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Application of Analytic Signal Technique in the Evaluation of Groundwater Potential Zones of Sokoto Basin and Adjoining Areas Northwestern, Nigeria

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ABSTRACT: The analysis of high resolution aeromagnetic data over Sokoto basin was carried out to delineate the groundwater potential zones using the Analytical Signal technique. The aeromagnetic data was subjected to regional residual separation to obtain the residual data which was subjected to analytic signal analysis to obtain the analytic signal map. Qualitative interpretation of the analytic signal map revealed anomalous areas indicating rock contacts, faults, fractures and joints. The analytic signal data was contoured to obtain the contoured analytic signal map. Lineaments were extracted from the contoured map which yield lineament map of the area. The lineaments were analyzed into lineament density map. The lineaments density were classified into low, moderate and high lineament density areas. The lineaments were superimposed on the geologic map to further understand the spatial distribution of the lineaments on the rock units. The lineaments plotted on rose diagram reveal trends of NE-SW, NW-SE, E-W, N-S, NNE-SSW, ENE-WSW, NNW-SSE and WNW-ESE directions. The findings of this research indicate that the area have low, moderate to high lineament density. Therefore Areas with high lineament density are potential areas for groundwater development.
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KEYWORDS: Aeromagnetic data, Analytic Signal, Lineament Density, Groundwater Potentials, Sokoto, Nigeria

I. INTRODUCTION

Water is an essential resource for every community and therefore the main source of life on Earth. It is supplied by nature. However, it is alarming that this resource is becoming scarce everyday due to the increasing population. Surface water is becoming scares in the study area due to the climatic changes. Also this surface water where it is found available it posed a lot of danger as a result of pollutants and contaminants coupled with dissolved solutes that affect the quality of the water. The need for Groundwater as portable source of water cannot be overemphasized. This is because most groundwater are devoid of pollutants and contaminants. As part of the ways of providing solution to the water problem of the study area, aeromagnetic data was used.

The aeromagnetic data was analyzed to obtain the lineament density of the study area which are paramount to the understanding of groundwater potential zones. In delineating site that have potentials for hosting groundwater, it is important to understand the brittle deformation zones in the bedrock. These zones control groundwater transport and the hydrochemistry in the bedrock, and the rock mechanical properties.Lineament statistics are presented as Lineament density maps, density of lineament intersections per defined cell area and rose diagrams showing the orientation of lineaments. Lineament statistics is used to check the structural homogeneity in the rock and plays a vital role in groundwater flow in the bedrock as it indicate the location of potential channels especially where

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there are intersections between two or more deformation zones.

Lineaments density along with the degree of lineament intersection determine the degree of anisotropy of groundwater flow in the fracture network as in environments within high degree of interconnection where groundwater flow is smoother and uniform. The purpose of using intersection density is to estimate the areas of diverse fracture orientation (Mabee et al., 1994). In this research the lineament density were determined and used to classify the groundwater potential zones of the area into low, moderate and high. High groundwater potential areas are probable areas for groundwater development.

Recent studies have shown correlation between the yield of drilled groundwater wells and their distances to nearby lineaments (Lie and Gudmundsson, 2002). Well yield increases when approaching lineaments, this is because most lineaments are depressions that receive water by topography driven flow. Also most lineaments have high fracture frequency making them to have high hydraulic conductivity towards the centre. Lineaments are mappable linear or curvilinear that represent major mechanical breaks in bed rock (Lie, 2001). Lineaments are therefore structures that have been reactivated as joints and faults

The study area is part of the Illummeden embayment of West Africa (Fig. 1) located between eastings 4^{o}00' and 6^{o}00' and nothings 11^{o}30' and 13^{o}30'(Fig. 2). The area is characterized into sedimentary and basement rocks (Fig. 3 and 4). The basement area consists of Basalts, Granitoids and Migmatite-gneiss Complex. The sedimentary area comprises of the Illo/Gundumi Formations which are believed to be lateral equivalents and overlies the basement unconformably. The formations are continental in nature and are of Pre-Maastrichtian in age. It is characterized with clay, grits and basal conglomerates. The Taloka, Dukamaje and Wurno Formations of Rima group are Maastrichtian in age. The Taloka formation consists of mudstones and sandstones which are continental deposits of early Maastrichtian and overlies the

Figure 1: Major sedimentary basins of West Africa (Modified after, Ali et al., 2019).

Figure 2: Topographic Map of the area (Analysed from digital elevation model, 2006).

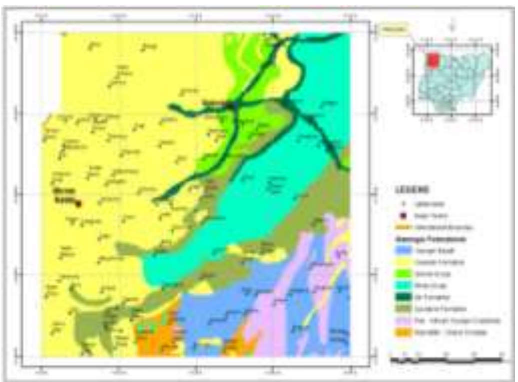

Figure 3: Geologic Map of the area (After, Nigerian Geological Survey Agency, 2006).

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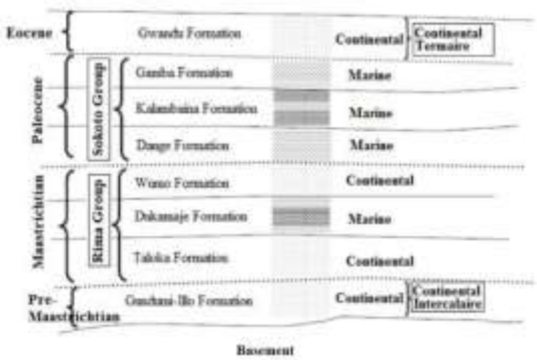

Figure 4: Stratigraphic succession of the Sokoto basin (After, Obaje et al., 2013).

Illo/Gundumi Formations unconformably. The Dukamaje Formation overlies the Taloka formation and is characterized by calcareous, fossiliferous limestones. It is a marine deposit of middle Maastrichtian. The Wurno Formation overlies the marine Dukamaje Formation. It is a continental deposit of upper Masstrichtian characterized by mudstones, clays and sandstones. The Dange, Kalambaina and Gamba Formations of Sokoto group are Paleocene deposits. The Dange formation overlies the Wurno Formation unconformably and consists of alternation of shales and limestones. The marine Formation was deposited during the early Paleocene. The Kalambaina Formation conformably overlies the Dange Formation. It is characterized by calcareous limestone and shales. It is a marine deposit of middlePaleocene. The Gamba Formation conformably overlies the Kalambaina Formation. It is a marine deposit characterized by shales and clays and is of upper Paleocene in age. The Gwandu Formation which is a continental deposit of Eocene age is characterized by clays, loose sands and semi consolidated sands. The Formation overlies the Gamba Formation unconformably and it is the youngest Formation of the basin. For more details of the geology readers are referred to Kogbe (1976), Obaje (2009) and Offodile (2002).

II. MATERIALS AND METHODS

Aeromagnetic Data Acquisition

The aeromagnetic data that was used for this research was obtain from Nigerian geological Survey Agency. The high resolution digital aeromagnetic data comprising of sheet numbers 8 (Sakwabe), 9 (Binji), 10 (Sokoto), 11 (Rabah), 27 (Leme), 28 (Argungu), 29 (Dange), 30 (Gandi), 49 (BirninKebbi), 50 (Tambawal), 51 (Gummi), 52 (Anka), 72 (Giru), 73 (Fokku), 74 (Donko) and 75 (Gwashi) on a scale of 1:100000. The Nigerian geological survey agency (NGSA) carried out a nationwide airborne aeromagnetic survey in 2009 to boost the country's economy from other sectors. The survey was carried out by Fugro airborne survey limited for the NGSA between 2004 and 2009. The acquisition, processing, compilation of the new data were jointly financed by the federal government of Nigeria and the World Bank as part of the sustainable management for mineral resource project. The aeromagnetic data was acquired using 3X Scintrex CS3 Cesium Vapour Magnetometer, were carried out by means of fixed-wing aircrafts flown at mean terrain clearance at 80 m with 500 m line spacing and nominal tie line spacing of 2 km.

Aeromagnetic Data Processing

Regional-Residual Separation

The total aeromagnetic data was subjected to regional residual separation to obtain the residual map. This was achieved through the Polynomial fitting method using the oasis montaj software. In polynomial fitting the regional is matched with mathematical Polynomial of low order which expose the residual features as random errors. The method is based on statistical theory where the observed data is used to compute, using the least square method. The mathematically described surface which gives the closet fit to the magnetic field that can be obtained within a specified degree of detail is considered to be the regional field and the residual is the difference between the magnetic field values thus determined (Udensi, 2001).

Analytic Signal

The analytic signal for edge detection in magnetic anomaly is widely used in magnetic interpretation as a means of positioning anomalies directly over their sources. The amplitude of the simple analytical signal peaks over magnetic contacts can be used to find horizontal locations and depths of magnetic contacts. This transformation is useful at low magnetic latitude because is independent of the inclination of the magnetic field. This important application made it suitable to be used on magnetic data over Nigeria because magnetic inclination for the country varies from 7˚N to 13˚S and it is classified as a region with low magnetic latitude. Magnetic derivatives are used to determine the shape and edge in magnetic data. The concept of analytical signal of magnetic anomalies was used to calculate the square root of the sum of squares of the data derivatives in the x, y and z directions of magnetic field as follows:

$$|A(x,y)| = \left[\left(\frac{\partial T}{\partial x}\right)^2 + \left(\frac{\partial T}{\partial y}\right)^2 + \left(\frac{\partial T}{\partial z}\right)^2\right]^{1/2} \quad (1)$$

where $T = $ magneticintensity

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The technique is used to estimate contact locations such as Faults, because the gradient is largest at the edges of tabular bodies. A number of assumptions about the surface are made, such assumptions are that the regional magnetic field, the source magnetization, the contacts are vertical, the contacts are isolated and the sources are thick. The method requires the two first order horizontal derivatives of the magnetic field, thereby making the method to be least susceptible to noise in the data (Roest et al., 1992, Philips, 1998, Boschelti et al., 2000 and Verduzco et al., 2004).

III. RESULTS

Total Magnetic Intensity Map of theArea

The total magnetic intensity map (Fig. 5) of the area revealed magnetic susceptibilities subdivided into three main sections: The northern part is characterized by low magnetic intensity values indicated by dark- light-blue-green-colour also the eastern, western and southern parts of the area are characterized by low magnetic intensity values having dark-light-blue-green-colour dominating the area. The south western and south eastern parts of the area are dominated by high magnetic intensity values, with pockets disseminated in the northern part, indicated by red-pink-colour. Yellow-orange-colours accompany by the red-pink-colours depicting medium magnetic intensity values. The lowest total magnetic intensity value of the area is 481.4 nT and highest value of 633.9 nT. The anomalies observed by visual inspection of the total magnetic intensity maps shows that most of the anomalies are trending NE-SW with others in NW-SE, E-W, N-S, NNE-SSW, ENE-WSW, NNW-SSE and WNW-ESE directions.

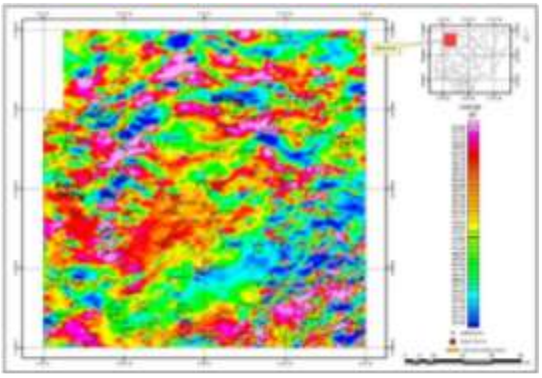

Figure 5: Total magnetic intensity Map of the area.

Residual Magnetic Intensity Map of the Area

The magnetic susceptibility of rocks in the area as revealed by the residual magnetic map (Fig. 6), show magnetic anomalies with high magnetic intensity value of 59.6 nT and a low magnetic intensity value of -81.2 nT. The pink colour anomalies have magnetic intensity ranging from 34.6 nT to 59.6 nT, which are prominent in the northern and southeastern parts, with pockets in the southwestern part. Red colour anomalies varies from 13.3 nT to 30.7 nT and are dominant in the northern, central and southwestern parts, with disseminations in the southeastern part. Yellow colour anomalies range from 2.5 nT to 11.8 nT and occur along the red colour anomalies, dominating the entire map. Green colour anomalies are present in the northern, southeastern, northeastern and southwestern parts, with pockets of small occurrence in the south-south and varies from – 17.2 nT to 0.8 nT. Blue colour anomalies range from – 81.2 nT to – 19.9 nT and are the most dominant, occurring in almost every part of the map. The orientation of the anomalies are as it was observed on the total magnetic intensity map.

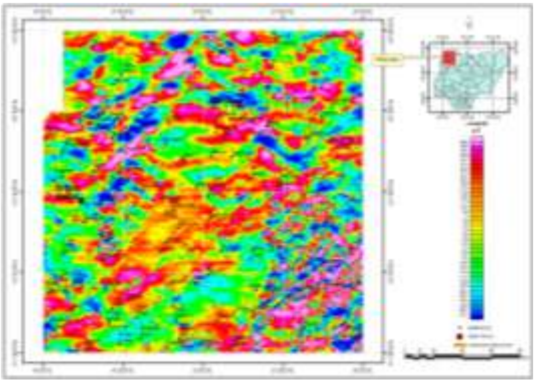

Figure 6: Residual magnetic intensity Map of the area.

Analytic Signal Map of the Area

Figure 7a is the analytic signal map of the study area. It was produced from the residual magnetic map. The map enhances sharpness of geologic contacts of rocks and it is from the analytic

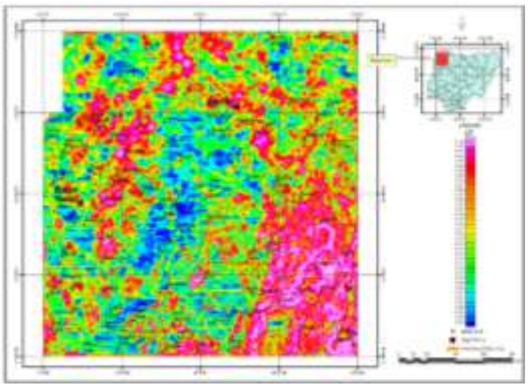

Figure 7a: Analytic Signal Map of the area.

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Signal map that Figure 7b was produced. Figure 7b is the contoured analytic signal map of the study area with lineaments that were manually drawn. A total of six hundred and seventy six (676) lineaments were drawn and measured. Figure 7c is a lineament map of the lineaments that were extracted from the contoured analytic signal map which was used to produce the lineament density map. Figure 7d is the Lineament density map is a measure of quantitative length of linear feature per unit area which can indirectly reveal the groundwater potentials as the presence of lineaments usually denotes a permeable zone. the lineament density were classified into low density areas with lineament density of 0 to 2 km/km^2, moderate lineament density areas varying from 2 to 7 km/km^2 and areas with high lineament density varying from 7 to 30 km/km^2. Thus areas with higher lineament density are regarded as good for groundwater development. These areas on the lineament density map occur in the southeastern part, western and northern parts of the map. Figure 7e shows lineaments superimposed on the geologic map. It was observed that, most of the lineaments are more pronounced on the Gwandu formation, Rima group, Gundumi Formation, Younger Basalts and Pan-African Granitoids.

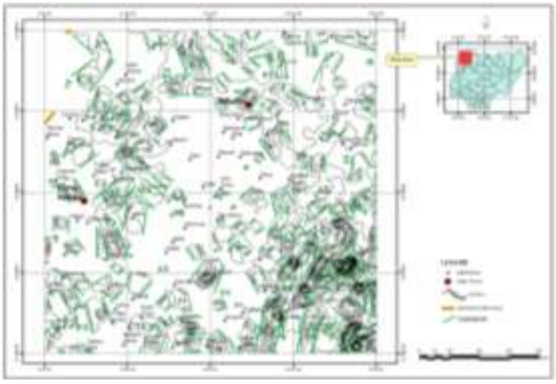

Figure 7b: Contoured Analytic Signal Map of the area.

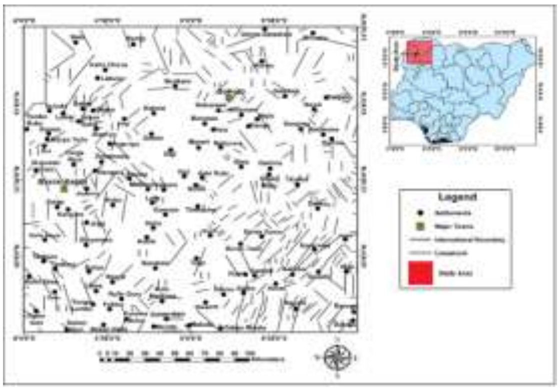

Figure 7c: Lineament Map of the area.

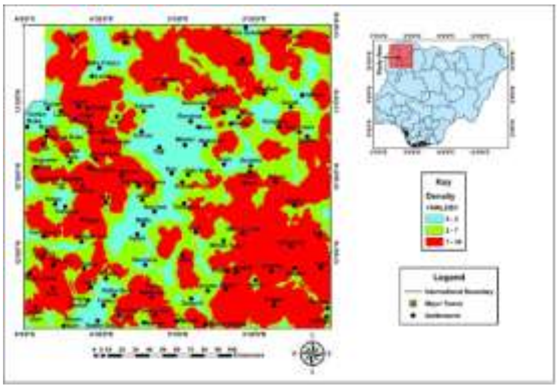

Figure 7d: Lineament density Map of the area.

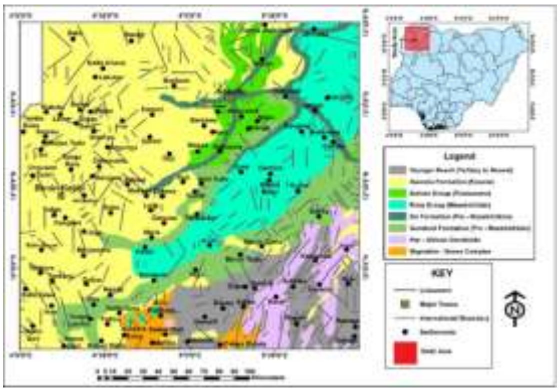

Figure 7e: Lineaments superimposed on the geologic map of the area.

Rose Diagram of Lineaments of the Area

The lineaments are similar in orientation to the observed trends on the total magnetic and residual magnetic intensity maps having NE-SW, NW-SE, E-W, N-S, NNE-SSW, ENE-WSW, NNW-SSE and WNW-ESE directions. These are further illustrated with rose diagram on Figure 8a showing the orientation of the overall lineaments in the study area, while Figures 8b and 8c shows the orientation of filtered lineaments of short and long length lineaments of the study area. These lineaments were filtered using a range of 0.1 km to 5.9 km for short length lineaments and 6.0 km and above for long length lineaments.Short length lineaments are sparsely distributed throughout the study area, while long length lineaments dominates the eastern and western parts of the study area. This could be the effect of deep seated intrusions while the short length lineaments, could be as a result of the effect of near surface igneous intrusions. These lineaments, in the eastern part occur mostly in the Basement rocks and some parts of Rima Group and in Gwandu Formation in the western part.

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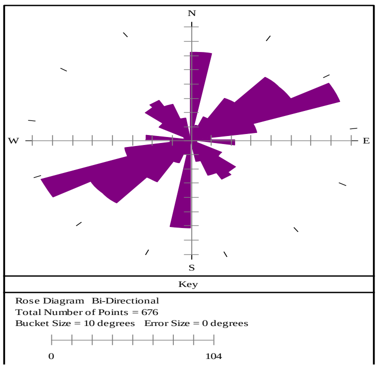

Figure 8a: Rose diagram showing the overall orientation of lineaments in the area.

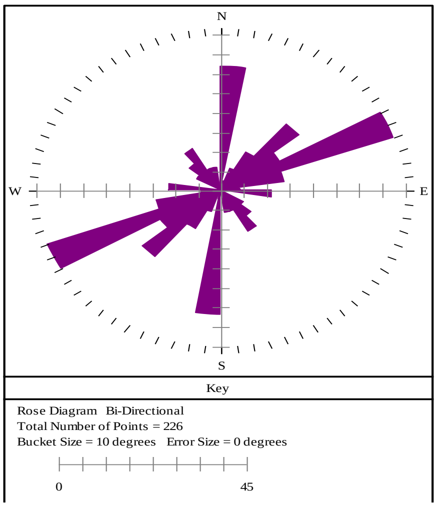

Figure 8b: Rose diagram showing short length lineaments filtered from the overall lineament Map of the area.

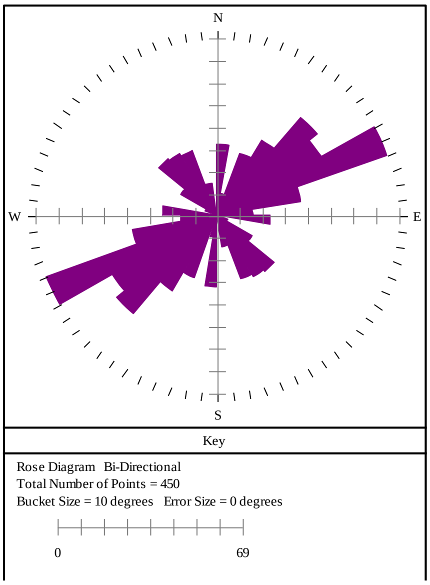

Figure 8c: Rose diagram showing long length lineaments filtered from the overall lineament Map of the area.

IV. DISCUSSION

The Lineaments that were extracted from the contoured analytic signal map revealed that the lineaments are dominant in southeastern, southwestern, western, northcentral and northeastern parts of the area. These lineaments that were filtered into short and long length as shown on the rose diagrams revealed the source and origin of the lineaments. The long length lineaments are as a result of deeper magnetic sources which could be products of deep seated plutonism. While the short length lineaments are products of shallow or near surface igneous intrusions. This is an indication of the brittle nature of the rocks. Brittle rocks yield easily when subjected to stress unlike ductile rocks.

The porosity of rocks determines its hydrogeological properties and this depends on the texture and mineralogy of the rocks. Fresh non-fractured crystalline rocks, have very low porosity which can be increased by fracturing and weathering; volcanic rocks are characterized by varied porosities, Basalts have porosity of one percent or less, pumice has porosity of eighty five percent. The permeability depends on the degree of interconnection of the pores within the rocks. Fractures and joints provides links that connect the pores thereby serving as pathways for the movement of groundwater. Weathered zones have a lot of void spaces and groundwater can easily store in.

Weathering, fracturing and erosion is limited in crystalline rocks, as a result groundwater occurs only in small, isolated pockets. Rocks dominated by unstable ferromagnesian minerals tend to weather into clayey, sometimes, micaceous in permeable non-bearing water rock formations. Rocks consisting of quartz and other stable minerals will disintegrate into porous and permeable water bearing gravelly or sandy medium. The yield of metamorphic and plutonic igneous rocks decreases rapidly with depth. The decrease is as a result of the combine effect of the weight overlying the rock and the tendency of surface disturbances to penetrate only a short distance into the bed rock. The increasing weight of the overlying rock tend to close, the joints, fractures and faults at depth. The distance between fractures increased rapidly with depth. Hence, when the depth of a borehole increases the frequency of interception of fractures decreases.

Apart from textural properties of rocks, structural control also determines the availability of groundwater. The patterns of structures in geological formations are mostly as a result of tectonic activities postdating the emplacement of the rock formations. Fracture zones are zones of weakness, which when not filled by clay particles, or mineralized, provide conduits for groundwater. Therefore areas of high lineament density are potential areas for groundwater exploration.

V. CONCLUSION

The research was necessitated as a result of the persistent water shorted in the area. The analysis of high resolution aeromagnetic data over the Sokoto basin was carried out to delineate groundwater potential zones, which will aid and argument the water shortage been experienced in some of the communities of the study area and to enhance and boost more productive areas for future water development. The findings of this research indicate that the potentials for groundwater in the Sokoto basin are classified into Low, Moderate and High potential areas. Therefore areas with high groundwater potentials are productive areas for ground water development.

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