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APPLICATIONS OF GIS IN THE BIDA BASIN HYDROCARBON EXPLORATION NIGER STATE, NIGERIA.

[1]JIYA, S.N, [2]OBAJE, N.G AND [2]AWEDA, K.A

[1]Department of Geography Ibrahim Badamasi Babangida University, Lapai, Niger State. [2]Department of Geology and Mining, Ibrahim Badamasi Babangida University, Lapai, Niger State.

ABSTRACT

A previous study on the hydrocarbon prospectivity evaluation of the Bida Basin by a team of geologists at the Ibrahim Badamasi Babangida University Lapai, funded by the Niger State Government was able to delineate some prospective areas in the basin. The most prospective areas defined in that study are the Pattishabakolo, Kandi, and the Ahoko-Agbaja prospective areas. The study achieved its objectives based on preliminary geological prospectivity mapping, aeromagnetic geophysical and organic geochemical assessments. The study however did not give specific

Introduction

The Bida Basin has a similar cross-sectional geometry with the Benue Trough in addition to having an irregular floor (Nwajide, 2013). Petters (1995) regarded the basin as an arm of the Benue Trough with lithic fills that resemble short-lived Santonian delta, with average depth to basement of 3.39km and sediment thickness decreasing outward from the basin center (Udensi and Osazuwa, 2004). Wright *et al.*, (1985) viewed the Bida Basin as lying on a southeasterly projection of the Gao Trench, and also constitutes a northward extension of the Anambra Basin, since the sediments are unfolded, mainly non marine and are confined to the Campanian-Maastrichtian age range.

Geophysical methods have been used for groundwater exploration and aquifer delineation and are increasingly becoming more relevant in a wide variety of hydrological and hydrogeological investigations. Geophysical methods are generally non-invasive or minimally invasive, fast, and cost effective, and provide information on the spatial distribution of the physical properties of subsurface features. Thus, the spatial distribution and temporal variability of the subsurface hydrological state can be inferred from the resulting geophysical models. Also, estimates of the hydrological and petro-physical parameters that influence flow and transport processes within the subsurface porous media can be made.

The study area, Kutigi – Enagi region (Figure 1), has recently witnessed increased pressure on groundwater from boreholes and wells as a result of ongoing oil exploration in the Bida Basin

GPS-defined locations for the drilling of the wild-cats, neither did the study relate its finding to environmental and social impacts that may arise as a results of future exploration, drilling and production activities on the settlement patterns, population, vegetation and farmlands. This project uses different applications of Geographic Information System (GIS) to consolidate the earlier study to define specific drilling locations and to relate these locations to the settlement patterns, population, vegetation, biodiversity and farmlands in the locations and surroundings.

Keywords: *Geographic Information System (GIS), Hydrocarbon Prospectivity, Bida Basin Exploration, Drilling Locations, Settlement Patterns.*

and in addition to increase in human population. The area is known to have marginal groundwater potential with boreholes drilled having low to moderate yields and are unable to provide the required water needs of the growing demand resulting to huge economic lost in the part of government and other stake holders. Thus, making provision of clean and sustainable water provision to meet domestic supply is difficult to come by. Siting of water wells within the area has been done mainly based on recommendations from vertical electrical sounding (VES). The exercise has resulted in random success, with average borehole success rate of about fifty percent (50%). Idris-Nda *et al* (2014) has classified this area as being hydro geologically complex with low groundwater yield to boreholes. This is likely to result from rapid lateral facies change in sedimentary basins. Such facies change can best be captured by integrating detailed local geology with multi-geophysical data. Such efforts have been conspicuously lacking in the study area where boreholes have been located at best on the basis of isolated VES data. Sandstone, siltstone, clay and shales have been reported from outcrop sections and borehole cuttings within the area. This varied lithology is an indication of rapid lateral facies changes upon which borehole failure may occur. This research unravelled the aquifers in the area, their thicknesses and depth by integrating local geology and multi-geophysical approach and delineate high yield prospective areas for groundwater exploration to meet the growing demand.

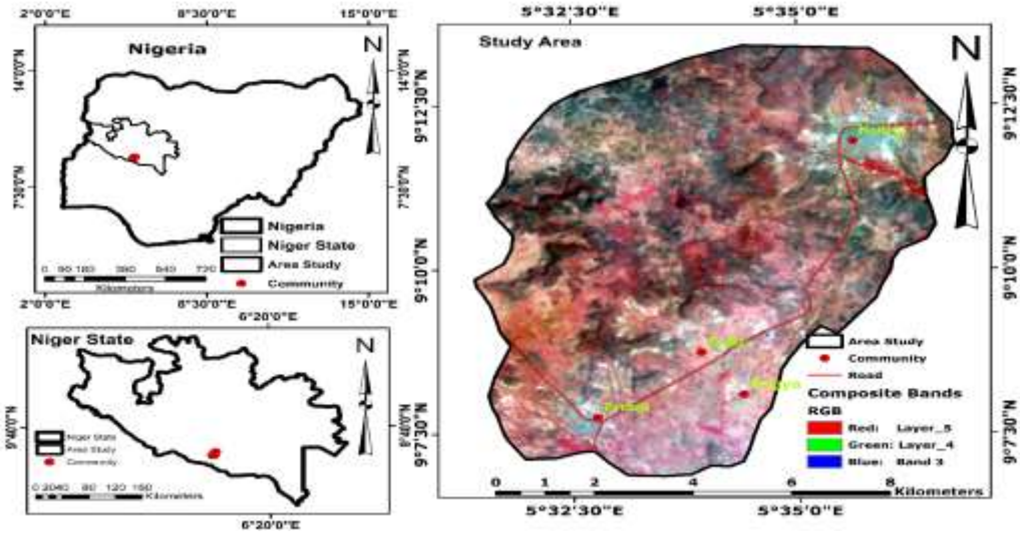

Figure 1. Location of the Study Area

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Stratigraphy of the Bida Basin

The basin (Figure 3) is divided into two sectors; the Northern Bida Basin (Sub-Basin) and the Southern Bida Basin or Lokoja Sub-Basin (Table 1).

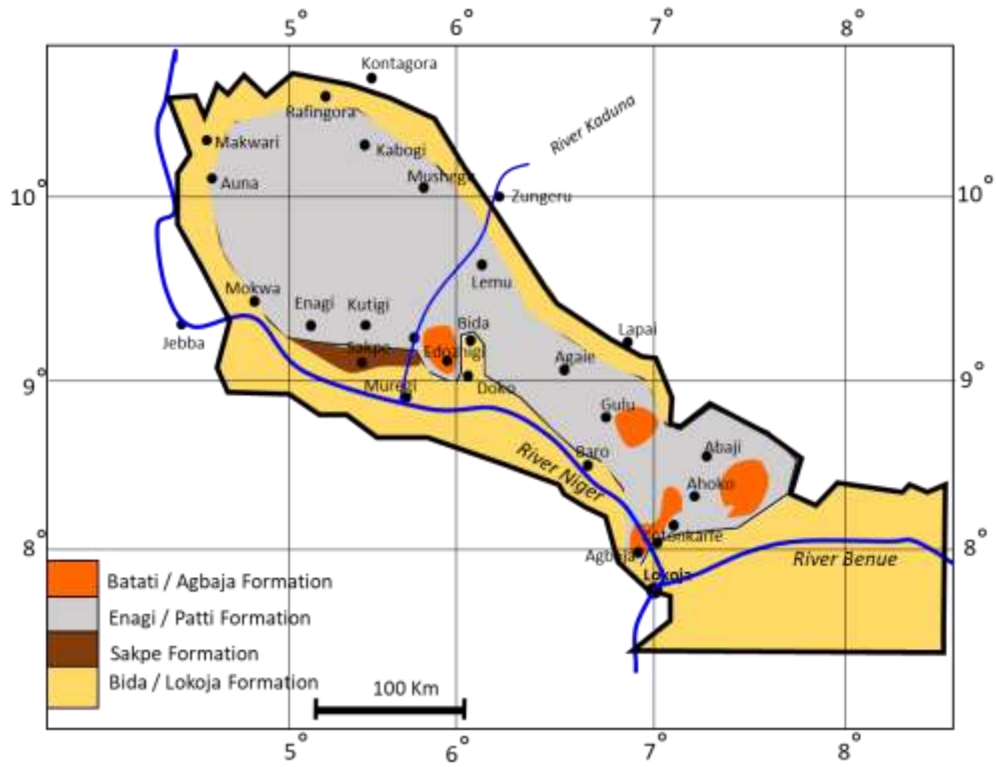

Figure 2. Map of the Bida Basin (Modified after Obaje et al., 2013)

Table 1. Stratigraphic Succession of the Bida Basin (Modified after Obaje, 2009; Nwajide, 2013)

Age	Southern Bida Basin (Lokoja Area)	Northern Bida Basin (Bida Area)
Maastrichtian	Agbaja Formation	Batati Formation (Upper Ironstone) Edozhigi Member Kutigi Member
	Patti Formation	Enagi Formation (70m)
Campanian		Sakpe Formation (Lower Ironstone) Wuya Member Baro Member
	Lokoja Formation (100 – 300 m) Basal Sandstone	Bida Formation (80m) Jima Member Doko Member
	Base of Lithic Fill (Unexposed)	
Precambrian	Crystalline Basement Complex	

Four stratigraphic units are recognized in the Northern Bida Basin. These formations, from the oldest to the youngest are; the Bida Sandstone Formation, the Sakpe Ironstone Formation, the Enagi Siltstone Formation and the Batati Ironstone Formation with stratigraphic units that correlates with those in the Southern Bida Basin.

1. **The Bida Sandstone Formation**

   Bida Sandstone lies unconformably on the crystalline Basement Complex and consist of a basal conglomerate with a succession of cross-bedded, white to grey sandstones intercalated by kaolinitic clays believed to have been derived from nearby deeply weathered basement rocks (Rahaman *et al.,* 2019; Obaje, 2009) with evidence of mud and debris flow in the conglomerate. The basal beds of the formation are massive and flat while the upper part shows clear cross-stratification. Whiteman (1982) estimated the total thickness of the formation to be over 3000m, although it is uncertain whether the whole thickness belongs to only the Bida Sandstone (Nwajide, 2013). The deposits making up the Bida Sandstone are cyclic in nature and similar to those seen in the contiguous Lokoja Sandstone. The age of the Bida Formation is uncertain but is speculated to be Campanian – Maastrichtian (Nwajide, 2013). Adeleye (1972) recognized the Doko and Jima Members as the two members of the Bida Sandstone both of which are mappable on the Jima ridge. There is a general, but irregular, decrease in grain size of the respective facies, up the vertical profiles. The irregularity results from the cyclic arrangement of the different lithologies.

2. **The Sakpe Ironstone Formation**

   The Sakpe Formation comprises mainly oolitic and pisolitic ironstones with sandy claystones locally, at the base followed by dominantly oolitic ironstone which exhibit rapid facies changes across the basin at the top (Obaje, 2013). The unit are rarely encountered in the basin except in Sakpe village, west of Bida town where prominent outcrops and exposures are encountered (Adeleye and Dessauvagie, 1972; Obaje, 2013). According to Adeleye (1974), the formation is comprised of two laterally equivalent members; the Wuya Ironstone Member and the Baro Ironstone Member. The Baro Ironstone Member consists of oolitic ironstone and ferruginous sandstone which are locally pyritic and concretionary (Nwajide, 2013). The type section of the member is the Baro Plateau and it caps the plateau with a maximum thickness of about 3m. Specimen of *Turritella* and *Fuanus sp.* were recovered by Adeleye (1972). The Baro Member contains fossil wood and the icnogenus *Skolithos*. While *Faunus sp.* may indicate Maastrichtian age for the formation, the other fossils are not age-specific (Whiteman, 1982).

3. **The Enagi Siltstone Formation**

   The Enagi siltstone is believed to conformably overlie the Bida Sandstone Formation except in the areas of the occurrence of the Sakpe Ironstone Formation (Rahman *et al.,* 2019). It is dominated by siltstone, with sandstone-siltstone admixture and some clay stones and shales. The siltstones are generally whitish to grey-white in color and well-sorted, typified by those occurring within and around the town of Batati. Other subsidiary lithologies include sandstone-siltstone admixture and in some places with abundant massive claystones (Obaje, 2013). Fossil leaf impressions and rootlets occur occasionally within the formation. The formation ranges in thickness between 30m and 60m. Mineral assemblage consists mainly of quartz, feldspars and clay minerals. Bioturbation structures are rarely encountered within the Enagi Formation but foraminiferal recovery indicates that the formation is of shallow marine environment

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in most parts. The formation covers over 70% of the surface area of the Bida Basin. The type locality is about 6km east of Enagi and the exposures are commonly found just below the top of the mesas, as typified by the occurrence at Doko (Nwajide, 2013). The Enagi Formation was logged and mapped in details in Agaie, Batati, Enagi, Kutigi, Mashegu, Kandi and Ewan.

Adeleye (1972) interpreted the formation as having been deposited as the continental facies of an extensive delta. Nwajide (2013) however believes that this interpretation does not fit into the true deltaic setting. He is of the opinion that a lacustrine, pond marginal or transitional depositional setting may be considered. Shale and coaly shale have also been intercepted during borehole drilling at depth of between 30m and 100m.

4. **The Batati Formation**

The Batati Formation constitutes the uppermost units in the sedimentary sequence of the Northern Bida Basin. The formation consists of argillaceous, oolitic and goethitic ironstones with ferruginous claystone and siltstone intercalations and shaley beds occurring in minor proportions, some of which have yielded near shore shallow marine to freshwater fauna (Adeleye, 1974). The sporadic occurrences of the Enagi and Bida Formations wherever it occurs show that the Batati Formation occupies rift sinks (grabens) (Obaje, 2013). The areas present the thickest sediment piles. Although these areas may be interpreted as synforms, they are actually rifted structures, where the Batati Formation remains deposited in the grabens and eroded on the horsts (Obaje, 2013). Adeleye (1972) established that the formation consists of two members – the Edozhigi and the Kutigi Members. The Edozihigi Member consists of goethitic and oolitic ironstones, and averages from 1m to 5m in thickness, though it may be as thin as 30cm and as thick as 15m. The variability is attributed to erosion.

The Kutugi Member consists of mixed goethitic and kaolinitic oolites and has a maximum thickness of 2m. *Ostres sp., Lopha sp., Venericardia sp., Septifer sp., Faunus beyenburgi* and *Faunus miskalensis* were recovered by Adeleye (1972) from the ironstone. The ironstone are however not age specific nor even environmentally diagnostic (Nwajide, 2013). Adeleye (1972) had offered the assemblage as a basis for suggesting another southward excursion by Tethys Sea, producing the near shore marine conditions for the formation of the oolites. However, Murat (1972) and Whiteman (1982) suggested that the two ironstone formations – Sakpe and Batati – are Campanian age, and that the Bida Basin was in par a source area in the Maastrichtian times, when Ajali regressive sandstones were deposited.

Land Use Land Cover (LULC)

LULC exert enormous influences on the occurrence and renewal of groundwater resources in a terrain. Human socioeconomic activities have become a leading factor that alter the configuration of this important components in groundwater recharge process. In determining the LU factor in this study, the LULC map of the study area was generated from Landsat 8 acquired using 190/054 path and row. Six major land use types were delineated from the map (Figure 10); water bodies, cultivated lands, barren lands, built up areas, outcrops and vegetation respectively. The produced LU cover maps show that about 45 percent (%) of the study area comprises of outcrops, 22% is cultivated lands, water bodies cover 5%, vegetation was 12%, barren land was 4% and built-up area was 15%.

In mapping of prospective well, outcrop is often considered poor yield due to low or no permeability leading to poor well recovery. Built-up land on the other hand is characterized by dominance of high surface runoff, prevalent of nonporous surfaces especially in the developed world and low infiltration rates. Agricultural land and vegetation are the most suitable land cover type that produced high prospective well due to high infiltration and low runoff over these lands used type. Consequently, recharge capability is expected to be high over this land used type to give rise to optimal well performance due to shot recovery period.

To maximized groundwater resource potential of an area, LULC is critical in understanding the runoff and recharge process (Mukherjee & Singh, 2020). On this note, many groundwater potential prediction and mapping incorporated LULC of an area to accurately inferred recharge points which are critical to sustainable well performance using Analytical hierarchy Process (AHP) by assigning weight of evidence to the ensemble factors (Lamichhane & Shakya, 2019). In groundwater potential prediction, LULC along with other parameter exclusion significantly degrade the model accuracy (Mukherjee & Singh, 2020; Mseli *et al.*, 2021). Among the LULC types, agricultural lands can enhanced groundwater restoration (Kabeto *et al.*, 2022) and changes in this LUC will greatly alter the recharge rate thus, exerting a negative consequences on well performance and sustainability (Khan *et al.*, 2021; Kabeto *et al.*, 2022; Siddik *et al.*, 2022). Furthermore, in groundwater quality studies, agricultural lands appear to be the sources of pollution that significantly degrade the saturated zones water quality due to the infiltration of artificial fertilizer from the field. The infiltrated chemicals alter the chemistry of the groundwater thus, degrading quality of the zone. This scenario is more common in the semi-arid zones due to the impact of evaporation. In relating this to the result presented in Figure 9, cultivated land was only 22% of the study area thus, recharge process is more dominate in this region.

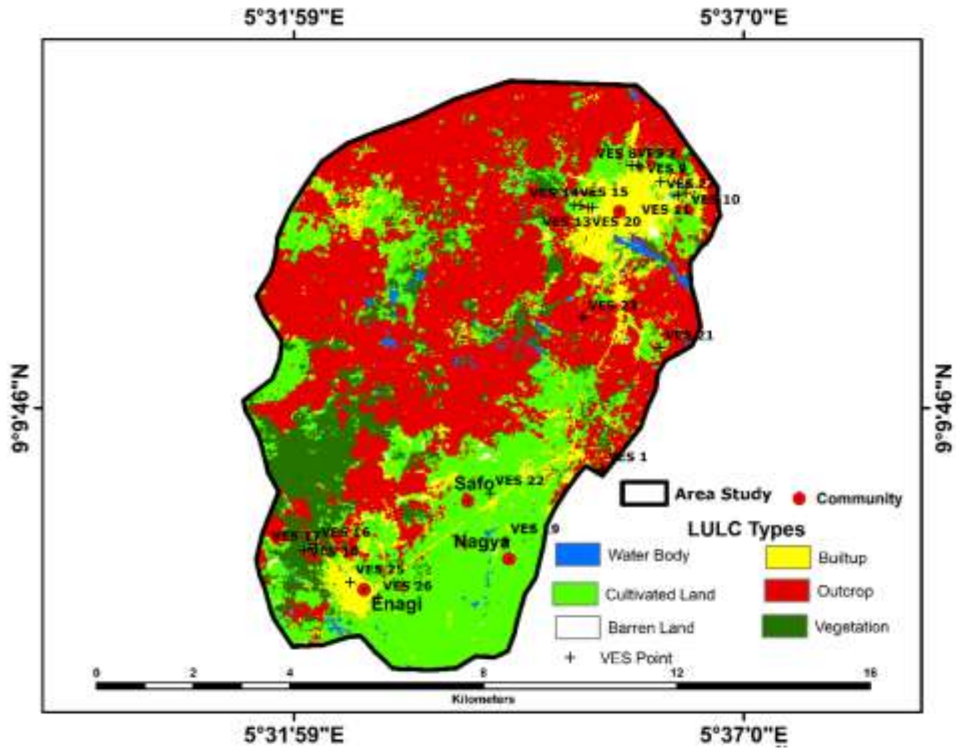

Figure 3: LULC Map of the Study Area

Result and Discussion

All the formations of the Northern Bida Basin occur within the study area. They are the Bida Formation, Sakpe Formation, Enagi Formation and Batati Formation (Figures 4). The Bida Formation makes up over 50% of study area, covering most of the basal areas. The Sakpe Formation on the other hand constitute about 25% of the area, covering the southern and

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central region and striking in northwest direction. In the northern area, the Enagi Formation directly overlies the Bida Formation without the Sakpe Formation interval. The regional dip of this formation is 20°- 25° in the southeast direction and makes up about 20% of the study area. The Batati Formation constitute about 5% of the study area and is found predominantly in the western, and northern parts where they overly the basal Enagi Formation. This formation also has a regional dip of 20° (Figures 4).

1. **Bida Formation**

   This formation is well exposed and studied at Enagi and Sakpe. The formation is generally made up of a fining upward sequence of sandstone, siltstone and mudstone with increasing bioturbation upward.

   The basal unit of the formation at Enagi consists of a massive, color mottled bed (5 meters thick) of fine to medium grained, fining upward, clayey sandstone that is separated from the overlying units by a flat regular ferroginized surface. The bioturbation index (BI) of this bed is 2-3.

   The unit above this is a gray to light orange colored, poorly sorted, pebbly coarse-grained sandstone which is increasingly more bioturbated (BI=3-4) towards the top (Plate 4). There is evidence of coarse lag units below which is an erosional surface separating it from the basal units. The coarse units are angular to sub-angular in shape and between gravels and small pebbles in size which are feldspathic (arkosic) in composition. This unit contains fractures of between 150° and 160° strike directions. The overlying unit is a tabular unit of interbedded fine sand, silts and clay which fines upward and becomes clayey towards the top. This unit contains horizontal burrows whose intensity increases towards the top, evidenced by the color mottling of the unit (Plate 5). There is a sharp surface at the top of the clay unit, marking the beginning of another unit, of which the basal unit is composed of coarse-grained sands that are granular in size. There is presence of a fining upward sand unit within the fine clay sequence of this unit. The bioturbation index here is between 3-4 and the burrows are more intense in the sandstone unit, with the burrows containing whitish fills.

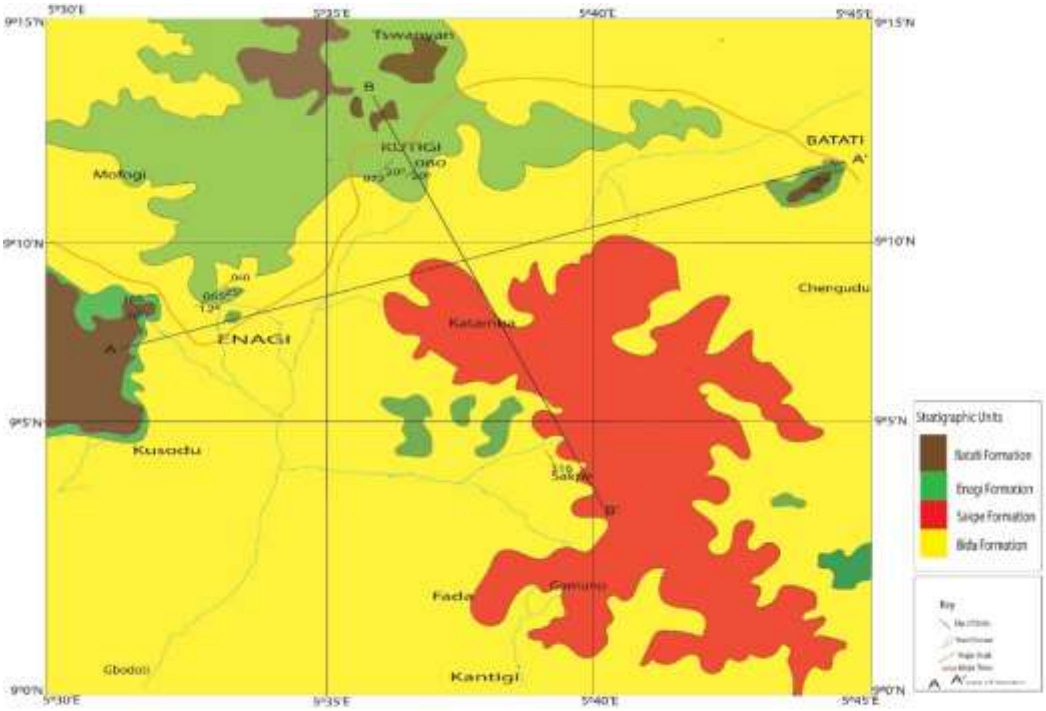

Figure 4. Geological Map of the Study Area

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MATERIALS AND METHODS

Research Design

Reconnaissance: Relevant data and maps related to the study were acquired from relevant agencies. These include topographic and aeromagnetic maps as well as remote sensing data. The topographic map was created into grids prior to deployment

1. **Field Studies**: Geological mapping was conducted systematically using the topographic map as a guide. Exposed rock sections were studied, logged and samples were collected. Identified locations for electrical resistivity studies was divided into profiles and the data collected along the profiles.
2. **Laboratory Studies**: This includes generation of thin sections from rock samples collected and petrographic analysis, determination of the grain size distribution and hydraulic conductivity of the collected aquifer samples.
3. **Data Processing, Analysis and Interpretation**: Results generated from the geological field studies, geophysical studies, remote sensing studies and laboratory studies were interpreted and analysed using various software.

Methods of Data Collection

Remote Sensing Method

The data were generated by processing the retrieved spectral properties as captured by onboard sensor. Satellite sensor onboard the Shuttle Radar Topographic Mission (SRTM) and Landsat 8-9 Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS) operated by United State Geological Survey (USGS) data were sourced for groundwater related data. Data considered relevant to the study were evaluated from two point of view viz, groundwater indicators and recharge process through the infiltration of water from saturated to the unsaturated zones. Consequently, topographic elevation, slope and stream network data were produced using the STRM sensor information. Lineaments, LULC, water bodies and physical terrain information were generated from the retrieved Landsat 8-9OLI/TIRS imagery of 2019 and 2021 using 190/054 path and rows respectively.
The generated data was then subject to radiometric and atmospheric correction in ERDAS 9.1 imagine application to optimized the image quality for accurate training sample selection. Consequently, all the generated data were imported and further processed in GIS environment using ArcGIS 10.5 application. All data were partitioned and subset to create the study area map as well as geospatial analysis using the geo processing extensions. Lineament data on the other hand was processed in Geomatica.exe 10.1 application using band 6 extracted from the Landsat data retrieved from the USGS archives.

Conclusion

Local geological studies were integrated with remote sensing data and different geophysical methods for groundwater exploration around Kutigi-Enagi areas of the Northern Bida Basin. The geological studies identified the sandstone, siltstone and clay stone units of the Bida and Enagi Formation with the Bida Formation making up over 70% of the study area. The drainage pattern, lineament density slope and land use land cover contributes to groundwater availability in the study area, with lineament having a lower weight because it is localized to a very small part of the area. Electrical resistivity studies revealed the dominance of H, Q and HK type curves which are good indicators of presence of groundwater. Although the aquifer appears shallower at Kutigi, groundwater abstraction is only sustainable here at depths above 50 meters. Bore wells drilled dipper than 30 meters around Enagi are sufficient to abstract sustainable groundwater to residents' need within the area.

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