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An Assessment of the Relationship between Lineament and Groundwater Productivity in a Part of the Basement Complex, Southwestern Nigeria.

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Abstract: *The study area is a basement complex environment with its associated difficulties in groundwater supply as a result of lateral discontinuity in basement lithologies. This study assessed and established the relationships that exist between lineaments and borehole yields. Five Hundred and thirteen (513) lineaments were extracted and analyzed from remote sensing data obtained from global land cover facilities of which several lineament maps were generated using ArcGIS® software. Twenty seven (27) yield data were interpreted, correlated and evaluated with the produced lineaments. Results indicated three (3) categories of yields exist in the study area: low yields (<0.2 l/s), moderate yields (0.5 -1.0 l/s) and high yields (>1.0 l/s). Thus, the high yielding boreholes are found at the center of the study area where lineament density is high. Further analyses carried out show that the productivity of a borehole is strongly affected by its closeness to an extensional lineament but insignificantly influenced by its closeness to a lineament intersection points in the area. The study also indicated that the presence of thick overburden to bedrock is also a key factor in controlling groundwater productivity.*
Keywords: A*rcGIS® Software, Groundwater, Intersection Point, Lithologies, Remote Sensing, Yield.*

I. Introduction

Groundwater is dynamic, replenishable and occurs uniquely in different natural environments. Its reservoir called an "aquifer" is restricted to features produced by weathering and tectonic processes. Its occurrence especially within the crystalline terrain is very complex due to lateral discontinuity of lithologies. However, groundwater in such environment is basically located within regoliths (overburden), fractures, fissures and joint zones (Mogaji et al., 2011; Goki et al., 2010). Asiwaju-Bello and Ololade (2013) recognized both weathered and fractured zones as aquifers within the basement terrain. Fractures, faults, joints and linear geological formation, or a straight course of streams, may be referred to as lineaments and are inferred as areas and zones of increased porosity and permeability in hard rock areas (Raju, 2001). Therefore, lineaments are linear features of tectonic origin that are identified as long narrow and with relatively straight tonal alignments in satellite images (O'Leary et al., 1976; Sander 2007). The mapping of linear features on various types of maps or remotely sensed data is one of the keys to understanding groundwater occurrence, especially in areas with igneous and metamorphic rocks. Sometimes lineament mapping, regardless of geologic environment, is believed to be the panacea for successful groundwater exploration (Sander, 2007; Nag and Lahiri, 2011). The detection and delineation of hydrogeologic structures usually facilitate the location of groundwater prospect zones in typical basement settings especially in high lineament density intersection areas. Many authors recognize that these zones of high lineament intersection density are feasible zones for groundwater prospecting and highest water-storage capacity (Edet et al., 1994, Olorunfemi et al, 1999, Omosuyi et al., 2003, Mogaji et al., 2011, Anifowose and Kolawole, 2012). This is because lineaments create lines of weaknesses, pathways and foci for weathering processes through which groundwater occurred therein. These lineaments can easily be manually extracted by satellite imagery or from aerial photographs (e.g., Süzen and Toprak 1998; Arlegui and Soriano 1998; Leech et al. 2003; Cortes et al. 2003; Nama 2004, Hung et al., 2005) and employed in the groundwater yield interpretation. Hence, it is well understood also that lineaments have undisputable influence on the productivity of groundwater in any particular crystalline environment. Kim et al. (2004) posited that mapping of lineaments are closely related to groundwater occurrence, yield, surveys, development and management. It is obvious that lineament presence in an area control to a larger extent the flow and yield of groundwater (Magowe and Carr, 1999; Fernandes and Rudolph, 2001; Anifowose and Kolawole, 2012).

The study area is a basement terrain and has been affected both litho- and tectono-stratigraphically (Rahaman, 1976) at different geological times, as such the rocks have been deformed with manifestation of interesting structural features and are widely spread as lineaments in the form of joints, shear zones, mylonites, faults, strike ridges and straight-channeled streams (Odeyemi et al., 1999). Even though the area is endowed with such structures, it is still faced with the problem of groundwater supply. This is basically due to the inability to locate wells close to or on lineaments. As such, the study is aimed at assessing the influence of the presence of lineaments and groundwater productivity in the study area.

II. Description Of The Study Area

The study area is situated in the Southwestern part of Nigeria, particularly within Ondo State and covers the whole part of Akure metropolis and its environs. Geographically, it is located between Latitudes 7^0 12′ and 7^0 19' North, and Longitudes 5^0 08′ and 5^0 18' East (Fig. 1). The areal extent of the study portion is approximately 234 square kilometers. The study area is drained mainly by Rivers Ala, Owena and Ogburugburu (Anifowose and Kolawole, 2012) which are structurally controlled along the major E-W lineament directions forming a dendritic drainage pattern. The soil types in the area include the brownish-red clay, brownish gravelly clay and reddish clayey sand which are derived from migmatitic rocks and charnockites, while the reddish clayey sand, which is derived from the Quaternary coastal plain sands and alluvial sands that characterize the southern part of Ondo State (Anifowose, 1989).

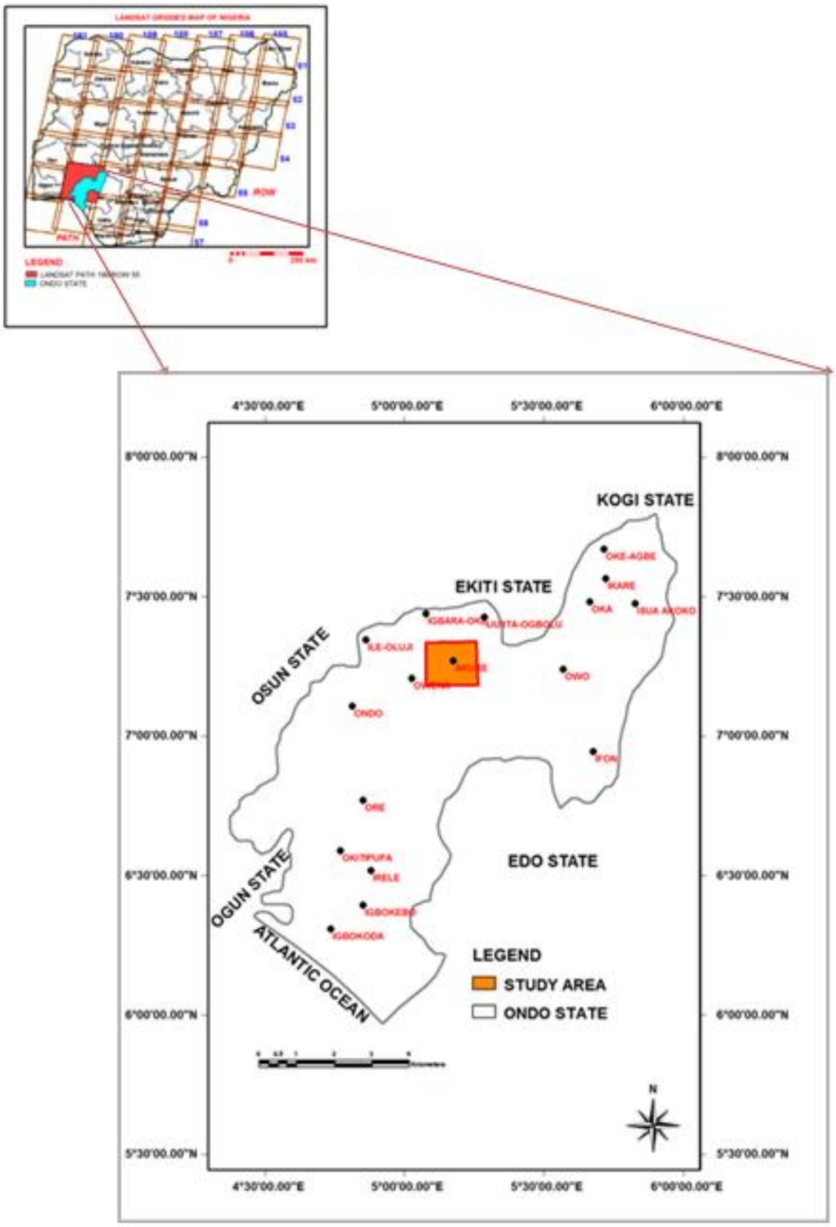

Figure 1: Location map of the study area

2.1 Geology And Hydrogeology Of The Area

The study area is underlain by crystalline Precambrian Basement Complex rocks. The lithological units include migmatite-gneiss, granite-gneiss, charnockites, quartzites and granites (Olarewaju, 1981) (Fig. 2). These rocks form inselbergs, isolated/residual hills and some continuous ridges. They gneisses are basically migmatite or granite gneisses. The migmatite-gneisses, being the oldest rocks in the Nigerian Basement are both litho- and tectono-stratigraphically basal to all suprajacent lithologies and orogenic events (Rahaman, 1976). They are widely spread covering the north-eastern parts through the city center to the south-eastern part of the study area. They are composite rocks characterized by strong foliation and alternation of mafic and felsic minerals. The granite gneisses have lenses of feldspar phenocrysts aligning together to give a gneissic texture (gneissosity). The charnockites occur as large individual boulders with smooth rounded to sub-circular bodies within the complex and cover approximately 10% of the study area. They are the youngest of all the rock types in the area and are found mostly around the northern part of the study area. The charnockitic rocks in the region are dark greenish to greenish grey in appearance, non-foliated and very heavy in hand specimen. Quartzite series are metasedimentary rocks which occupy about 5% of the area and occur within migmatite-gneiss and other rock types. The rock is very brittle and liable to fracturing in most cases. They are creamy to whitish in colour and essentially very few minerals are visible in hand specimen; quartz and small flakes of muscovite. In most places the muscovite are completely decomposed into clay leaving the resistant quartz. This is commonly observed in most of the blasted wells in the study area. The granites belong to the older granite series and occupy about 25% of the study area. They are found at the north-eastern and southern parts of the area. They range in texture from medium to coarse grain. Two principal varieties are recognized in the area; biotite granites and porphyritic granites. The biotite granites are fined grained and rich in dark coloured minerals such as biotite and hornblende, and also well fractured. The porphyritic granites are porphyritic in texture and less fractured.

The charnockites weather into low permeability clayey (low resistivity) materials with low groundwater discharge capacity. Gneisses and granites weather into higher permeability sandy clay and clayey sand and sand with higher groundwater discharge capacity while quartzites fracture excellently to increase permeability. The topography is generally rugged and characterized by hills of varying heights with gentle slope. Generally, five aquifers types have been identified (weathered layer aquifer, weathered/fractured aquifer-unconfined or partly weathered aquifer, weathered/fractured-confined aquifers, weathered/fractured unconfined/fractured-confined aquifer and fractured-confined aquifer) (Olorunfemi and Fasuyi, 1993).

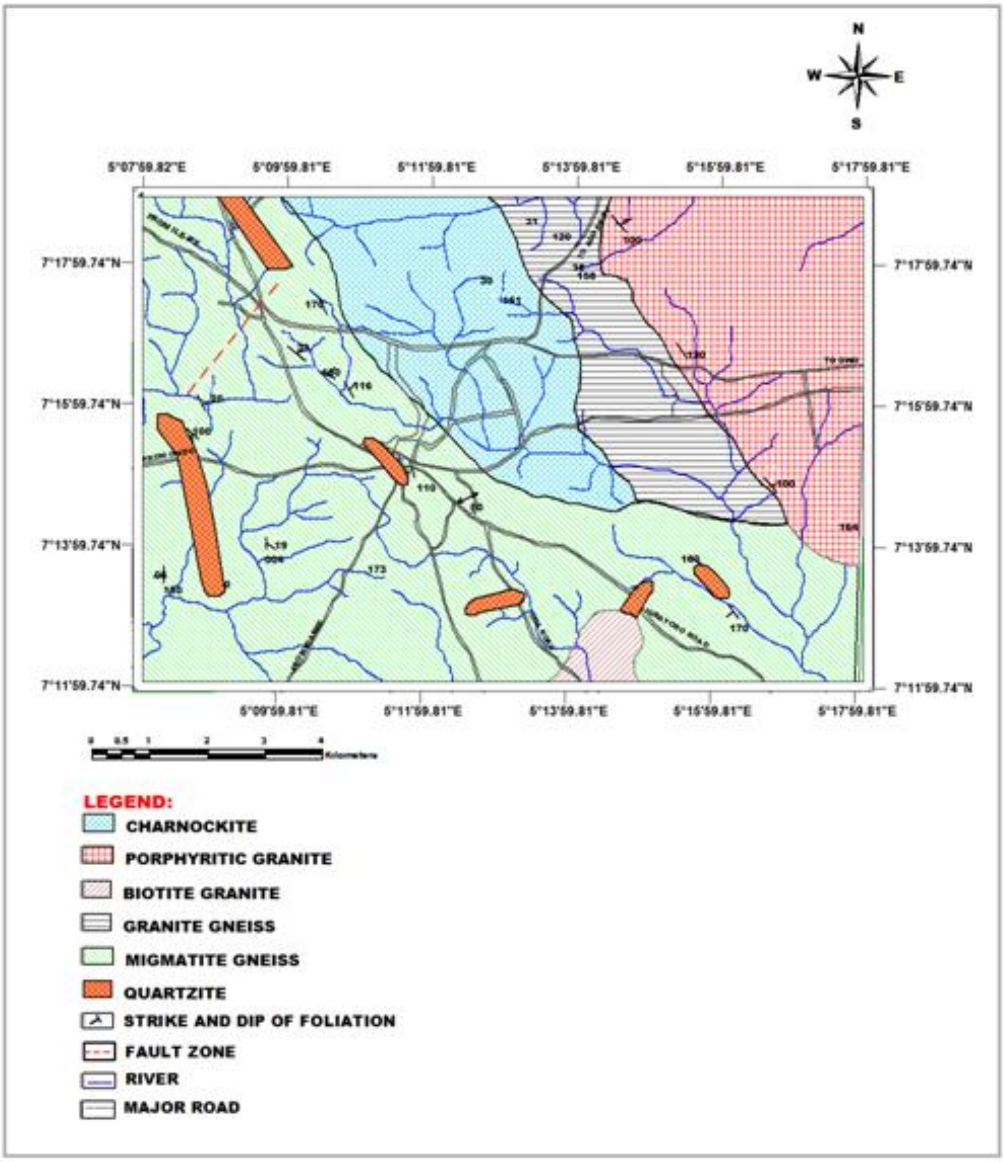

Figure 2: Geologic map of the study area (modified after Olorunfemi et al., 1999).

III. Materials And Methodology

The research methodology involved the extraction of lineaments from Landsat TM band 5, Shuttle Radar Topographic Mission (SRTM) DEM and Normalized Difference Vegetation Index (NDVI) imageries. Landsat TM band 5 (infrared), being the image that displayed lineaments best compared to the other bands was linearly enhanced by employing a convolution filter of a kernel of 3 * 3 pixel size along 45^0 differences through a complete circle and again by 3*3 median filters and 2% linear stretching. These were done in order to enhance specific linear trends of higher spatial frequencies and improve visualization for lineament extraction in view of the dense settlement nature of the study area. The tone differences between rock types caused by colour differences at the boundaries of contrasting lithological units, breaks in crystalline rock masses and visible faults were keenly noted during extraction. However, hydrogeologically negative lineaments such as joints, faults and shear zones were digitized as groundwater potential lineaments (Solomon and Ghebreab, 2006). The processed SRTM DEM was loaded into ERDAS Imagin where an advanced hillshade was created. The colour hill-shade was created by filtering three hillshades using three sun directions: West, North-West and North. Also, a Normalized Difference Vegetation Index (NDVI) of the study area was subsequently produced and in order to reduce the effect of haze from the image acting as a veil on shorter wavelength bands, a haze reduction routine process was applied on it in ERDAS Imagin before digitizing the vegetation that are aligned along fractures. The processed imageries were then used for lineament identification, digitization and extraction. Thus, the traces of the lineaments extracted from the above sources were compiled on one map and converted into digital vector format using ArcGIS after field check, and removal of questionable lineaments. The lineament density map was extracted using script files - Avenue™ language (Kim et al., 2004) incorporated into ArcView 3.2 GIS software for more systematic analyses. The script files has seven (7) vital components from which two scripts ("Remove-Node" and "Generalize") were customized for error corrections during lineament extraction. The "Remove-Node" and "Generalize" scripts helped in removing all duplications registered during digitization. The other Avenue ™ scripts are lineament statistics, lineament length density, lineament cross-point density, lineament selection and calculation of densities scripts. The lineament statistics script was used to analyze the orientation of lineaments from the optimized lineament map made by the above two scripts and to get the lineament statistics for the area. The lineament statistics obtained were transferred to Grapher™, Rockworks™ and Surfer™, and a rose diagram was plotted to show the orientation of the lineaments. The calculation of lineament length density value and cross-point density value script was used to calculate the sum of the lineament length, the number of lineament counts and the number of lineament cross points. Consequently, a lineament density intersection map was constructed and analyzed in Surfer™. However, since the area is a basement terrain, it is expected that structural trend variations in different direction may occur and as such the lineaments were further analyzed using lineament selection script in order to extract those lineaments that have been formed as a result of tectonics known as extensional fractures or lineaments (Larson, 1972; Caponera, 1989; Travaglia 1989). The extensional fractures were analyzed from the general rose plot (striking between N60^{0}W and N60^{0}E directions). These lineaments were employed in showing their relationships with groundwater productivity. The borehole yields as well as the depth to bedrock data obtained from Ondo State Ministry of Water Corporation were superimposed on the extensional lineaments for analyses in ArcGIS platform. A correlation graph was plotted in Surfer™ for the borehole yields with the extensional lineaments.

IV. Results

Figure 3 show a total of 375 lineaments extracted from Landsat TM band 5 in 0^0, 45^0, 90^0, 135^0, 180^0, 225^0, 270^0 and 315^0 filter directions. A total of 64 lineaments digitized along the fractures show the concentration of the lineaments with high groundwater potential on Normalized Difference Vegetation Index (Fig. 4). Fig. 5 show results of 74 lineaments extracted from SRTM DEM of the study area. The integrated lineament extracts from the three images is presented in Fig. 6 and the generated lineament intersection density map presented in Fig. 7. From these maps, it shows that the central part of the study area contains lineaments that may be of high groundwater potential due to lineament intersection. Fig. 8 shows a rose diagram with most lineaments trending in N-S structural direction. The rose plot was analyzed for tensional lineaments and 339 extensional lineaments were gathered for correlation with borehole yields (Fig. 9). Fig. 10 and Table 2 indicated the relationship between the extensional lineaments, lineament intersections and borehole yields in the area. The borehole yields was closely correlated with the distance to the nearest lineaments and distance to extensional lineament intersection point respectively (Figs. 11 and 12 respectively). Table 3 and Fig. 13 show the influence of bedrock depth to the yield of the area as well as the lineament intersection points.

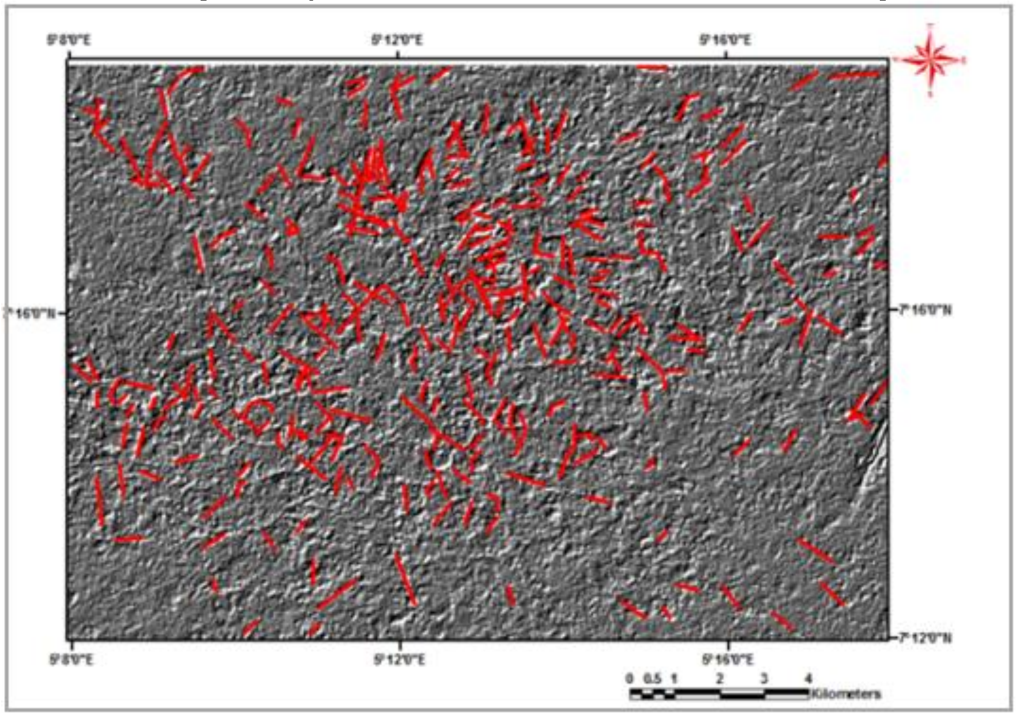

Figure 3: Lineament traces on Landsat TM band 5 of the study area

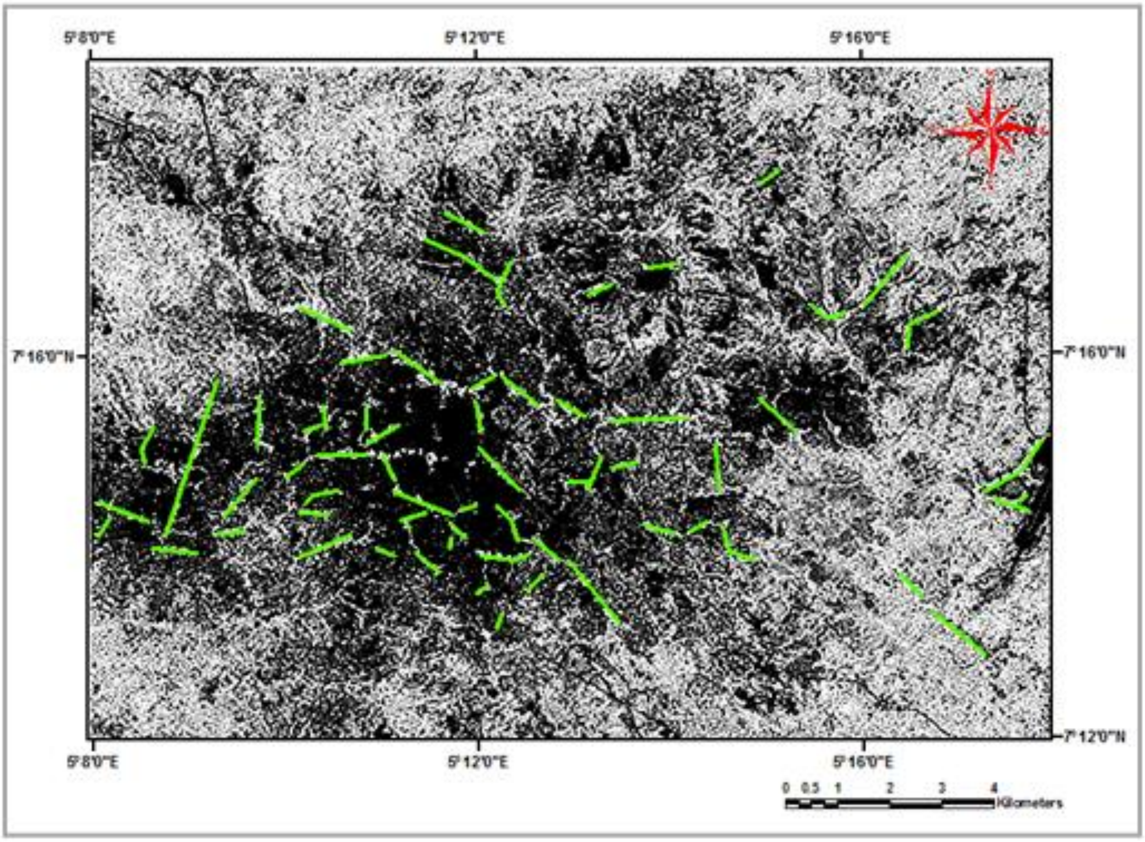

Figure 4: Lineament traces on processed Normalized Difference Vegetation Index (NDVI) of the area.

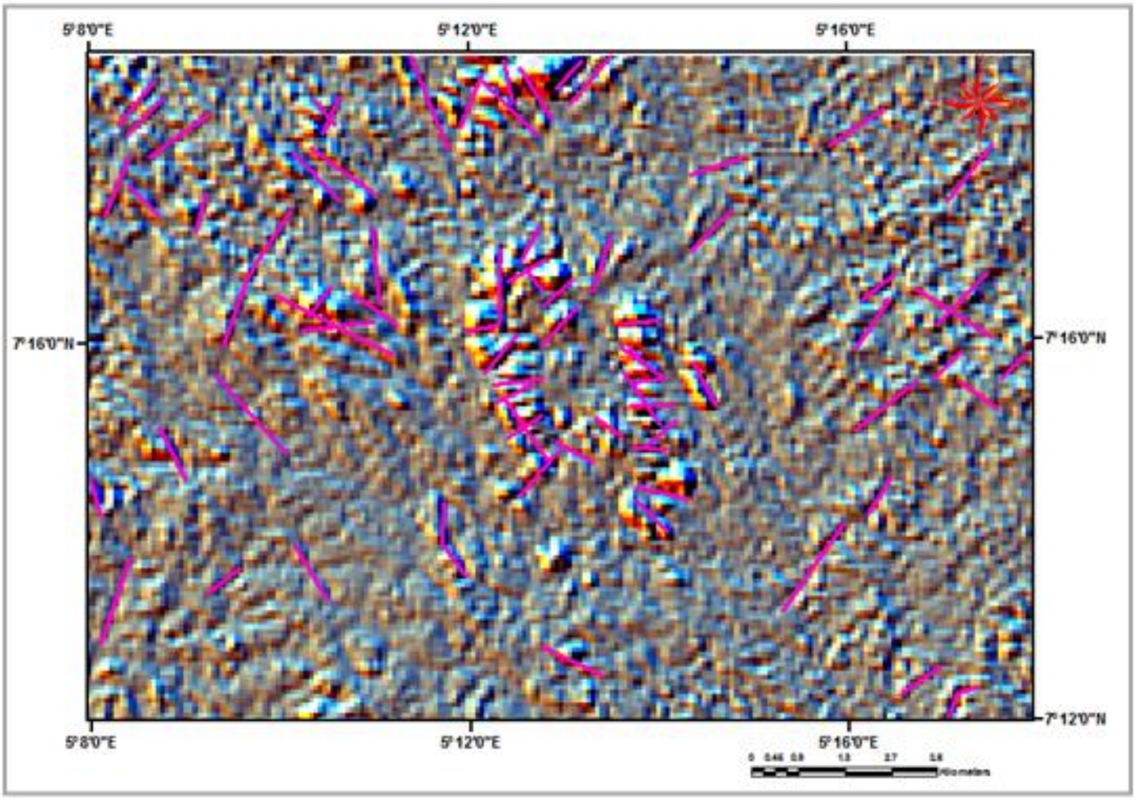

Figure 5: Lineament traces on SRTM DEM of the study area.

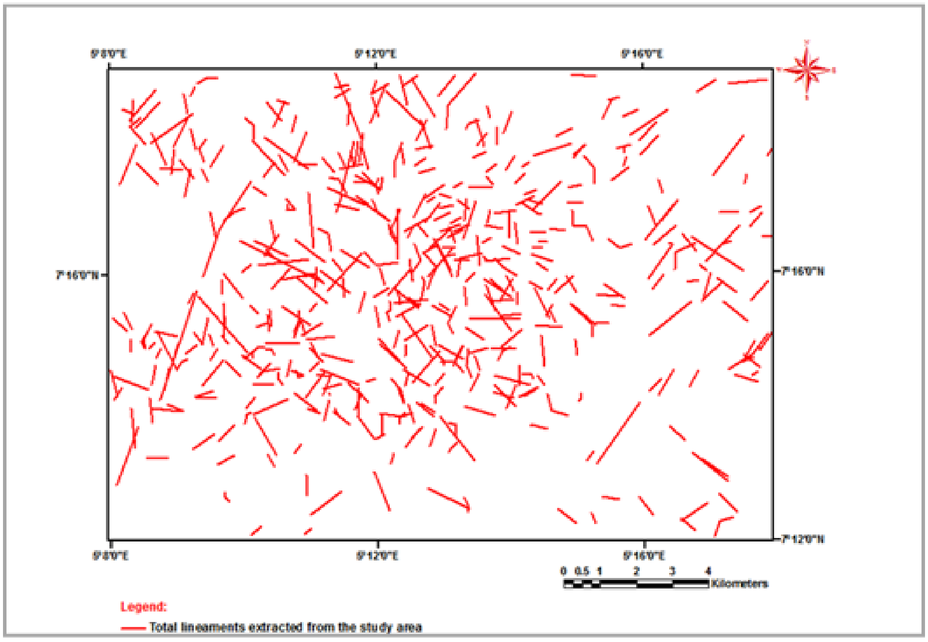

Figure 6: Lineament map of the study area.

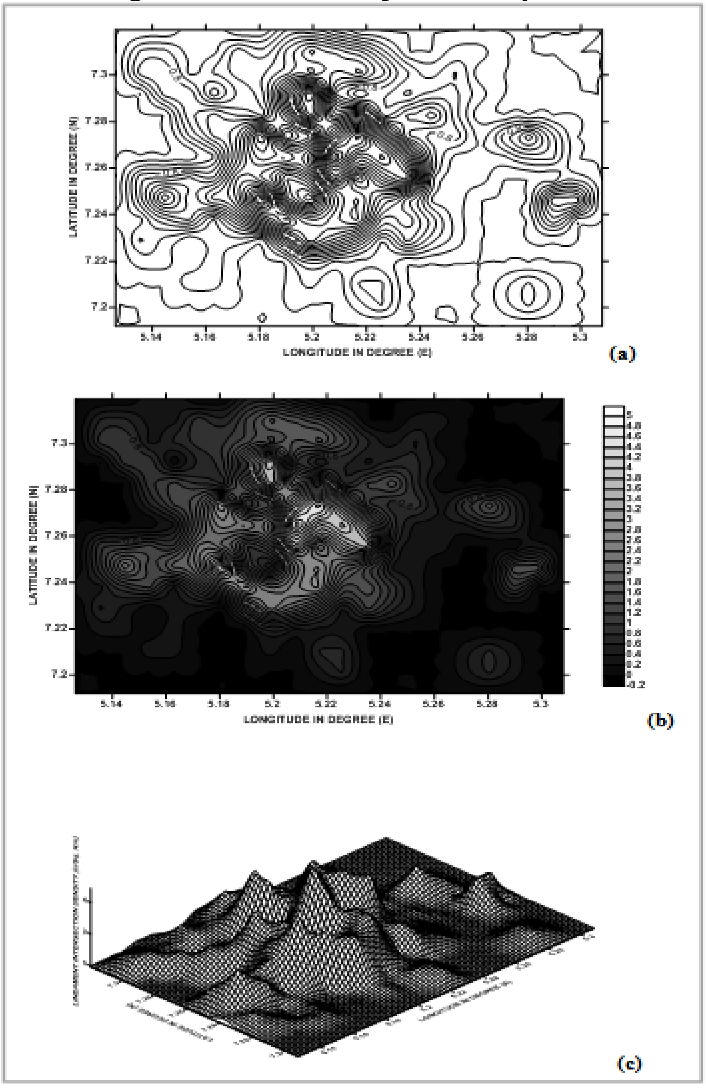

Figure 7: Lineament intersection density map (a) Contour map (b) Filled contour map (c) 3D wireframe map.

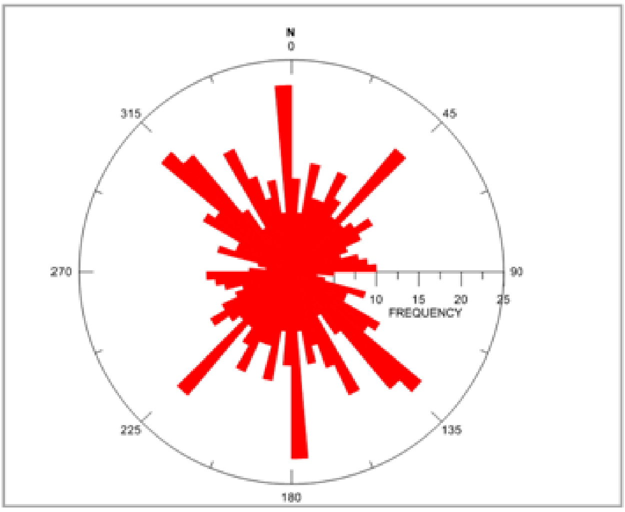

Figure 8: A generalized rose diagram of the study area showing N-S, NE and NW structural trends

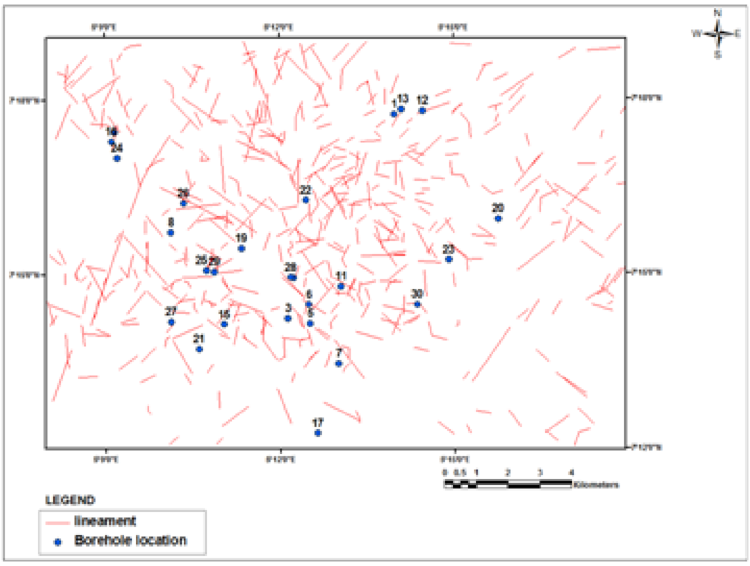

Figure 9: Borehole locations superimposed on lineament map

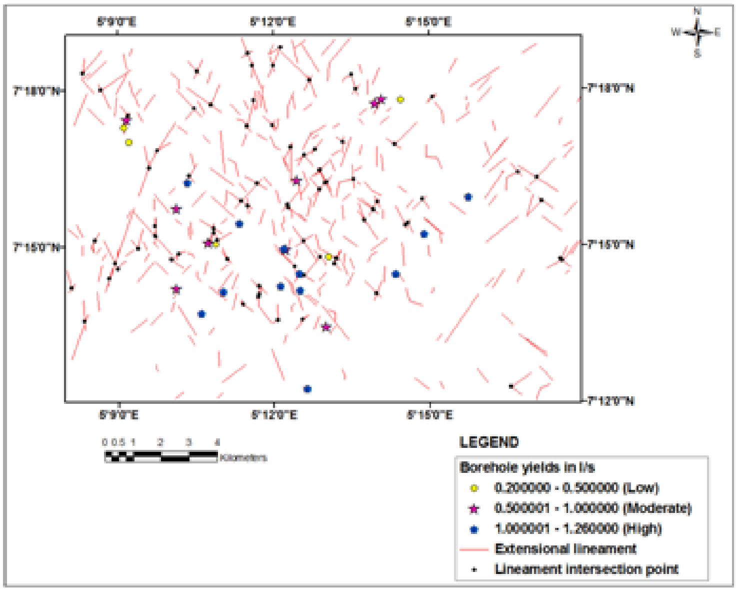

Figure 10: Borehole yields superimposed on extensional lineament map

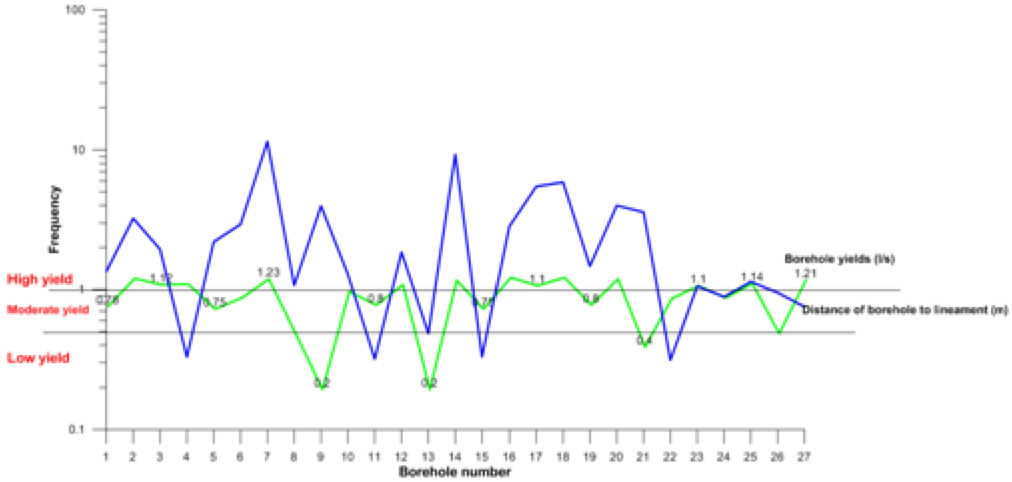

Figure 11: Correlation between borehole yields and distance to nearest lineament

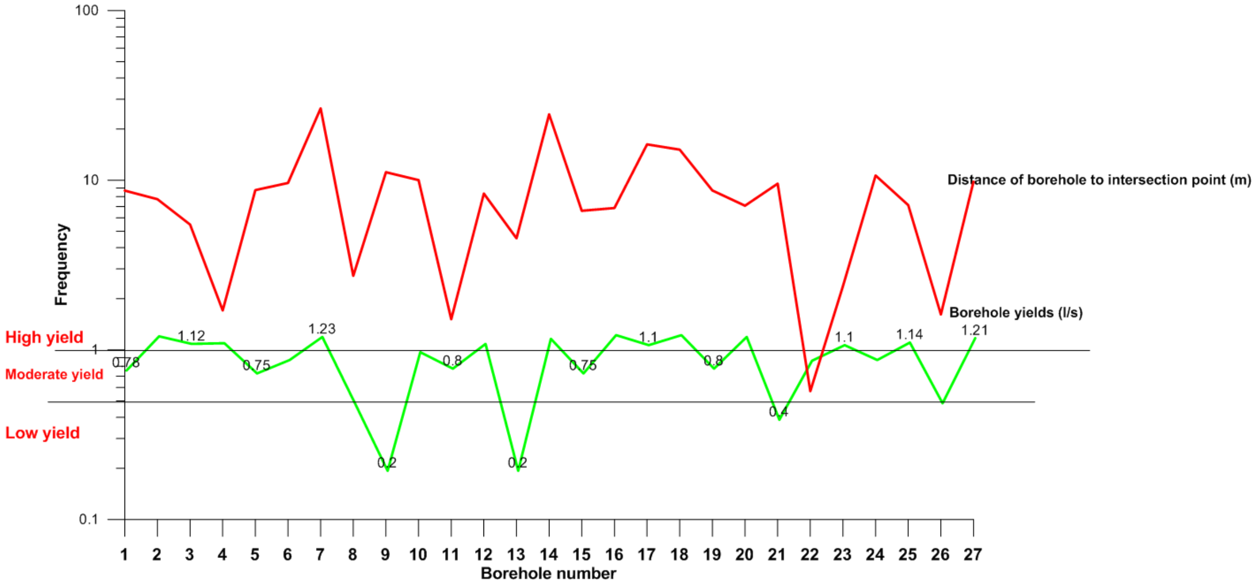

Figure 12: Correlation between borehole yields and distance to intersection point

Table 2: Correlation between yields, distance to lineament and intersection point of lineament of the study area

Borehole N0	Longitude (E)	Latitude (N)	Yield (l/s)	Dist. to lineament (m)	Dist. to intersection (m)
1	5.232777778	7.29558333	0.78	134.75	867.81
2	5.202166667	7.23730556	1.24	323.7	772.28
3	5.208555556	7.23583333	1.12	194.29	547.56
4	5.208194444	7.24122222	1.13	32.86	170.89
5	5.216722222	7.22427778	0.75	219.54	874
6	5.168666667	7.26205556	0.9	292.99	962.29
7	5.3	7.20588889	1.23	1150.56	2649.31
8	5.217472222	7.24647222	0.5	107.3	273.15
9	5.241	7.29661111	0.2	396.62	1113.9
10	5.234916667	7.297	1	128.51	1001.22
11	5.152694444	7.29069444	0.8	31.76	151.46
12	5.183833333	7.23561111	1.12	185.12	833.92
13	5.151916667	7.28805556	0.2	48.38	454.52
14	5.210694444	7.20444444	1.2	927.68	2443.21
15	5.203861111	7.24891667	0.75	32.91	659.8
16	5.189055556	7.25741667	1.26	283.36	685.17
17	5.262527778	7.26563889	1.1	546.75	1625.66
18	5.176722222	7.22866667	1.26	587.51	1513.08
19	5.207361111	7.27111111	0.8	146.94	869.78
20	5.248277778	7.25394444	1.23	399.77	707.45
21	5.153388889	7.28330556	0.4	358.61	954.32
22	5.178888889	7.25111111	0.89	31.21	57.07
23	5.172361111	7.27038889	1.1	105.75	237.24
24	5.168694444	7.23647222	0.9	88.62	1065.32
25	5.203138889	7.24905556	1.14	113.7	712.9
26	5.181166667	7.25066667	0.5	94.81	161.53
27	5.239333333	7.24113889	1.21	75.14	980.42

Table 3: Borehole data from localities of the study area

N0.	Locality name	Long. (E)	Lat. (N)	Elevation (m)	Yield (L/S)	Total Depth (m)
1	Igoba(II) community, Akure	5.23278	7.29558	347	0.78	27.3
2	Y & B's Place Ireakari	5.20217	7.23731	356	1.24	31
3	VIP Lodge Government House (BH 2)	5.20856	7.23583	347	1.12	40
4	VIP Lodge Government House (BH 1)	5.20819	7.24122	347	1.13	25
5	NUT House, Oda Road	5.21672	7.22428	362	0.75	36
6	Lafe Inn	5.16867	7.26206	374	0.9	17.87
7	Alafe Kajola, Ehin Ala	5.3	7.20589	335	1.23	25
8	Ondo State Electricity Board (OSEB)	5.21747	7.24647	375	0.5	41
9	Retired Bishop House, Modulore est.,Igoba	5.241	7.29661	378	0.2	20.81
10	Deeper Life Area, Igoba	5.23492	7.297	359	1	30
11	Atanlusi Layout Community, off Aule Rd	5.15269	7.29069	348	0.8	13
12	Adewole Falowo St., Comm., Oke-Aro	5.18383	7.23561	406	1.12	30
13	Alaba Layout Comm. Aule road	5.15192	7.28806	374	0.2	17.78
14	Cannan Land, off Ijoka Rd	5.21069	7.20444	364	1.2	28
15	Ondo State High Court premises	5.20386	7.24892	358	0.75	33
16	CAC Prim. Sch., Oke Igan	5.18906	7.25742	332	1.26	35
17	Asamo/Irowo Quarters, Oba-Ile	5.26253	7.26564	326	1.1	25
18	Familusi Layout Oke-Aro	5.17672	7.22867	334	1.26	40
19	Ikere Street, Ijapo Estate	5.20736	7.27111	351	0.8	33
20	Bishop Gbonigi's residence, Oba-Ile Estate	5.24828	7.25394	335	1.23	30
21	Alaba Layout	5.15339	7.28331	347	0.4	30
22	St. Louis Grammar School	5.17889	7.25111	340	0.89	29
23	Scripture Union, Nigeria	5.17236	7.27039	357	1.1	23
24	Ogundipe Comm. 2, Ajipowo Estate	5.16869	7.23647	350	0.9	29
25	Ondo State High court premises	5.20314	7.24906	356	1.14	30
26	St. Louis Nursery/Primary School	5.18117	7.25067	344	0.5	28
27	Police Headquarters (beside Mosque)	5.23933	7.24114	369	1.21	40

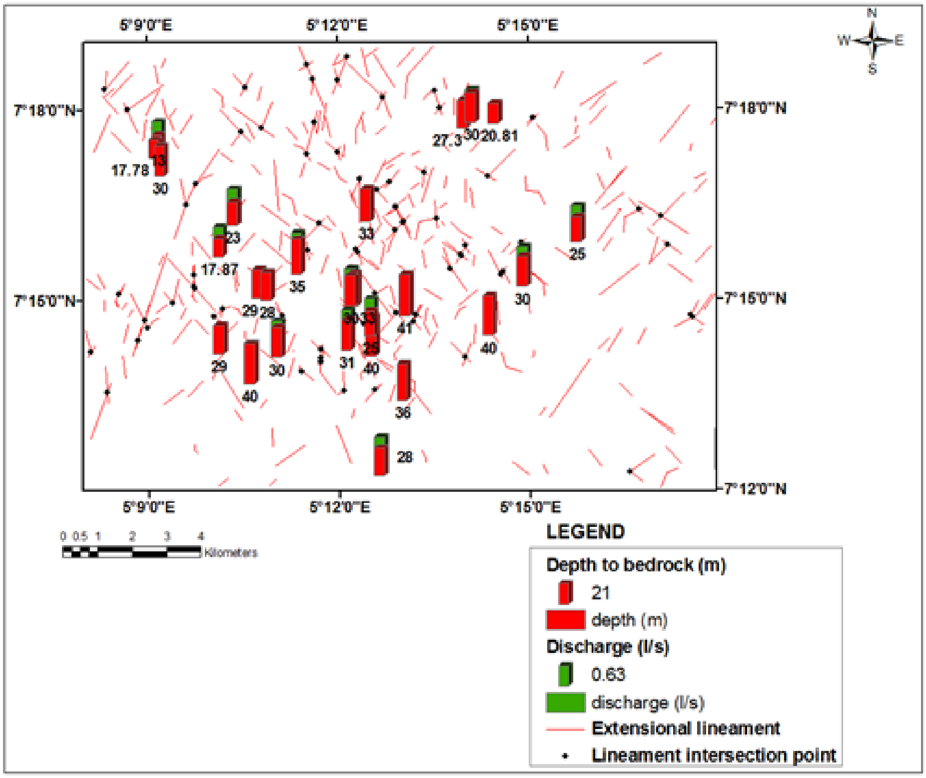

Figure 13: Borehole locations superimposed on lineament map

V. Discussion

The lineament intersection density at the central part of the study area is high and this portion is a good target area for groundwater productivity. The lineaments trend mainly in N-S, NE and NW directions, as such serves as pathway and storage points for groundwater. Therefore, the location of boreholes in the study area is concentrated at such part that is expected to give an excellent yield for groundwater supply. However, it is not all the lineaments extracted in the study area that are relevant to groundwater exploration even though are negative lineaments (Solomon and Ghebreab, 2006). They important extensional lineaments strike between $N60^0W$ and $N60^0E$ directions. These preferred lineaments are most essential in comparison and correlation with groundwater productivity. There are basically three (3) categories of borehole yields in the study area; low yields (<0.2 l/s), moderate yields (0.5 -1.0 l/s) and high yields (>1.0 l/s). Only five (5) boreholes in the study area have low yields of less than 0.2 litres of water per second while nine (9) boreholes have moderate water discharge rate of between 0.5 litres per second and thirteen (13) boreholes with high yields of more than 1.0 litres per second. This elucidated that there are generally moderate to high yields in the study area which could be attributed to the presence of high lineament density. It has been observed that the boreholes with high yields are mostly found around the central part of the map where there are more lineaments while most of the low yielding boreholes are either found far away from the lineaments. Generally, results indicated that borehole yields and distance to a nearest lineament are well correlated i.e. the area shows that the presence of lineament to a borehole increase its productivity in the study area while the closeness of a borehole to an intersection point of lineament has little or no much influence on the yield of boreholes in the study area. Interestingly however, increased depth of a borehole and/or thick overburden may improve the yield or discharge in the study area.

VI. Conclusions

The main aim of this research work is to assess, evaluation and analysis the relationship between lineaments and deep groundwater productivity of the study area. The result showed that borehole yields ranges from low (<0.2 l/s), moderate (0.5 -1.0 l/s) and high (>1.0 l/s) in the study area. Many extensional lineaments occur in the study area and are discovered to be relevant to groundwater productivity and to a large extent improve borehole yields. Groundwater productivity is strongly affected by its closeness to lineaments but insignificantly influence by the presence of lineament intersection points in the study area. However, groundwater productivity tends to be influenced by the increase in depth of a borehole due to greater pressure gradient and/or thick overburden. This shows that lineament is not the only factor that influences groundwater productivity in an area but other factors such as may equally play crucial parts in deep groundwater productivity.

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