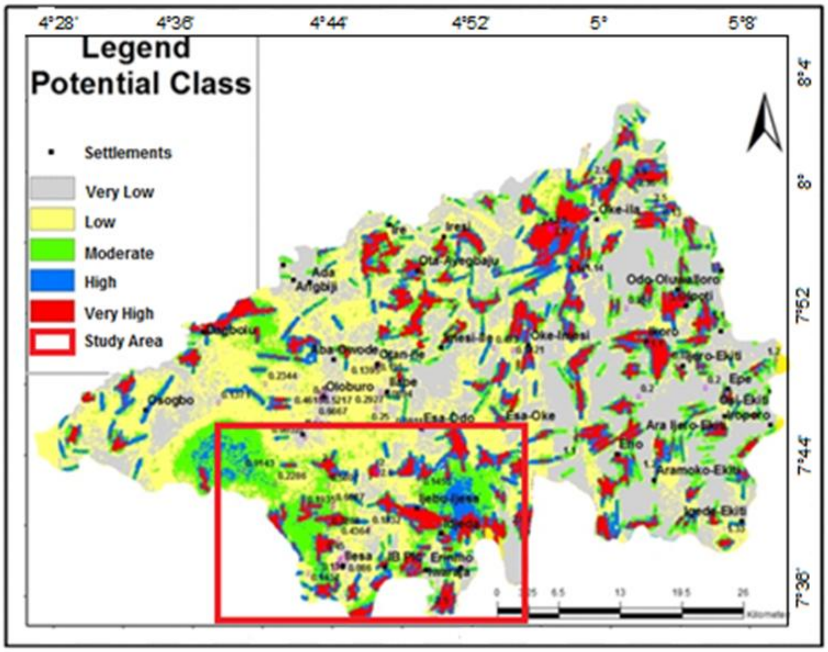

Fig. 5. Groundwater potentials in the study area [8]

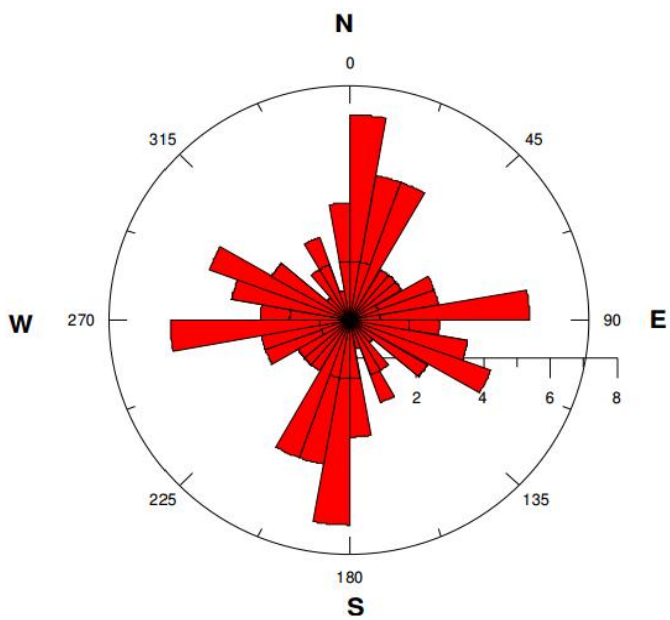

Fig. 6. Rose Diagram showing the direction frequency of lineaments in the area

4.2 Directional Frequency of Lineaments

Directional frequency of mapped lineaments across the study area has been presented using a rose diagram. It was interpreted as a statistical means of representing the anisotropy of the fractured environment, as well as fissure development tendency on a regional scale. The rose diagram of the detected lineaments show two prominent trends in the directions of the northeast (NE) and southwest (SW) axes, which are also the principal directions of the regional structures in basement complexes of Nigeria.

5. CONCLUSION

The mapped lineaments across the study area have provided an insight into the lineament and fracture thus enabling us to determine the groundwater potential in a typical basement terrain with the aid of GIS technique.

The results of the analysed lineament indicated that the area has numerous long and short fractures whose structural trends are mainly in the north-east and south-west directions. The cross-cutting lineaments are relatively high in areas around the central northeastern and southwestern parts of the study area, but relatively low in the other areas. The study has also been able to set an example where real data on groundwater quantity can be used in the selection of target sites for groundwater exploration. Data revealed that sites with possible high yield were related to the high value intervals of lineament densities. Lithology (Rock type distribution) and topography were revealed to affect the distribution of promising sites.

Conclusively, the zones of high lineament intersection density are feasible zones for groundwater prospecting in the study area. Further detailed geophysical mapping can be successfully carried out for quantitative and integrated evaluation of groundwater potential in these zones of the study area.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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