Remote Sensed-based Groundwater Potential Evaluation: A Case Study of Northern Part of Abia State, Nigeria

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Abstract

Groundwater potentials in the northern parts of Abia State comprising Bende, Ohafia and Arochukwu local government areas (LGA's), have been evaluated in terms of the terrain factors using Landsat 7 ETM+ Imagery integrated with Geographical Information System (GIS) and ancillary geologic and topographical data of the area. The objective of the study was to map groundwater potential zones and distributions for sustainable well development in the areas. The result of the analyses shows that the underlying geology and geomorphology played very major and significant roles than the drainage, lineament and land cover/land use in determining runoff, infiltration and recharge of precipitated water and hence, groundwater potential distribution in the areas. The shale dominated lowlands/valleys with low slopes, dense vegetation cover, high drainage and lineament frequency are characterized by poor hydro geological properties, significantly impairing infiltration and recharge and are poor groundwater potential zones. The sandstone dominated highlands characterized by large expanse of bare land areas, low drainage and lineament frequencies has excellent hydro geological properties and are therefore, highly sort groundwater potential zones. These apparent discrepancies and contradictions in the study are attributed to the effect of the underlying geologic formations. Poor and excellent groundwater potential zones are delineated in Bende (Ugwueke, Akanu, Elugwu and Umuhu, Ohafia (Nkporo and Okoi) and Arochukwu (Amangwu, Amelu-Abam and Ahuma) and Bende (Igbere, Alayi, Item), Ohafia (Abiriba and Ebem) and Arochukwu (Ututu) respectively. Therefore, productive boreholes could be cited in these excellent groundwater potential zones in the LGA's for sustainable water development in other to meet the water needs of the inhabitants.

Keywords: GIS, Landsat 7 ETM+, Groundwater Potential, Groundwater Recharge, Water Runoffs

1. Introduction

Although water is a natural resource available in most parts of the globe, it is however, distributed in uneven manner. While some places enjoy its relative abundance, others suffer from its scarcity, which is attributed mostly to climatic, geologic, geomorphic and anthropogenic factors. Potable drinking water is the basic need for any society to lead a healthy and productive life and for industries and agricultural activities to flourish (Ehirim and Ebeniro, 2010). However, industrial and technological adventures, agricultural activities and population growths have overstretched water requirements both in quantity and quality globally, with the implication that both surface and groundwater sources can no longer sustain man and his activities in relation to the environment.

Surface and groundwater are the major sources of water supply for consumption, industrial and agricultural activities. However, changes in climate due to global warming, deforestation, desertification and associated terrain factors have inadvertently affected surface precipitations. This unarguably, poses serious threat to availability, distribution and quality of surface supplies. The limited availability, uneven distribution and quality issues associated with surface water supplies, has made groundwater the most reliable and sustainable source of potable water supply in most parts of the globe.

Groundwater draws its source from surface flows and precipitations. It’s the water that saturates the pore spaces of rocks beneath the water table in the earth called aquifer. An aquifer is underground water saturated stratum that can yield usable amount of water to a well (Igboekwe and Akpan, 2011). Groundwater aquifer comprises porous and permeable rocks mostly sandstone and carbonate rocks that can store and readily transmit substantial volumes of water to wells. These are the huge storehouses of groundwater which varies in depth, thickness and yield.

The potential for groundwater depends on competing terrain factors such as drainage, geology, slope, geomorphology, lineament, vegetation and land cover/land use which varies spatially over the surface of the earth. These terrain parameters govern recharge/runoff potentials of surface and precipitated water and therefore, determine the quantity, quality and distribution of groundwater in any ecological setting globally.

The present study is located in the northern part of Abia State, Nigeria, delineated by latitudes 5° 28' N and 5° 56' N and longitudes 7° 38' E and 7° 69' E, respectively (Figure 1). The study area is comprised of Bende, Ohafia and Arochukwu Local Government Areas (LGA’s). These areas lie in the rain forest vegetation zone characterized by high annual rainfall that ranges from about 2000 mm to 2400 mm and high relative humidity (John et al., 2015).

Figure 1: Location Map of the Study Area

The prevalence of water scarcity due to geologic, topographic and structural complexities has been identified as a major problem. This has limited developmental, industrial and agricultural activities in the areas. Therefore, the evaluation of these terrain factors for possible indications groundwater potential zones in a speedy, accurate, cost-effective and efficient way using modern assessment tools cannot be overemphasized. This will ensure that groundwater is confidently and adequately mapped, wells drilled and produced to meet the water needs of the population.

One of such assessment tools is remote sensing, which is based on the interactions of the incident radiant energy with the earth's surface (Hsin-Fu et al., 2016; Tahir et al., 2015; Kumar et al., 2007 and Raju et al., 2017). Depending on the surface texture of the terrain factors, incident radiant energy may be reflected, transmitted or absorbed resulting to changes in direction, magnitude, wavelength and phase. These changes are detected by remote sensors, processed and interpreted to obtain information regarding the groundwater potential zones and distributions of the area (Chowdhury et al., 2010; Rashid et al., 2011 and Ibrahim and Ahmed, 2016).

This study therefore, focuses on the evaluation of these terrain factors from satellite imagery integrated with Geographical Information System (GIS), to map and ascertain distribution of groundwater potential zones in the study areas.

2. Method of Study

Two sets of data were used for this study. These are the Satellite imagery (Landsat 7 ETM+) and ancillary data (topographic and geologic maps) from the study area. Landsat 7 EMT+ imagery of 30m resolution was acquired from Remote Sense Center (RSC), Jos, Nigeria. The remote sense data was radiometrically and geometrically corrected prior to further processing.

Edge enhancement, stretching, high pass filter and directional filtering were applied to data using ERDAS IMAGINE software in order to enhance image quality and resolution. Furthermore, Maximum likelihood classification scheme (MLCS) was employed and the resulting imagery was then exported to ArcGIS software where it was integrated with the Shuttle Radar Topographic Mission (SRTM) data and ancillary data to generate thematic maps of groundwater terrain factors such as lineament, slope, elevation, geomorphology, drainage, geologic and land cover/landuse maps of the study areas. These maps were subsequently analyzed visually for groundwater potential zones and distributions in the areas.

3. Results Presentation

Thematic maps of remote sense-based groundwater terrain factors are presented. These include the geology, slope, elevation and drainage. Others are geomorphology, lineament and land cover/landuse maps. These maps are characterized by distinct patterns and color gradations that reflects the impact of each factor on groundwater. The individual maps were visually inspected and evaluated for groundwater potential zones and distributions in the areas.

The geologic map show that the study area lies in two major sedimentary basins, namely the Abakilike and Anambra basins, comprising principally of early to late Cretaceous sediments of southeastern Nigeria. Ohafia and Bende each lie partly in Abakilike and Anambra basins, while

Arochukwu lie in Anambra basin only. There are basically eight litho-stratigraphic units observed, ranging from Eze - Aku to Bende -Ameki Formations (Figure 2).

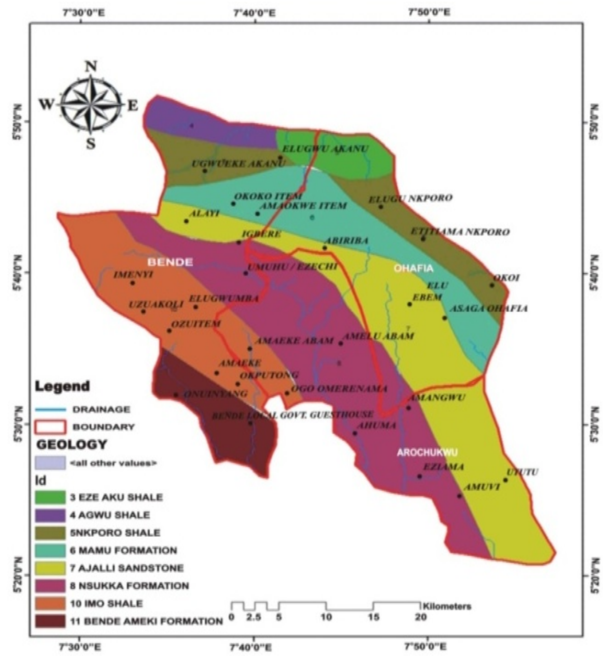

Figure 2: Geologic Map of the Study

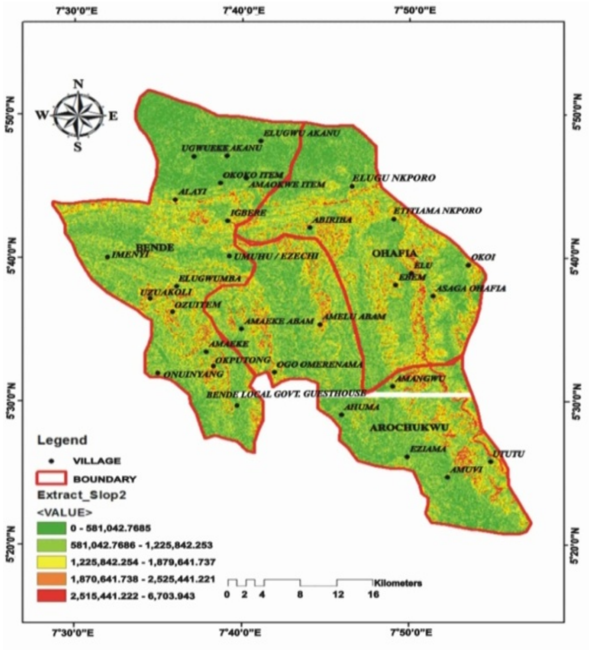

Figure 3: Slope Map of the Study Area

The slope or steepness map trends generally southward and is defined by low and high slopes (Figure 3). Low slope was delineated at the northernmost parts of Bende (Akanu and Ugwueke), Akanu in Ohafia and Amuvi in the southeast of Arochukwu. High slope areas were delineated in Bende (Alayi, Ameke and Elugwumba), Ohafia (Elu, Abiriba, Nkporo and Ebem) and Arochukwu (Ututu, Amangwu, Ameke). Areas of low slope suggest relatively flat lying terrain and steep terrain for high slopes. Low slope areas are characterized by low runoffs, high infiltration and high groundwater recharge while high runoffs, low infiltration and low groundwater recharge characterize high slope areas (Surayabhagavan, 2017).

The elevation map is characterized by a ridge-like structure of high elevation that stretches from Ututu in Arochukwu through Ohafia to Bende (Alayi and Item) in the west and bounded by areas of low elevation on either side of the ridge structure (Figure 4). Low elevation was delineated in Bende (Ugwueke and its environs), Ohafia (Akanu) and southwest of Arochukwu (Ahuma, Eziama and Amuvi). Elevated areas were delineated in Bende (Alayi and Item), Ohafia (Elu, Abiriba and Ebem) and Arochukwu (Ututu). Low elevation (lowlands/valleys) constitute areas of probable low runoffs, high infiltration and groundwater recharge while elevated areas are characterized by high runoffs, poor infiltration and consequently poor groundwater recharge (Deepa et al., 2016); Raju et al., 2017).

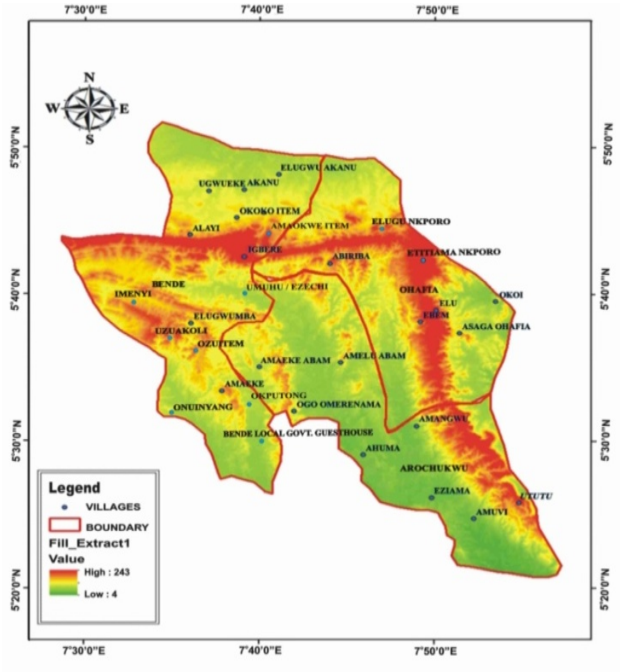

Figure 4: Elevation Map of the Study Area

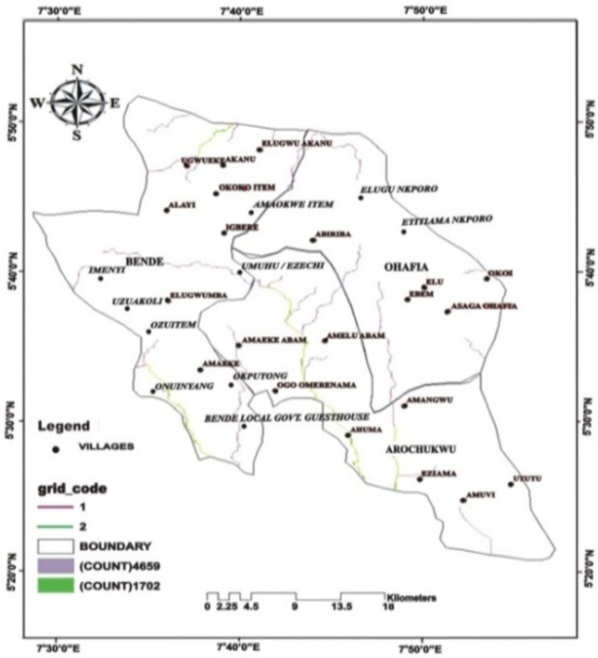

Figure 5: Drainage map of the Study Area

The drainage map shows that the study area is moderately drained. Arochukwu LGA is the most drained, Ohafia is intermediate while Bende is the least drained. The drainage is characterized by parallel and dendritic patterns, sourced from the flanks of the ridge and flows predominantly southward in the study area (Figure 6). The dendritic flows are dominant and fairly distributed centrally in the area, while parallel patterns are localized to the southeast of the study area. Dendritic drainage patterns reflect litho-facies, permeability and porosity variations in the path of flow, while parallel patterns are indications of structural controls by faulting and tectonics (Rajesh et al., 2007; Shaban et al., 2006).

The geomorphology of the study area is characterized by two distinct features; a ridge stretching from the west to the southeast and adjoining lowlands and valleys on either side of the ridge (Figure 5). The ridge stretches from Bende (Alayi and Item) in the west, to the east of Ohafia through Elu, Abiriba and Ebem and Ututu in Arochukwu to southeast. These areas are elevated with steep gradient and therefore, expected to exhibit high runoffs, poor infiltration and groundwater recharge. Bende (Ugwueke and its environs), Ohafia (Okoi) and Arochukwu (Ahuma, Eziama and Amuvi) lie in lowlands and valleys with low steep gradient. They exhibit low runoffs; high infiltration and high groundwater recharge (Shivaji and Nitim, 2014).

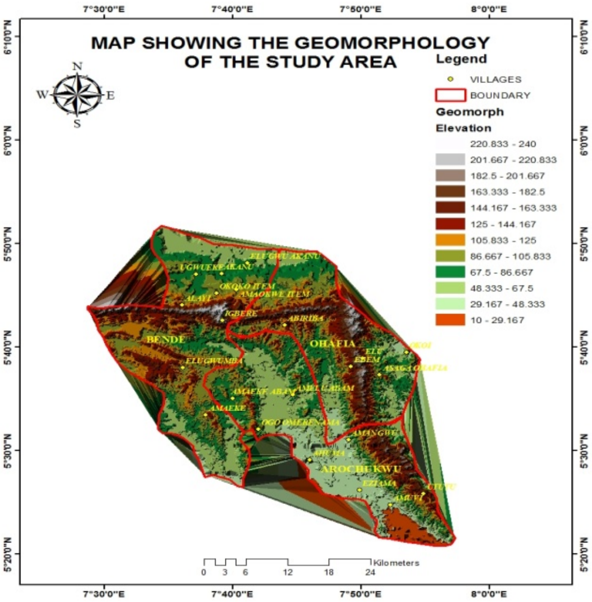

Figure 6: Geomorphology Map of the Study Area

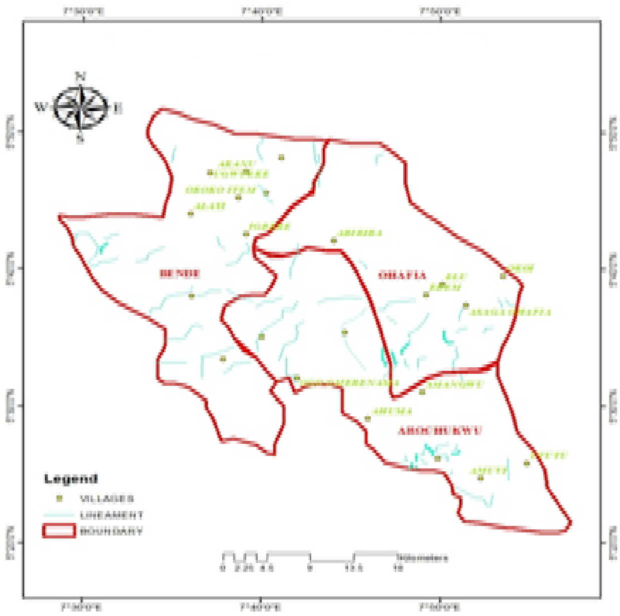

Figure 7: Lineament Map of the Study Area

Lineament map of the study area is characterized by both short and long linears (faults/fractures) trending NE-SW, NW-SE, E-W, and N-S. The NE-SW linears are predominant and longer, while the NW-SE, E-W, and N-S are localized and shorter (Figure 7). Linears act as conduit for groundwater infiltration and recharge and are mostly concentrated in the central part of the study area, especially in Bende (Ameke and Elugwumba), Ohafia (Asaga) and Arochukwu (Eziama, Ameke-Abam, and Amelu-Abam). The low land areas or valleys exhibit high lineament densities than the ridge side. This suggests high infiltration and recharge in the low land areas than the ridge side (Mulwa, 2005: Raju et al., 2017).

The land use/land cover map of the study area is classified into vegetated and developed/bare lands (Figure 8). Ohafia is more developed and less vegetated, Arochukwu is less developed but more vegetated, whereas Bende is moderately developed and vegetated with large expanse of bare land areas. Among the developed areas are Abiriba, Ebem and its environs) in Ohafia, Uzuakoli, Ugwueke, Alayi, Igbere, and Item in Bende and Ututu, Amangwu and Amuvi in the southern part of Arochukwu. The developed and less vegetated areas are expected to have more runoffs and less infiltration and recharge than the less developed and more vegetated land areas (Olutoyin et al., 2014).

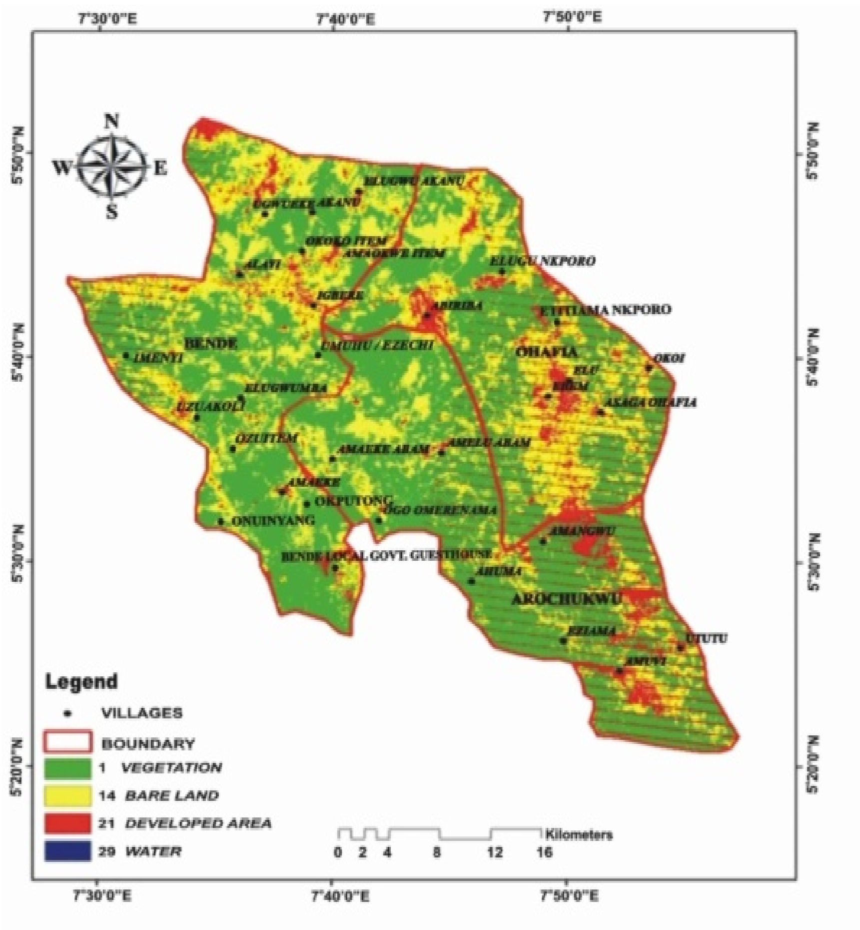

Figure 8: LCLU Map of the Study Area

4. Discussion of Results

Geology, slope, elevation, geomorphology, drainage, lineament and land cover/land use, are critical terrain factors that govern recharge, occurrence and distribution of groundwater in any hydro geologic setting. Thematic maps of these potential groundwater indicators were generated from remote sensing data integrated with GIS and visually evaluated. Each map varies spatially and show distinct patterns characterized by color gradations that reflects heterogeneity in sediment formations, topography and complexity in structures that affects runoffs and infiltration potentials and hence, recharge, storage and potential distribution of groundwater in Bende, Ohafia and Arochukwu Local Government Areas of the study.

Analyses of results reveal that among the investigated terrain factors, the underlying geology plays a major and significant role in determining runoffs and infiltration hence, recharge and groundwater potentials in the area. The study areas lie in two sedimentary basins, namely Abakilike and Anambra basins, underlain by early to late Cretaceous sediments ranging from Eze-Aku to Bende-Ameki Formations (Reyment, 1965; Hoque and Ezepue, 1977). These are predominantly shale formations with the exception of the Ajali sandstone Formation in the Anambra Basin. The Ajali sandstone Formation is wide spread in Ohafia and Arochukwu and thins out towards Bende area.

Shale formations are distinctly characterized by poor hydro geologic properties (especially, porosity and permeability), that affects runoffs and infiltration of surface precipitated water. Such precipitations end up mostly as runoffs resulting in poor infiltration and groundwater recharge. This is in contrast to the permeable and porous Ajali sandstone Formation where precipitations go into underground flows enhancing groundwater recharge. Consequently, the shale dominated parts in Bende (Ugwueke, Akanu, Elugwu and Umuhu), Ohafia (Nkporo and Okoi) and Arochukwu (Amangwu, Amelu-Abam and Ahuma) are regarded as poor groundwater potential zones. High groundwater potential zones occur in Bende (Igbere, Alayi, Item), Ohafia (Abiriba and Ebem) and Arochukwu (Ututu) areas underlain by the Ajali sandstone Formation.

The slope, elevation and geomorphology maps show that the study areas are characterized mostly by highland dominated sandstones with adjoining shale dominated lowlands and valleys. Ohafia is the most elevated, Bende is intermediate while Arochukwu lie mostly in low lands/valleys. The highlands and lowlands/valleys are associated with steep and low slopes, respectively. The highlands stretch from Bende (Alayi and Igbere) in the Northwest through Ohafia (Abiriba, Elu and Ebem) and Arochukwu (Ututu) to the Southeast. This is flanked by lowlands in Bende (Ugwueke, Elugwu and Akanu), Ohafia (Okoi and Akanu) and Arochukwu (Eziama, Ahuma, Amuvi and Abam). These features were formed by uplifting and folding of sediments during the separation of the African plate from the South American plate in the Albian and early Cretaceous. Subsequent tectonics and deformation of the basins in the Santonian led to the present landforms (Reyment, 1965).

Steep slopes in Bende (Elugwumba, Ameke, Igbere), Ohafia (Abiriba, Elu) and Arochukwu (Ututu), enhances runoffs due to low residence time of surface precipitations to infiltrate into the ground. This results in channeled flow in the shale dominated lowlands/valleys in Bende (Ugwueke and its environs), Ohafia (Okoi) and Amuvi, Ahuma and Eziama in Arochukwu and causing gully erosion with characteristic poor infiltration and recharge. These lowland/valley areas are therefore, poor groundwater potential zones. This result agrees with the observations of Deepa et al. (2016) and Raju et al. (2017), which reported that steep slopes are poor groundwater potential zones, but contrast their observations that low slope areas are generally good groundwater potential zones.

The highland areas in Bende (Alayi and Item), Ohafia (Abiriba, Ebem, Elu) and Arochukwu (Ututu) are dominated by the sandstones of the Ajali Formation that are more resistant to denudation than shale on the adjoining lowlands/valleys. The highland dominated sandstones are characterized by relatively flat surfaces which reduce runoffs and enhance infiltration and recharge of precipitated water into the underlying formation. These are areas of good groundwater potential zones. However, these results contrast the observations of Deepa et al. (2016); Obimba et al. (2017) and Raju et al. (2017), which reported that highlands and steep slopes are poor groundwater potential zones while lowland and less steep slope areas are good groundwater potential zones. These resulting conflicts are attributed solely to the underlying geology of the study area.

The drainages source their waters from the steep slopes of sandstone dominated highlands in Bende (Item), Ohafia (Abiriba) and Arochukwu areas in the west, central and northeast, respectively and flows southward into the shale dominated low lands and valleys in dendritic and parallel patterns reflecting lithological and structural controls (Shaban et al., 2006; Krishnamurthy et al., 2000). Arochukwu is the most drained, Bende intermediate while Ohafia is the least. Result shows that the shale dominated lowlands/valleys are well drained than the sandstone highlands. Drainage frequency is a reflection of the impervious nature of the underlying formations (Obimba et al., 2017). High drainage frequency is associated with the shale dominated lowlands and valleys and low frequency to the sandstone dominated highlands. As such, shale dominated lowlands and valleys exhibit more drainage frequency than sandstone dominated highlands and therefore, tend to have less groundwater potentials than low drainage frequency sandstone dominated highlands (Adeniyi and Anifowose, 2017).

The lineaments (faults and fractures) are mostly concentrated in the shale dominated lowlands and valleys than the sandstone highlands. They are more concentrated at the western part of Bende, the central part of Arochukwu and Asaga area in Ohafia. The lineaments trend mostly in the NE-SW in line with the tectonic trends of the basins. However, NW-SE, E-W, and N-S trends were also observed. Lineaments serve as conduits for movement and storage of groundwater and are related to surface drainage (Selvam et al., 2014). Comparison of the drainage and lineament maps of the areas show that the drainage does not conform to structure since there is no apparent drainage that could be matched with the lineaments. This observation suggests that these lineaments are not connected to surface drainages or subsurface flows and therefore, are considered as localized weak zones through which surface precipitations are channeled down slope to the lowlands and valleys than surface infiltration zones for groundwater recharge.

Finally, land cover/land use pattern is characterized by vegetated, developed and bare land areas. Ohafia (Abiriba, Ebem and its environs) and Bende (Alayi, Igbere, Item and Ugwueke) lie in bare and less vegetated land areas while Arochukwu is more vegetated and has minimum bare land areas. The bare lands are mostly concentrated in the high lands than the more vegetated lowlands or valleys. The bare lands are reflections of infrastructural developments, industrial and agricultural activities. This suggests that Bende and Ohafia are more developed than Arochukwu. Bare lands degrade soil structure, enhance runoffs and reduce infiltration and groundwater recharge and therefore poor groundwater potential zones, while vegetation cover does the opposite (Thompson et al., 2010). Again, this observation contrasts the result of this study due to the complex hydrogeologic characteristics of the underlying formations. The underlying sandstone formations in the bare land areas reduces runoffs, but enhances infiltration and recharge and therefore, are good groundwater potential zones in contrast to the mostly vegetated low lands and valleys underlain by the impervious shale formations.

5. Conclusions

Groundwater potentials in Bende, Ohafia and Arochukwu LGA's have been evaluated in terms of the terrain factors. The result of the analyses shows that the underlying geology and geomorphology played very major and significant roles than the other terrain factors in determining runoff, infiltration and recharge of precipitated water and hence, groundwater potential distribution in the areas.

The shale dominated areas were observed to lie in the lowlands/valleys with low slopes, dense vegetation, high drainage and lineament frequency. These lowlands/valleys areas are characterized by poor groundwater potentials due to poor hydro geological properties of the formations which significantly affect infiltration and recharge. The highlands are dominated by Ajali sandstones with steep slopes, bare lands, low drainage and lineament frequency and are characterized by good and excellent hydrological properties. These apparent discrepancies and contradictions in the study are attributed to the effect of the underlying geologic formations.

Therefore, shale dominated lowlands and valleys with low slopes in Bende (Ugwueke, Akanu, Elugwu and Umuhu, Ohafia (Nkporo and Okoi) and Arochukwu (Amangwu, Amelu-Abam and Ahuma) are characterized by poor groundwater potentials while the highland dominated sandstone areas flanked by steep slopes in Bende (Igbere, Alayi, Item), Ohafia (Abiriba and Ebem) and Arochukwu (Ututu) areas underlain by the Ajali sandstone are high groundwater potential zones. Furthermore, the lineaments could not be associated with any surface drainage in the study and therefore, considered as localized weak zones through which surface precipitations are channeled down slope to the lowlands and valleys than surface infiltration zones for groundwater recharge and therefore, the reason for the poor groundwater potentials in these areas.

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