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Geohydrological study of weathered basement aquifers in Oban Massif and environs Southeastern Nigeria: using Remote Sensing and Geographic Information System Techniques

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Abstract: *The focus of this research is to model the geohydrology of the precambrian Oban Massif using geospatial techniques. Groundwater control indicators such as geology, geomorphology, drainage density, lineament density, land use / land cover and slope steepness were derived from landsat ETM^{+} imagery, ASTER DEM and SRTM DEM. Image processing software such as ENVI 3.2, ARC GIS9.2 and PCI Geomatica were used for image processing , digitizing and lineament density computation respectively. Weighted averages of the groundwater controlling factors were used to produce thematic maps of geology, lineament density, drainage density, slope steepness, land use/land cover and geomorphological units. The thematic maps were overlaid in a GIS environment to model the ground water potential map of the area. Arc GIS, Arc View and Map Info were used for geographic Information System analysis. ERDAS imagine 8.6 and ENVI 4.2 were used for georeferencing, image analysis and coordinate transformation. ASTER DEM was used for analysis of geomorphology. For vegetation, discrimination in land cover / land use mapping band 4: 3: 2 for landsat ETM^{+} was used. Unsupervised was used to have a general idea of the area. Supervised classification was used for final land use/ land cover mapping. Result show that geology, lineament density, and slope steepness are the most influential groundwater controlling factors of groundwater potential. Their degree of influence can be summarized as geology > lineament density> slope>geomorphology>drainage density>land use / land cover. From the groundwater potential map, four groundwater potential zones: very good, moderately good, fair and poor. Successful boreholes drilled in the groundwater favourable potential areas should be reticulated to the neighbourhood with poor groundwater potentials to salvage groundwater problem in the study area.*
Key words: *geohydrology, thematic maps, reticulated, supervised unsupervised classification*

I. Introduction

The provision of water for drinking and other domestic uses in rural communities is largely by harnessing of groundwater through hand dug wells. This is common in Cross River State, and particularly Oban Massif, which lies in the Precambrian weathered basement rocks with unconfined and shallow water table. Groundwater exploitation in hard rock terrains is only feasible; because in basement complexes where water is restricted to secondary porosity and thus to the fractures and the weathered zones, most areas experience water shortage because drilling on hard rock has low success ratio. The study of lineaments has been proposed by Meijerink (1986) to alleviate the problem.

Geohydrology and groundwater exploration refers to the identification and location of zones of groundwater recharge in a particular river basin or a catchment. Knowledge of the geology of the terrain, topographic and surface features are mapped in a bid to evaluate from peak to valley area where water from different higher elevations can move and accumulate (Candra and Manisa 2012). The delineation of such places from the entire area, are then earmarked for groundwater exploration. Remote Sensing and GIS is a rapid and cost effective tool in producing valuable data on geology, geomorphic units, lineaments, drainage, land cover and land use and slope steepness that assist in revealing groundwater potential zones, which can be combined with follow up hydrogeological investigations (Mayilvagan, et al 2011).

The traditional approach of groundwater exploration applying geological, hydrogeological and geophysical methods are expensive in relation to high cost of drilling, time consuming and cumbersome for groundwater exploration on a regional scale (Ndatuwong and Yadev, 2014). In addition, these methods of investigation do not always take into consideration the different factors that govern the occurrence and movement of groundwater (Ndatuwong and Yadev 2014). Existing papers on the application of remote sensing and GIS elsewhere on groundwater occurrence and mapping can be found in Mayilvigan et al 2011, Sitender and Rajeshwaren 2011, Ndatong and Yadev 2014, Talabi and Tijani 2011 etc, although Edet et al 1998 researched on groundwater exploration in the study area using remote sensing from a different standpoint. The objective of this study is to use the technique of remote sensing and GIS to identify the geohydrological condition of the study area for future groundwater resources development, identify groundwater recharge and discharge zones and recommend appropriate methods to salvage the problem of potable water scarcity in the area.

II. Study area

The study area Oban Massif and environs is situated in Akamkpa and Biase Local Government area in Cross River State. The study area is located between latitudes N05^0 18' 57.7'' to N05^0 45' 26.8'' and longitudes E08^0 34' 39.4'' to E008^0 05' 20.5'' as shown in Fig. 1. The area encompass Oban Hills and forest which have a common boundary with Ebonyi State along the Cross River channel. It is bounded by the Calabar Flank in the south and bounded by the Mamfe Mbayment in the North (Fig. 1). The area was selected to reflect abortive boreholes within the Precambrian basement of the Oban Massif and the prolific aquiferous sedimentary terrain in the adjoining Mamfe Mbayment.

The area experience a tropical climate with distinct wet and dry seasons, with an annual rainfall of about 2000mm and temperature range of 28^{0}C to 36^{0}C. Temperatures and humidity are generally high averaging about 26^{0}C and 80^{0}C (Okereke et al 1996). The soil is mostly lateritic due to weathering products from granites granites and other volcanics. The soil is suitable for cultivation of vegetables and tuberous crops hence there is small scale farming by the locals around the area. CRBDA, (2008) reported the mean daily relative humidity and evaporation of 76.86% and 3.85mm/day respectively in the study area.

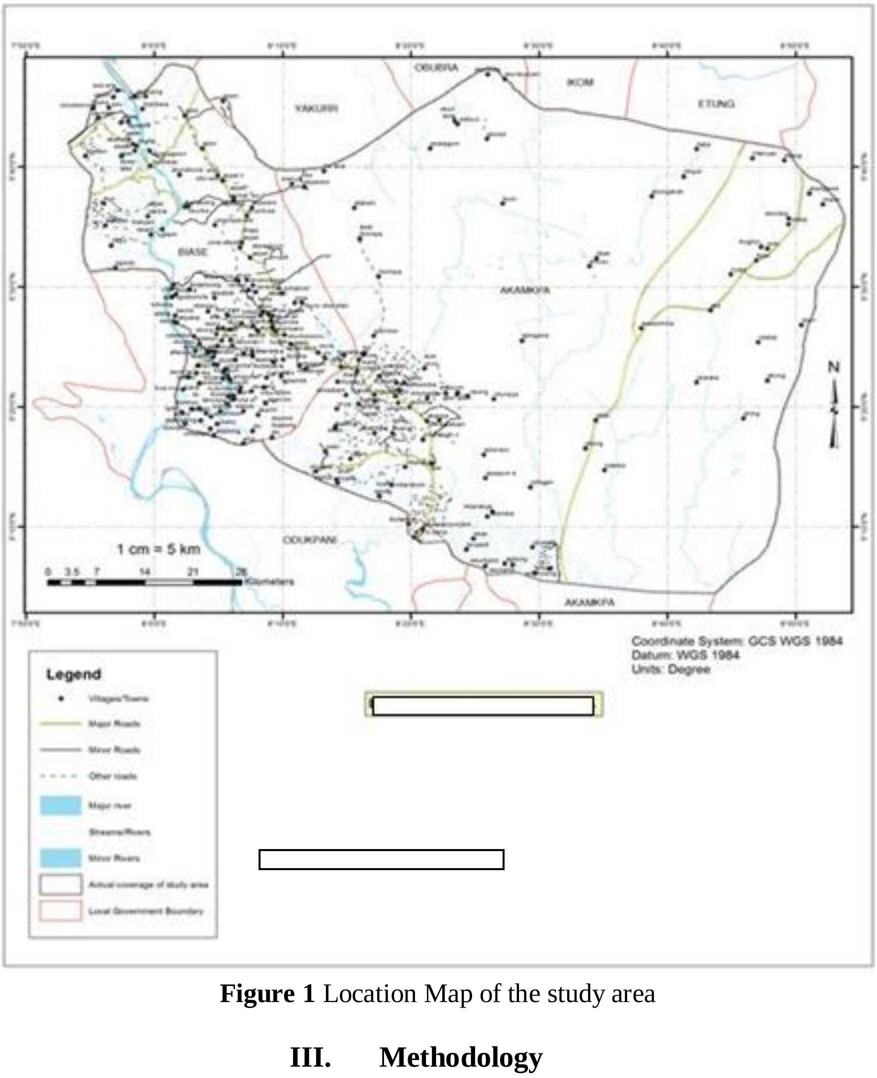

Figure 1 Location Map of the study area

III. Methodology

3.1 Data used

Landsat 7 sensor satellite imagery ETM$^+$ thermatic mapper of 30m spatial resolution acquired in 2000. The imagery used comprised path 189 row 190 path 190 and row 55 of 2001 and 2002 respectively. Other ancillary data include ASTER DEM and SRTM DEM down loaded from NASA's land process distribution centre Ames Research Centre (www.nasa.gov/centre/ames/home, a geological map on a scale of 1:500,000 and hydrogeological and structural map on a scale of 1:250,000. A map projection of UTM zone was downloaded from global land cover and land use facility from the website data service (glovs.usgs.gov) including field observation data were used in this study for validation.

3.2 Method

This includes the production of thematic layers on slope steepness, geomorphology, land use and land cover of the area, lineaments, drainage and geology. Thematic layers were prepared using Geographic Information System (Arc GIS 9.2). the groundwater potential map was produced by weighted linear combinations, where each class individual weight was multiplied by the map scores and then the result . in the application of multicriteria evaluation, a set of relative weights was assigned for each map using the continuous weighting scale established by Satty, (1977). The weights calculated for each factor map based on the relative importance to groundwater accumulation. The groundwater potential index was then gotten by computing the individual indicator scores and then summing up as given in the following expression as given by Shetty et al (2008).

GPI pixel score = $W_G X_{value} + W_{Gm} X_{value} + W_{DD} X_{value} + W_s X_{value} + W_G Xvalue + W_{LU} X_{value}$

W_G = rank of geology X_{value} = pixel rating in each map

W_{Gm} = rank of geomorphology

W_{DD} = rank of drainage density

W_s = rank of slope

W_{LD} = rank of lineament density map

W_{LU} = rank of land use /land cover

IV. Result and discussion

4.1 Slope Steepness

Slope is one of the factors governing the percolation of groundwater into the subsurface, this makes it a suitable groundwater indicator. Infiltration is higher in gentle sloped area than at steep slopes, because at high slope area surface runoff is enhanced allowing minimal residence time for rainwater that explains why there is less infiltration at high slopes compared to gentle slopes. Slope amount was analysed from SRTM DEM. The derivation of slope amount using spatial analysis was classified into five classes Fig 2 as shown in table 1. Reclassified slope map showing zones of favourable groundwater accumulation are presented in Figure 2.

Table 1 showing slope classification

Slope class	Slope in degrees
1	0-6
2	6-12
3	12-20
4	20-23
5	33-76

Slope range from 0-6 was classified as very good for groundwater for groundwater accumulation. Class of slope ranging from 6-12 was identified as good for groundwater potential. Slope grouped into a range of 12-20 was described as suitable for moderate groundwater storage. While slope class from 20-23 was considered to be fair and 33- 76 were adjudged to be poor for groundwater accumulation. Slope steepness has as a groundwater control indicator has average contribution for groundwater accumulation (Shetty el 2008). Slope steepness has is influential in groundwater potential such that Teixeira et al (2008) assigned it 14% weighting percentage in groundwater modeling in hard rock terrain in Portugal.

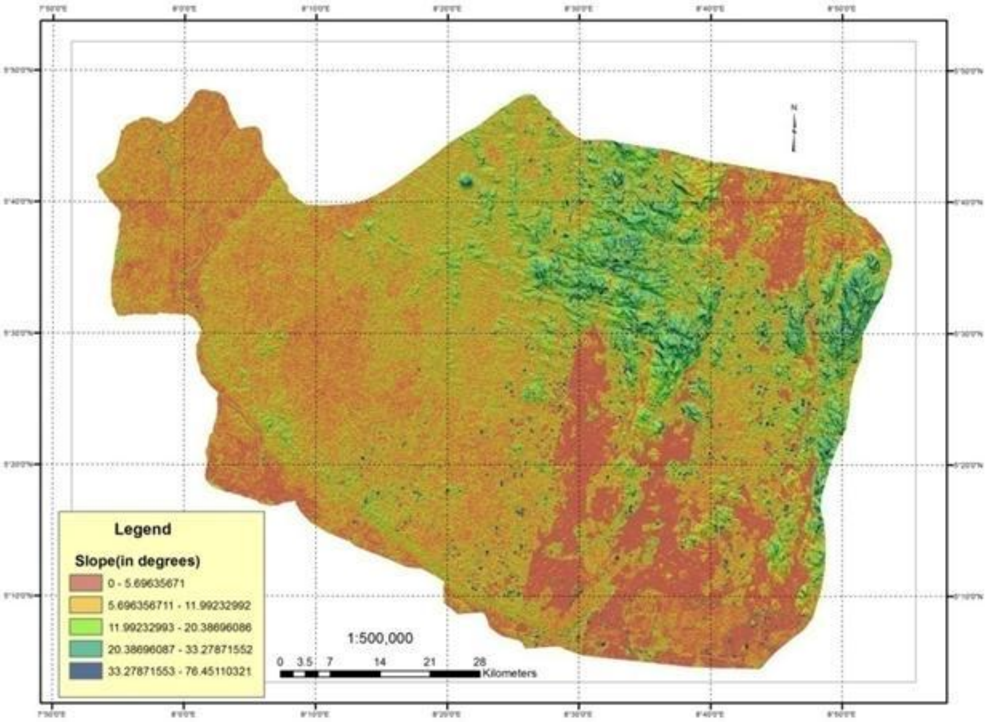

Figure 2. Slope map of the study area

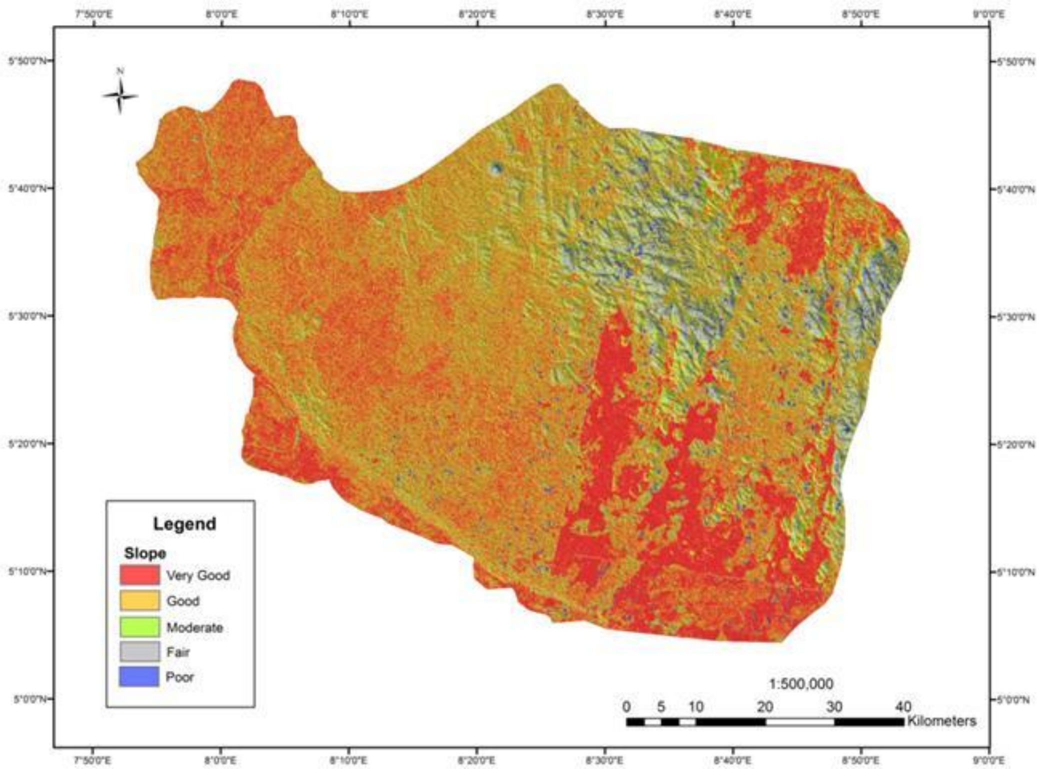

Figure 3. Stability range of slope for groundwater occurrence in the study area

4.2 Geomorphology

Hydogeomorphological classification (Figuere 4 was based on digital elevation model (SRTM) and visual interpretation of landform features was based on local knowledge of the landform types in the study area. Remote sensing studies provides an advantage for better studies of hydrogeomorphological units in combination with geological parameters in this study which is considered very important technique in the preparation of integrated hydrogeomorphological maps for groundwater targeting (Nduwatong and Yadev 2014).

A classification of five different landforms modeled in the study area is presented in Fig. 4 and summarized in Table 2. The stability ranges of groundwater accumulation of the area is shown in figure 5.

About 50% of the study area is made up of pedilpains. The Precambrian basement rocks dominated the eastern flank of the Oban Massif. The plains have a good to very good potential with high yield wells and characterized by gentle to flat slopes. This conforms with the findings of Sereme (2003). Das (2002) suggested that channel filled sediments and pediments with moderate thickness >20m and weathered materials have good potential aquifers.

Table 2 showing geomorphic units of the study area

Hydrogeomorphological units	Description	Groundwater prospect
peaks	Mountain peak	poor
Ridges	Isolated chain mountains	fair
Scarps	Steep slopes adjacent to steep v- shaped gullies representing fault lines	moderate
Terraces/pediments	Conservatively inclined erosion surfaces formed by runoffs covered with alluvium or soil	good
Plains and pediplains	Flat to gentle sloping topographic features forming plateaus at basaltic rock in crystalline rocks represent pediplains or flood plains	Very good

Channeled filled land cover and high lineament concentration sites are good artificial recharge sites (Das 2002). Talabi and Tijani described hilly areas poor water prospect zones in the basement complex of region of in Ekiti State southeastern Nigeria. The pediplains are favourable and are good groundwater potential sites (Sitender and Rajeshwari 2011).the geology of an area is strongly influenced by lithology and structure of the underlying formation (Shetty et al 2008).

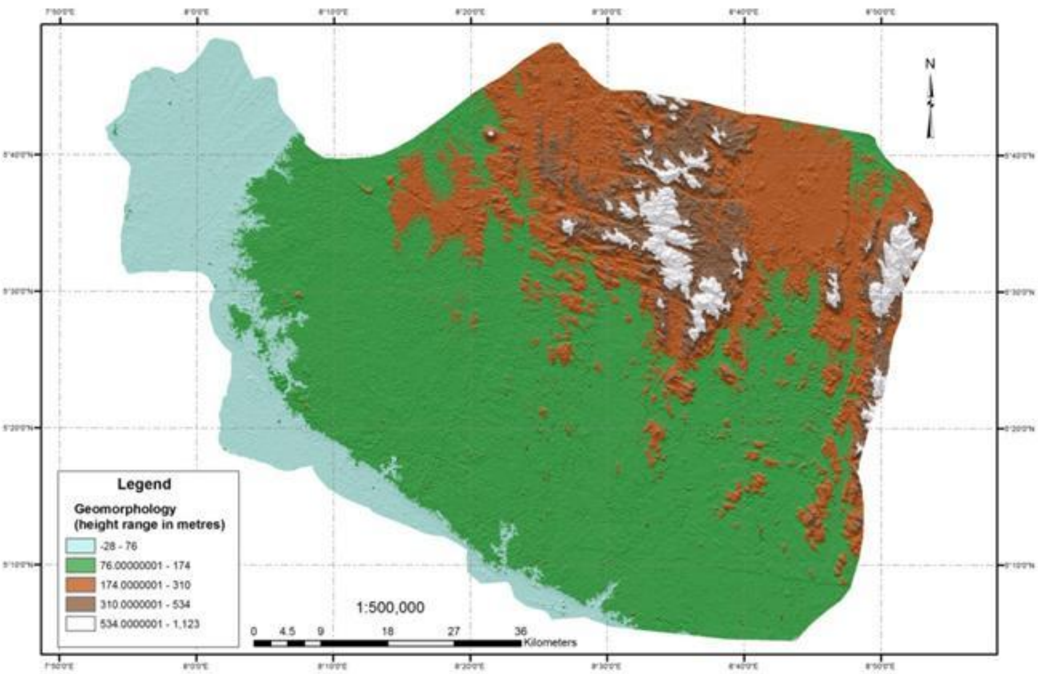

Figure 4. Geomorphology units of the study area

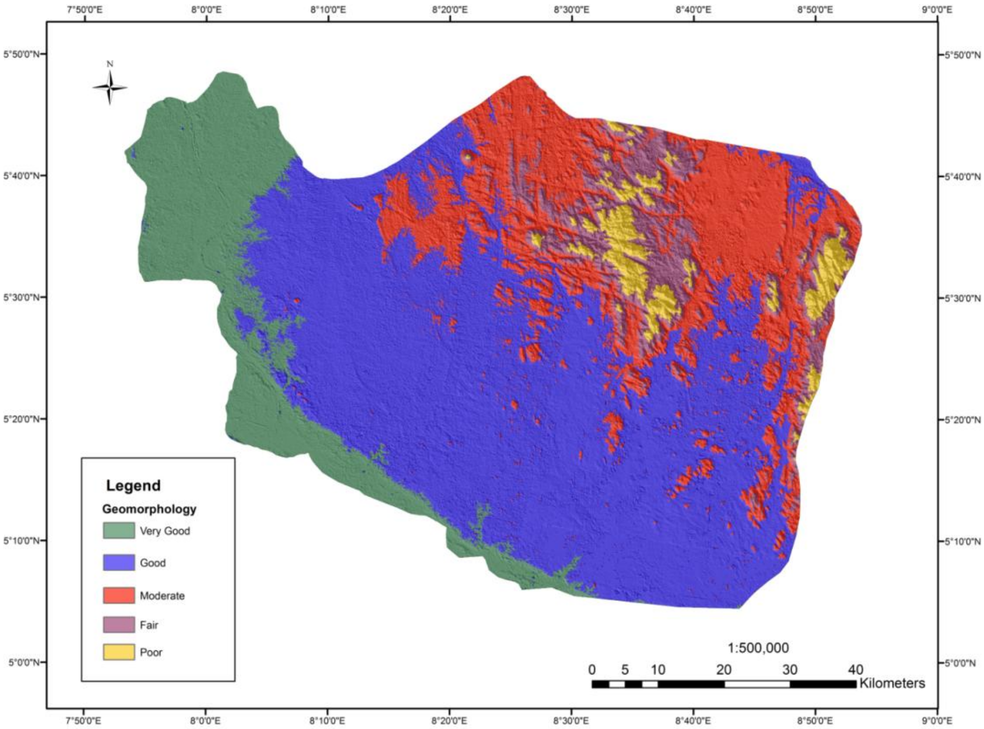

Figure 5. Stability ranges for groundwater accumulation in the study area

4.3 Land use / land cover

One of the factors influencing groundwater occurrence is physical processes acting upon because it is a reflection of the area. Land use / land cover was interpreted from landsat images by visual inspection, unsupervised classification and supervised classification and printouts from bands 5, 4, and 3 (Fig. 6). The physical processes caused by land use / land cover are impact of climate change, geologic and topographic conditions on the distribution of soils, vegetation and occurrence of water (Ndatong and Yadev 2014).

Reclassified land use / land cover (figure 7 showed five classes of based on which land features are favourable for groundwater potential. Zones in water and wetland areas are graded as very good for groundwater potential. This views square with findings of Das (2002) and Ganapuram et al (2008) who described wet lands as favourable groundwater potential sites. Forested areas were described as in this study as moderate to good groundwater potential zones. Vegetation can affect groundwater storage either positively by trapping water on foliage and causing the water to go down through the roots to recharge ground water or negatively through evapotranspiration where water droplets is frequently intercepted by vegetation thereby decreasing recharge (MAB CONSULT (2002). Cultivated grassland was graded as good due to the furrows created by farming operations that enhance the residence time of water on the surface and so enhance infiltration to recharge aquifers. Settlements were described as poor groundwater areas due mostly to concretization.

Land with different vegetation cover can benefit groundwater infiltration through roots that help loosen the rock and soil for easy water percolation. Organic matter in soil heightens the formation of structural composition resulting to elevated hydraulic conductivity decrease direct runoff by vegetation and increasing the chances of infiltration to recharge aquifers (Teixera et al (2008).

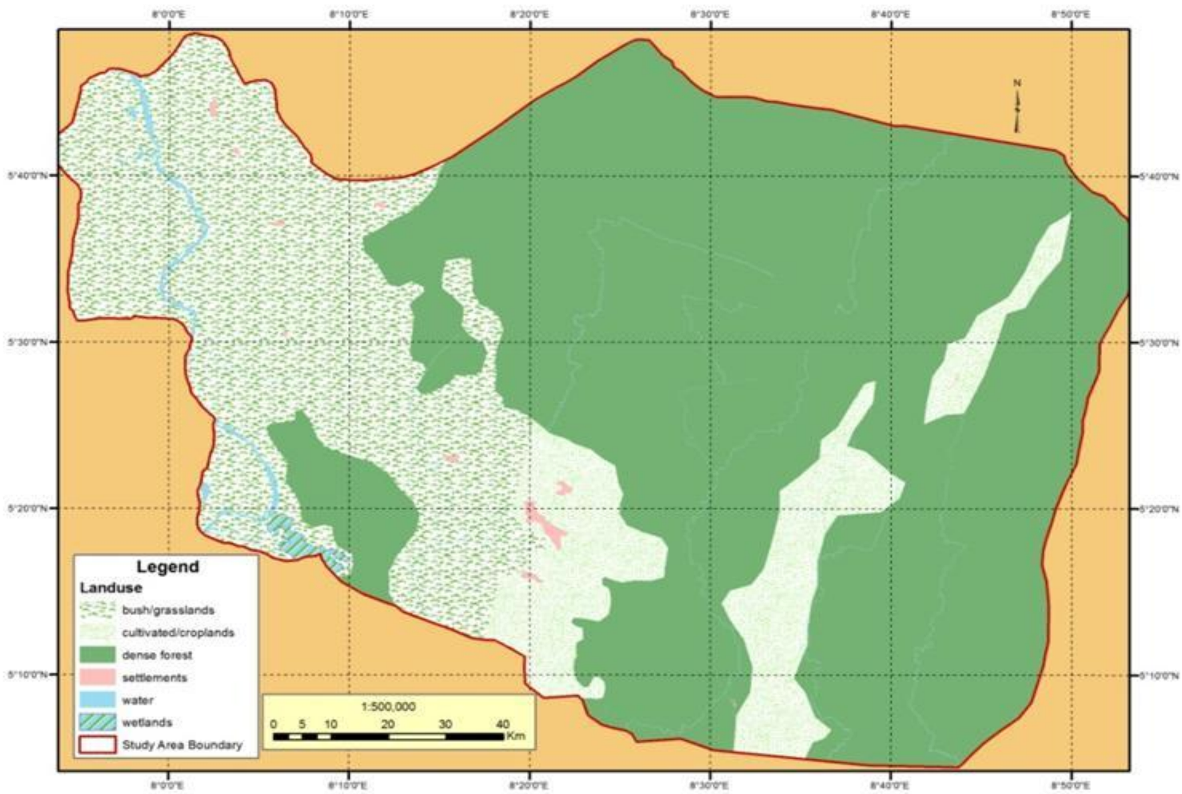

Figure 6. Land cover /Land use Map of the study area

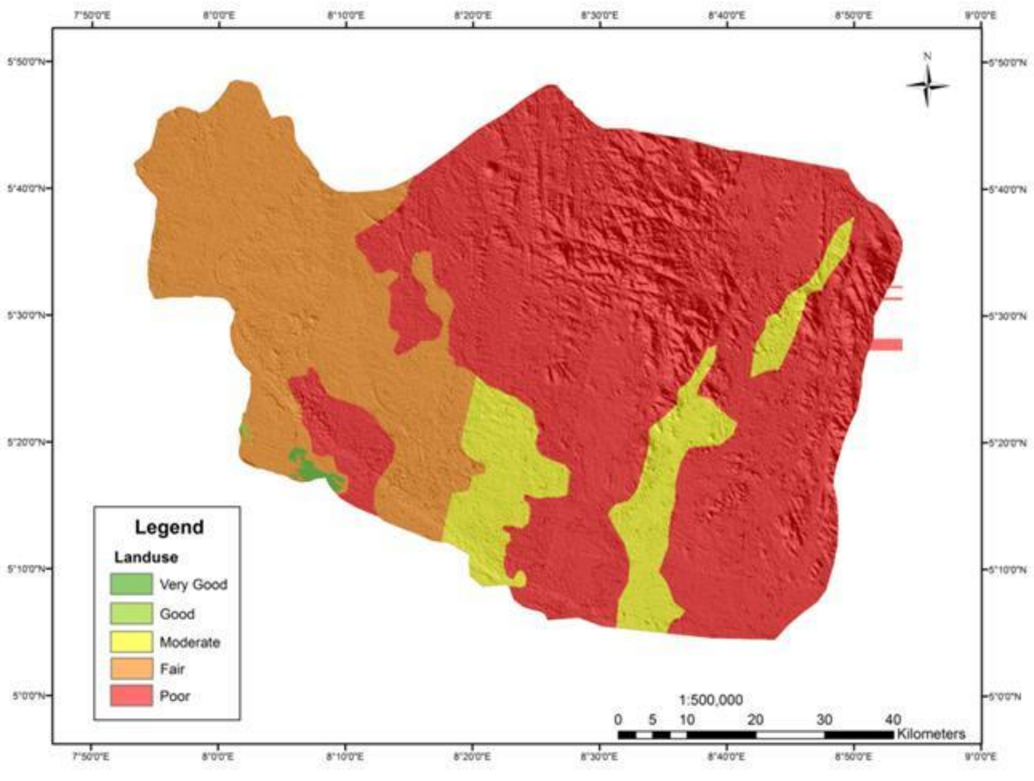

Figure 7. Stability range of Land use/Land Cover for groundwater accumulation in the study area

4.4 Drainage

The drainage (figure 8) was analysed from SRTM DEM and topographical map. The dominant drainage pattern in the basement area ranges from rectangular to sub parallel. In the sedimentary area , it ranges from subdendritic to anomalous. The drainage density map (figure 9) shows ranges of drainage and their groundwater potential suitability as 0-0.46 graded as very good, 0.46-1.39 considered to be good, 1.39-2.38 described to moderate and 2.38-3.77 classified as fair for groundwater accumulation. The drainage pattern of an area is controlled by the underlying lithology and can be used to deduce the regional fracture pattern of an area (Edet 1990, Anor et al 1990). Dense drainage pattern depicts high of fracturing of the underlying rocks. Drainage pattern in an area is a reflection of subsurface formations while drainage density is proportional to surface runoff (Faniran and Jeje 2002, Talabi and Tijani, 2011).

Low drainage density enhances chances of recharge and contributes positively to groundwater potential if other groundwater indicators are favourable (Edet et al 1994 and Talabi and Tijani 2011). In the comparison of two formations, the one with a higher drainage density is less permeable as such a poor groundwater potential indicator (Edet et al 1998). These fundamentals were taken into consideration in the drainage modeling program for groundwater potential in this study.

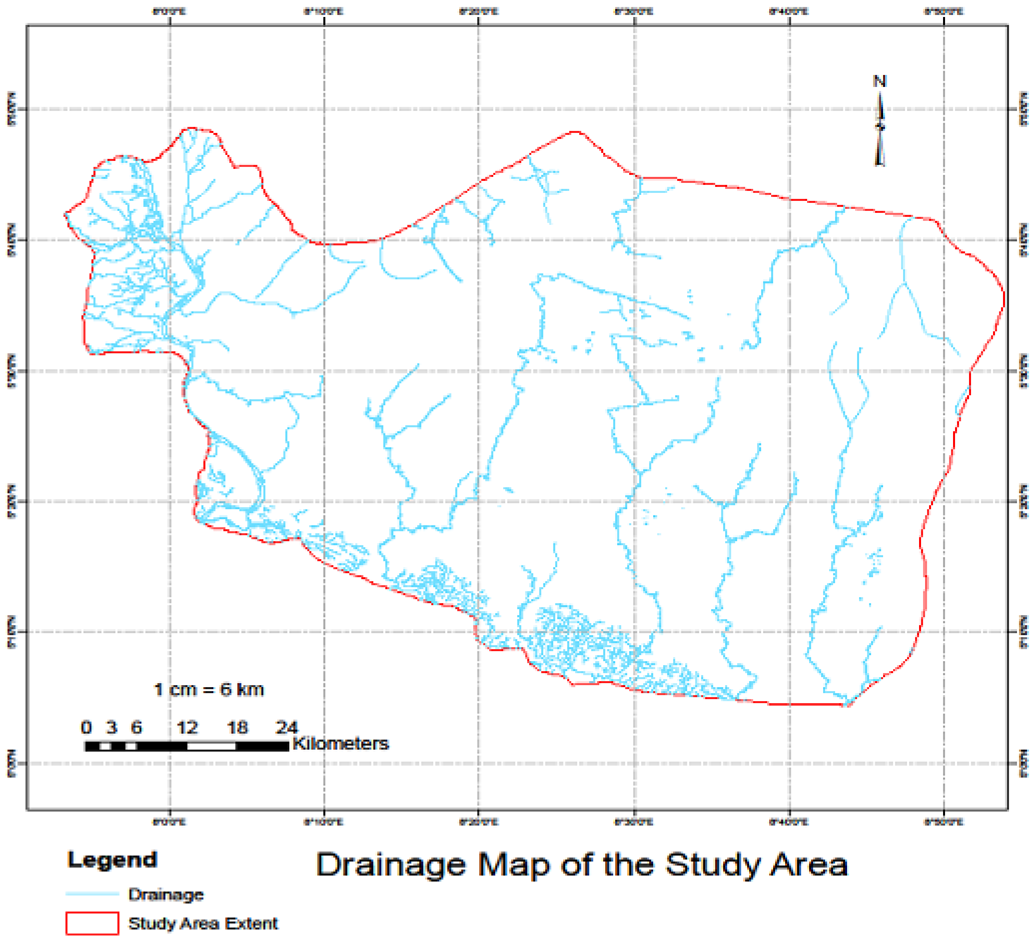

Figure 8. Drainage map of the study area

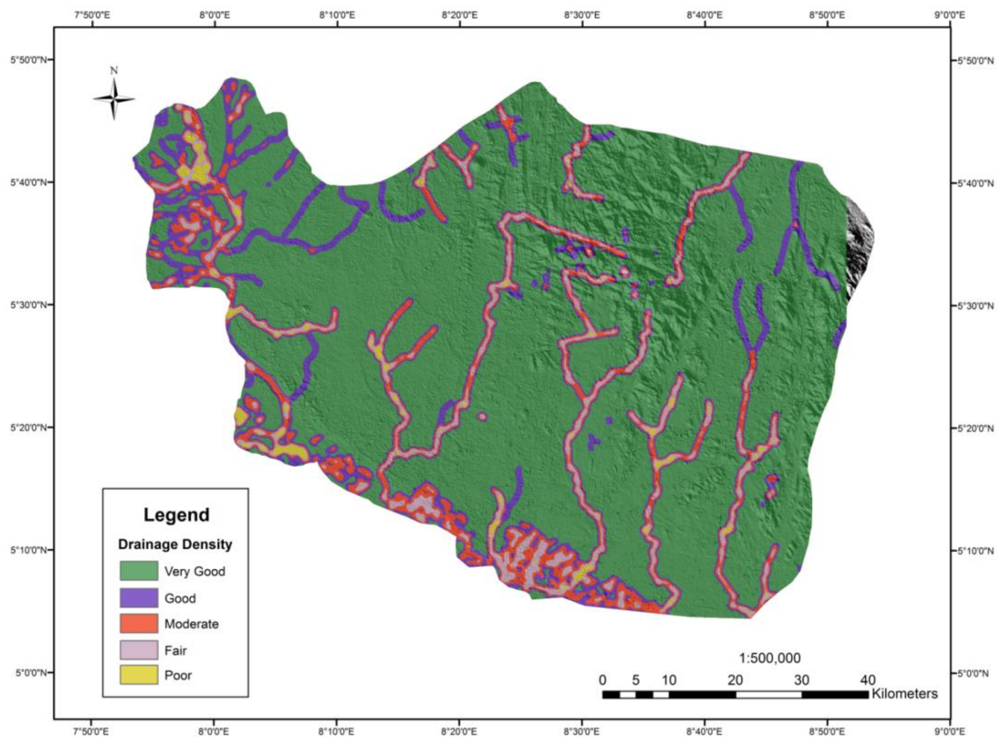

Figure 9. Stability range of drainage density map for groundwater accumulation in the study area

4.5 Lineaments

Lineaments in this study were modeled from satellite imagery (figure 10). Lineaments were extracted using lineaments extraction algorithm of PC1 Geomatica software. Lineaments were extracted by edge detection thresholding and lineaments extraction steps such as; filtering of the input landsat imagery using the Gaussian function. The lineament density map was computed using the script PL-DENS.

The lineament density map (Fig.11) in this study was classified into five classes based on their suitability for groundwater storage. Lineament ranges from 0.2-2.95 were described as scanty. Lineament density range from 6.25-9.55 is recognized as moderate and from 9.55-13.28 was described as high lineament density and where lineaments range of 13.28-22.13 is of high lineament. Reclassified lineament density map (Fig. 6) show that very high lineament density has very good potential for ground water accumulation, while the high and moderate lineament density zone represent good to moderately good groundwater storage potential. On the other hand, the sparse lineament density region is considered to be of fair to groundwater storage potential. The scanty lineament density is considered to be of poor groundwater capacity.

Groundwater potential in Precambrian crystalline igneous and metamorphic rocks is generally governed by the presence of fractures and the degree of their connectivity (Angyekum and Dapaah- Siakwan 2006). In hydrogeological applications structural trends such as discontinuities in form of faults, joints, bedding planes or foliation, drainage lines (lineaments) are very useful (Mogaji et al 2011). Research shows that lineament density intensity decreases with increasing distance away from the lineament (Shetty et al 2008). Lineament density studies enable s good understanding of flow systems, because faults and fracture zones act as path of high permeability and concentrated groundwater flow or acts as barrier to flow (Contes, et al 2008, Mejerink 2007).

Lineaments can be used to infer groundwater flow paths and storage as well as transmissivity, hydraulic conductivity and storage coefficient of geological formations (Teixeria et al 2008). This forms th basis of applying lineament density in this study for groundwater modeling. Automated lineaments extraction has advantage over manually digitized ones due to its ability to uniform approach to different imageries and its ability to extract lineaments not recognizable by the human eye (Hung et al 2005).

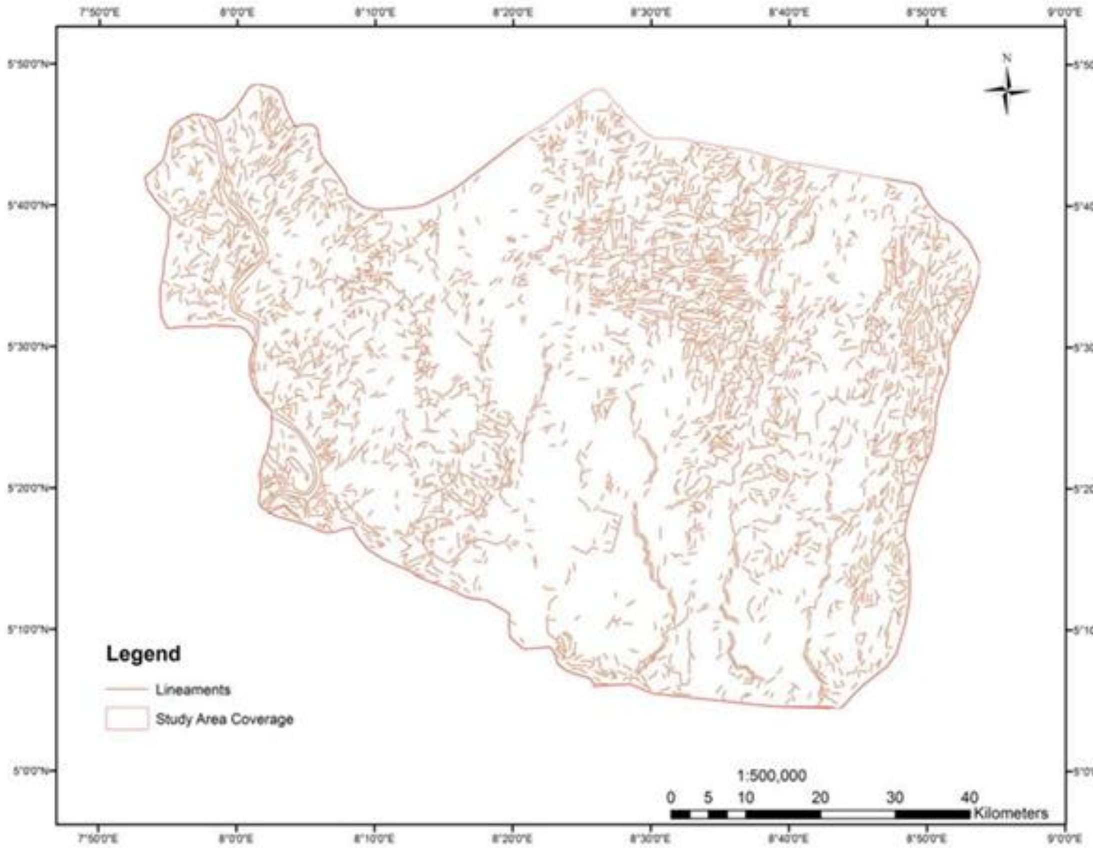

Figure 10. Lineament Map of the study area

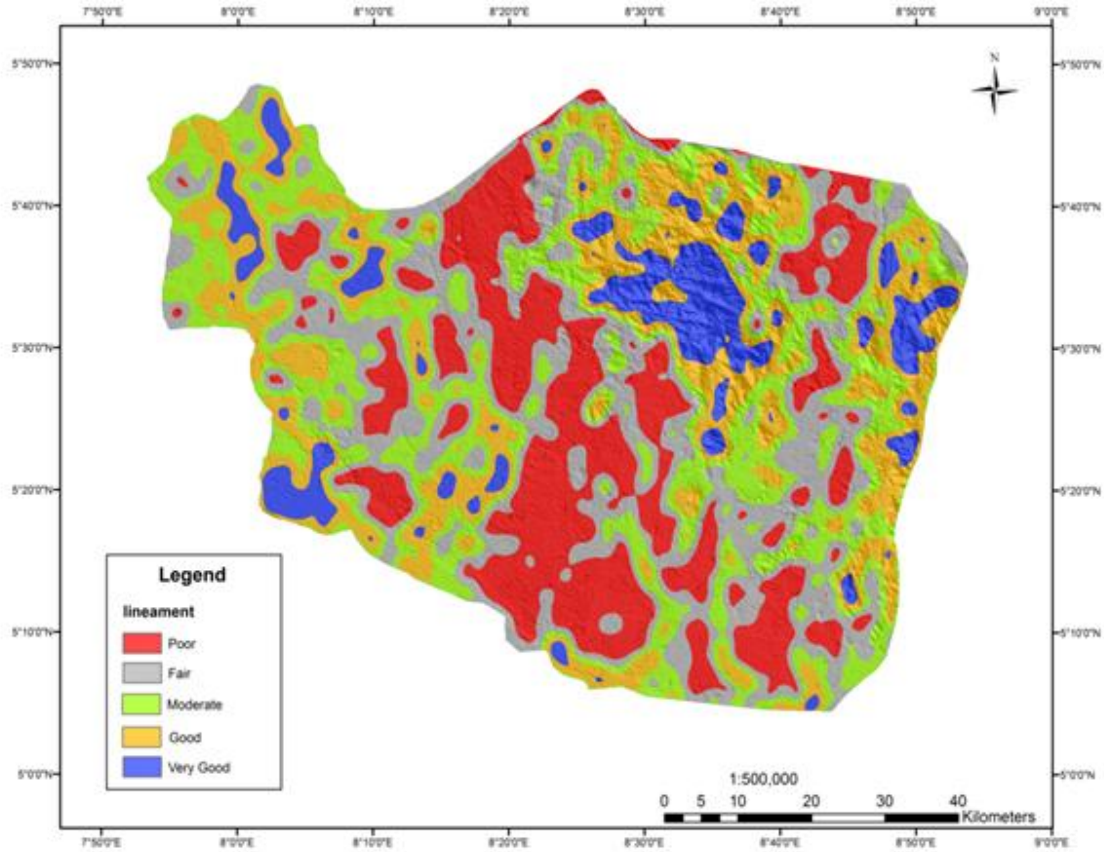

Figure 11. Stability range of lineament density map for groundwater accumulation

4.6 Geology

The geology of the area is mostly weathered granites banded amphibolites, pegmatite gniesses and the western flank is mostly granodiorite and of schistose rocks. In the sedimentary region we have consolidated sandstones and gravelly sands (Fig.12). Reclassified geological map (Fig. 13) shows that sandstones, silts and gravelly aquifer were classified as very good for groundwater storage while weathered pegmatites were ascribed to be of good aquiferous units. Banded amphibolites and schist were considered to be moderately good aquifers. Dolerites and diorites were assigned to fair in ground water storage, but unfractured granite gneiss and granodiorite were noted to be poor aquifers unless when imparted with secondary porosity. Pegmatites are commonly a locus of tectonic movement and can be prolific conduits for groundwater (Hazell, Cratchy and Jones 1992). Granitc rocks offer lowest yield boreholes owing to their impervious nature. The sedimentary region is mainly sandstones, silts, gravelly sands, clays and shales which are porous enough to be good aquifers. The lithology of the exposed rock is germane in controlling recharge. Some studies ignore this factor once drainage and lineament analysis are done. For example Edet et al (1998), Edet at al (1994), Edet (1990) and Mogaji et al (2011). This may be on the premise that lineament and drainage are indicators of primary and secondary porosity (El –Naqa et al (2009), but this does not suffice. Badmus and Olatinsu (2010) contended that borehole failure is mostly attributed to the type of geologic formation.

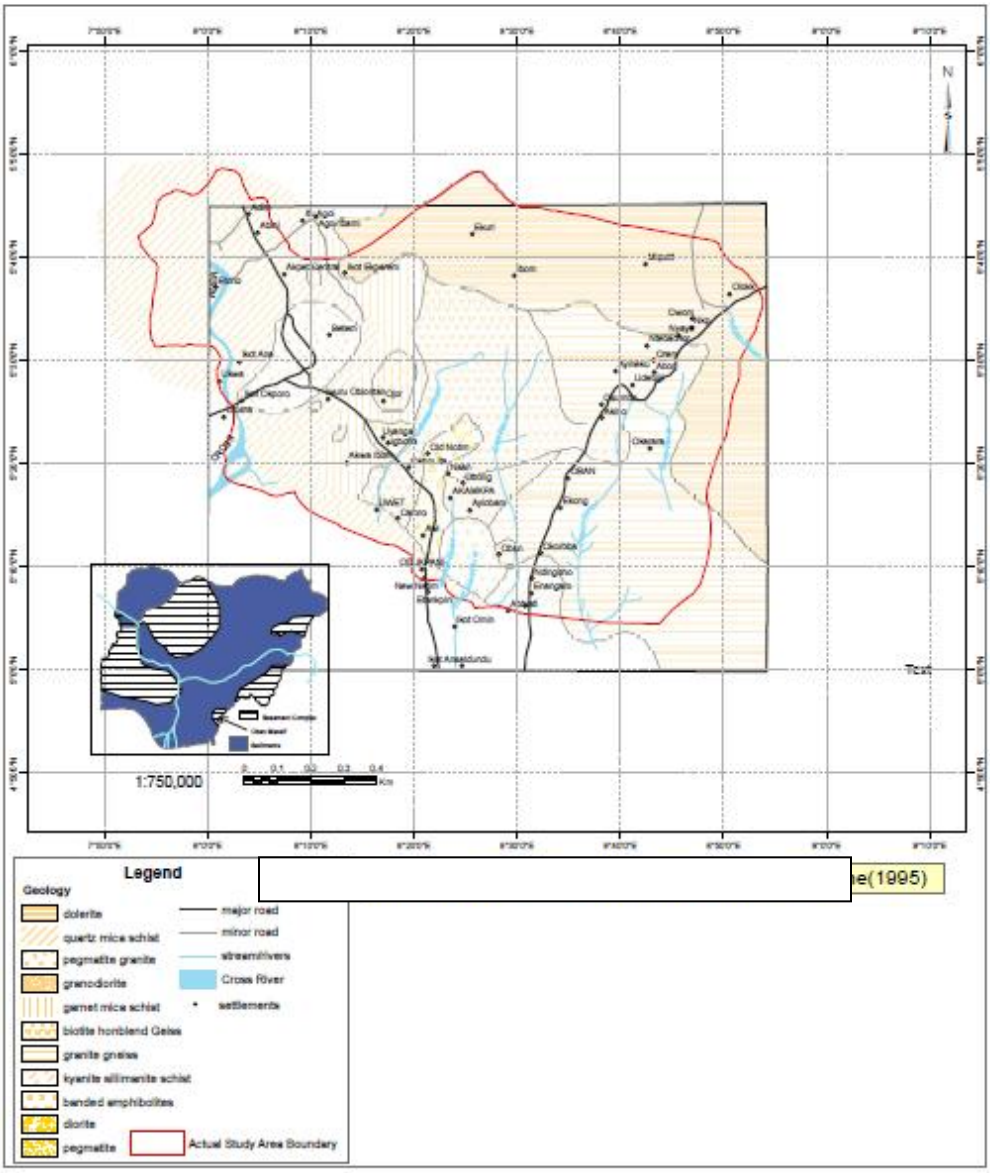

Figure 12. Geologic map of the study area

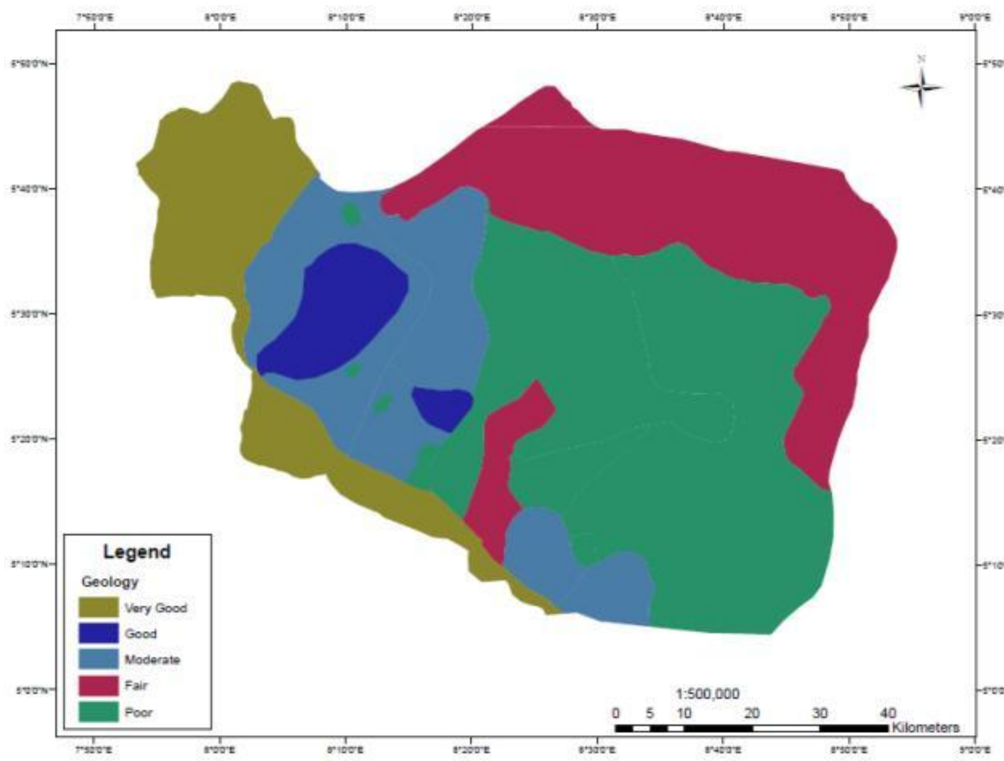

Figure 13. Stability range of reclassified geologic map for groundwater accumulation

4.7 Groundwater potential of the study area

The groundwater potential map (figure 14) was produce from the overlay of the six thematic maps of groundwater controlling factors: geology, geomorphology, lineament density, slope steepness, drainage density and land use /land cover. Results of the GIS modeling revealed that the study area is subdivided into four groundwater potential zones described as very good, moderately good, fair and poor. The zone reported as very good falls in the sedimentary areas. this is because sandstones are favourable groundwater zones (Weight, 2004). Lineament density were more concentrated in the very good groundwater potential zones which falls within the sedimentary zone. This is in symmetry with the findings of Anudu, et al (2011) in the basement and adjoining sedimentary areas in Nassarawa state. A comparison of figure 9 and 5 by overlaying the the lineament map over the groundwater potential map one can infer that the presence of lineaments alone does not imply that an area is a prospective water potential zone. It is easy to see that numerous lineaments occur in some groundwater poor prospect zones, rather geological and geomorphological parameters favor the zone to have good groundwater potential. This fact was also validated by Shetty, et al (2008).

From this modeling program it is obvious that the principal groundwater potential indicators in the study area are geology, slope and lineaments. This is in concord with similar investigations done elsewhere by MAB CONSULT (2000) in Moyale Subbasin Diere Arero in borenzia zone of Orombia regional state. Geomorphic units such as plains, pediplains and floodplains were indicated in the groundwater potential zones as very good, for groundwater targeting. This is in agreement with the groundwater prospecting conducted by Ganapuram et al (2009) and Sitender and Rajeshware (2011) in the Musi Basin and thurijapurin watershed jn Thiruvaransnone district respectively.

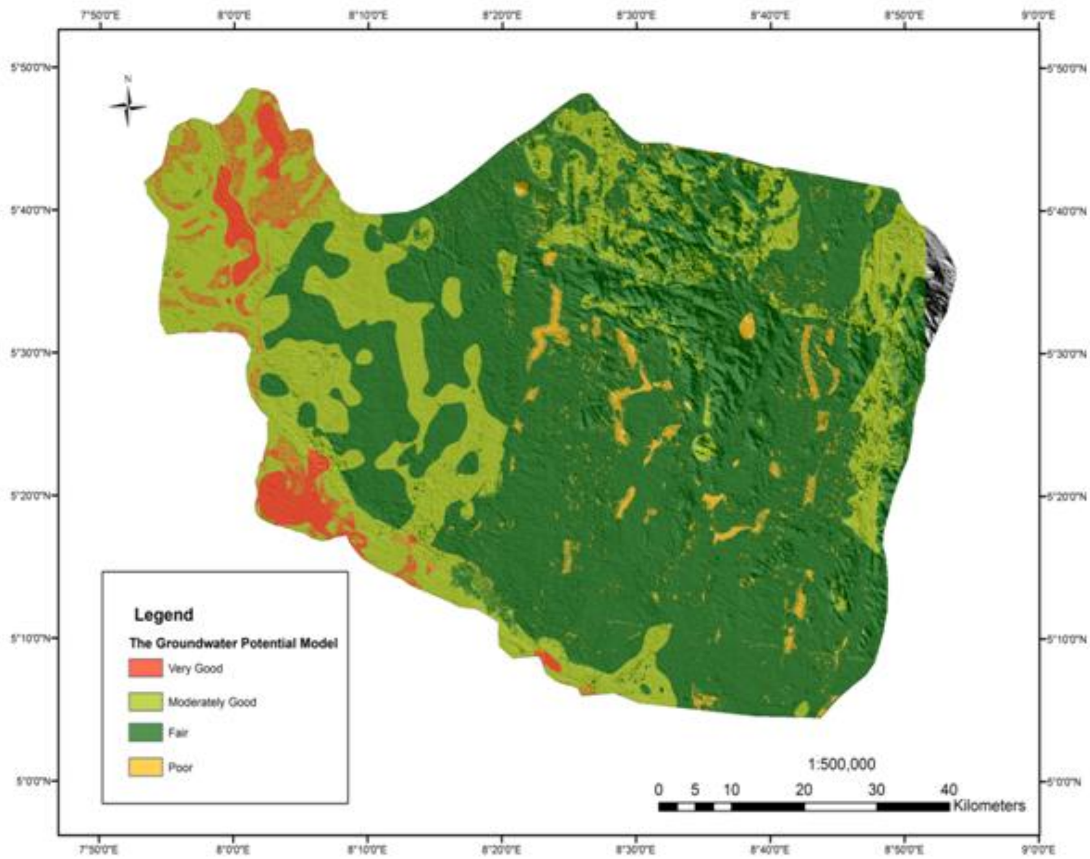

Figure 14. Groundwater potential map

V. Summary

The Oban Massif is in the Precambrian basement complex with a top lateritic overburden underlain by weathered granitic rocks which constitute the unconfined aquiferous units. Groundwater occurrence in the basement is controlled by the type of geologic formation, lineament density and slope steepness. Hydrogeomorphic units, drainage, land use and land cover are ancillary groundwater controlling factors. It can be summarized that the degree of groundwater controlled in the study area is of the order geology>lineaments>slope>geomorphic units>drainage>land use and land cover. The adjoining sedimentary terrain has a better groundwater recharge and prospect than the basement terrain. The most prolific hydrogeomorphological unit is the wetlands compared to channels, pediments and peaks in the study areas with gentle slopes, scanty drainage density, weathered fractured basement rocks or alluvium and gravelly sandstones, high lineament density and cultivated farmlands are favourable groundwater potential sites , high lineament density are possible recharge zones. The recharge zone is mostly from the eastern Oban Massif. The direction of groundwater flow is from the eastern Oban Massif to the western flank enroute the adjoining sedimentary sandstone aquifer.

Aquifer test parameters obtained from the field in drilled boreholes in the areas designated as very good and good water potential areas show better groundwater prospect. Aquifer parameters obtained from aquifer test in boreholes of the study area indicating better borehole performance clearly corresponded with the zones identified from modeling as good water prospective zones. Groundwater modeling in this study using geographic information system (GIS) identified typically four classes of groundwater prospective zones in the area, labeled as very good, moderately good, fair and poor groundwater prospective zones.

VI. Conclusion

Groundwater potential in the basement rocks of the Oban Massif and the adjoining sedimentary terrain is governed principally by geologic formation, lineament density, and slope steepness. Well yields in the basement can only be improved based on the impartation of secondary porosity. For a successful groundwater exploration, a thorough understanding of the geologic formation is condition precedent. Geospatial technique holds promise for groundwater exploration in basement rocks. A comprehensive study of groundwater control indicators of an area is crucial to meet success in groundwater exploration. Some high lineament density points may coincide with drainage lines, so lineament density is not an overriding groundwater control factor.

Geospatial technological application in the analysis of geological structure at a regional extent is cost effective. It can be used for planning and quick decision making on the exploration, exploitation, and management of groundwater in a particular geological terrain.

High lineament density zones are possible recharge zones. Areas delineated as good to very good groundwater potential zones should be used for follow up hydrogeologiacal exploration in the area. Where groundwater potential is reported to be poor, drilled and successful boreholes in good groundwater prospect zones should be reticulation the poor ground water potential neighbourhood. Also in poor groundwater potential zones, artificial recharge, rainwater harvesting and hydraulic fracturing should be carried out to surmount water scarcity problem and bring succor to the affected residents of such areas. artificial recharge methods such as drilling holes that can store water to facilitate infiltration to deeper layers can be used.

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