Integration of remote sensing data, GIS and geophysical survey for delineation of groundwater potential zones

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Assessing the potential zone of groundwater recharge is very important for the management of groundwater resources. The people of Ona-Ara have in recent times drilled many boreholes and wells without getting enough water and the water does not last long. Considering the high cost of drilling as well as time spent in it, there is a need for precision and accuracy before embarking on drilling. The present study attempts to select and delineate various groundwater potential zones for the assessment of groundwater availability in Ona-Ara Local Government Area of Oyo State, Nigeria using remote sensing, Geographic Information System Techniques (GIS) and Geophysical Survey techniques. In this study, quick bird high resolution imagery, Landsat 8 imagery on Path ⁄ Row: 151 ⁄ 055 for 2015 , Shuttle Radar Topographic Mission (SRTM), Digital Elevation Model (DEM) were used to prepare various thematic maps viz: Land Use/Land Cover (LULC), geomorphological, geological, slope, drainage density and lineament density. These maps were used to identify potential groundwater zones in the study area. The results obtained were validated with Very Low Frequency Electromagnetic (VLF-EM) and Vertical Electrical Sounding (VES). VES data were processed by partial curve matching and subsequently interpreted with Winglink software. True resistivities values and thickness of geoelectric layer were deduced from the interpretation. VLF-EM data obtained were filtered with the Karous-Hjelt (KH) filtering method and presented a 2D contoured and colour coded sections making use of the KHFFILT software. Four major land use types were identified from LULC map and they include Built-up area (49.31 km^2), Ibadan Airport (3.49 km^2), mixed vegetation (233.74 km^2) and riparian vegetation (1.34 km^2). The drainage basin was delineated into four sections which are river Ogundepo, Omi, Eripa and Eti-Olopa. Comparing the result of randomized VES with VES done at GIS delineated lineament, it was discovered that fractured zones are readily observed from the VES curve at GIS delineated areas. The study concluded that that an integrated approach involving remote sensing and GIS technique can be successfully used in identifying potential groundwater zones in the study area as it demonstrates Remote Sensing and GIS as a potential tool in locating groundwater reservoir areas. This can help in solving the complex geohydrological problems associated with groundwater occurrence and its development.

Key words: Groundwater, remote sensing, gis, geophysical survey, VES and VLF-EM.

INTRODUCTION

The growing significance of groundwater based on increasing demand has led to unscientific utilization, thereby creating a water stress condition (Waikar and Nilawar, 2014). This is an alarming situation, and therefore calls for a cost and time effective technique for proper evaluation of groundwater resources and management planning. The typical objectives of any exploratory groundwater investigations are to locate, delineate and evaluate new sources of groundwater. The use of geophysical methods provides valuable information with respect to distribution, thickness, and depth of groundwater bearing formations (Hubbard and Rubin, 2005). Geophysical exploration techniques are extremely helpful in mapping subsurface features, estimate aquifer parameters, and monitor hydrogeologic processes (Adiat et al., 2009; Ariyo and Adeyemi, 2009). Geophysical methods are conventionally employed for groundwater prospecting; though, there are several methodologies to locate and map the occurrence and distribution of groundwater. The advent and development of new technologies such as remote sensing have proved to be useful for quick and useful baseline information about the factors controlling the occurrence and movement of groundwater (Bobba et al., 1992; Meijerink 2000). Further, remote sensing techniques provide a synoptic view of large areas, facilitating better and quicker assessment, development, and management of water resources with collateral information (Preeja et al., 2011).

Remote sensing (RS) is an excellent tool used by hydrologists and geologists to understand groundwater exploration. In recent years, satellite RS data have been widely used in locating groundwater potential zones (Srivastav and Bhattacharya, 2000; Manimaran, 2012). These data are reliable, timely and also meet the essential requirements in the geographical Information System (GIS) domain, which are current, sufficiently accurate, comprehensive and available to a uniform standard (Phukan, 1999; Chandary et al., 2002). Application of remote sensing in groundwater hydrology to complement the conventional geophysical techniques had been reported in published research work (Yeh et al., 2014; Elbeih, 2015; Raju, 2015). The technique of integration of RS and GIS had proved to be extremely useful for groundwater studies (Saraf and Choudhury, 1998; Khan and Moharana, 2002; Sankar, 2002). Studies have shown remote sensing as a better tool useful for observation and more systematic analysis of various geomorphic units/landforms/lineaments due to the synoptic and multi-spectral coverage of a terrain (Nag and Ghosh, 2013; Nag and Kundu, 2016). Application of GIS and RS can also be considered for multi criteria analysis in resource evaluation and hydrogeomorphological mapping for water resource management (Waikar and Nilawar, 2014). The primary objective of the study is to use the advanced technology of RS and GIS in the delineation of groundwater potential areas. Identification of potential groundwater zones could aid in proper development and utilization of both groundwater and surface water resources, thereby improving the irrigation practices and agricultural income for standard living conditions of the society.

METHODOLOGY

Study area

The study area is Ona-Ara Local Government Area (LGA) located in the Southeast of Ibadan, Oyo State. It lies between latitude 7°00´ and 7° 15´ N and longitude 4°15´ and 4°18´ E. It covers a total land mass of 290 km² and total population of 265, 059 (NPC, 2006). The climate is tropical, typical of the sub-equatorial belt of the Southwestern Nigeria, with an average annual temperature that ranges from 25°C – 27°C. The climate is characterized by two seasonal climate regimes: wet and dry seasons. The study area is part of the basement complex of Southwestern Nigeria. A section of Ona-Ara Local Government Area considered in this study area falls within eastern – central portion of the LGA measuring approximately 3 km by 2 km. This region has a cluster of four lineaments namely: lineament 19, 4, 10 and 11 and is bordered by Adigun, Bale and Gbanga villages (Figure 1).

Identification of groundwater potential zone
The identification of groundwater potential zones was accomplished using remote sensing, GIS techniques and Geophysical Survey according to the flow chart illustrated in Figure 2.

Data acquisition

A range of spatial and non-spatial data was acquired for RS/GIS analysis of this research work. These datasets are very useful in understanding the hydrogeology of Ona-Ara Local Government Area. Table 1 shows the description of datasets used for this study.

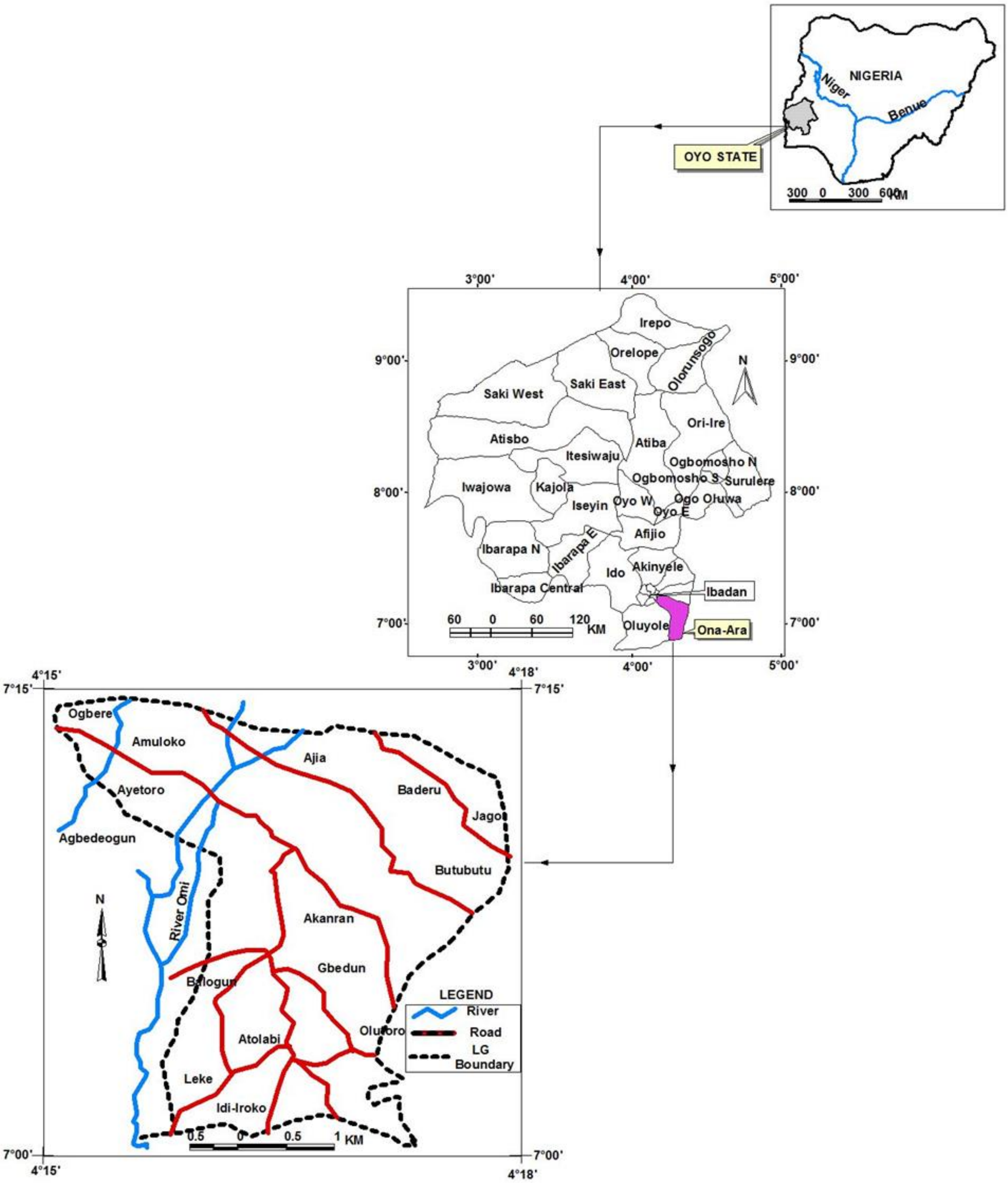


Figure 1. Map showing the location of the study area.

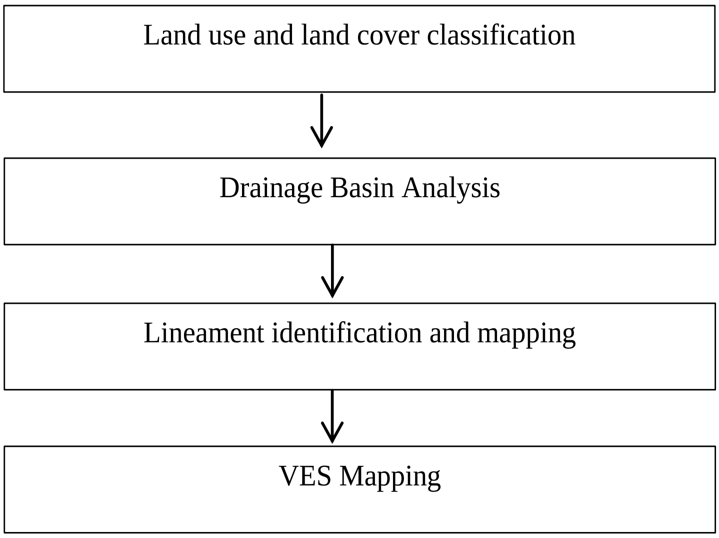


Figure 2. Remote sensing and GIS work flow.

Table 1. Watershed characteristics.

Section	Main River	Main river Length (km)	Total stream (Length (km); km/km^2)	Watershed area (km^2)	Drainage density
1	Ogundepo	4.58	10.27	10.11	1.02
2	Omi	9.41	69.98	58.71	1.19
3	Eripa	11.82	57.79	56.02	1.03
4	Eti – Olopa	7.80	24.40	21.09	1.16

Land use and land cover

In order to identify the land use and land cover classes and the way it has implications for ground water, we identified and interpreted categories from Quick bird and Landsat 8 imageries, using ISODATA unsupervised classification method (Campbell, 2002) with Eradas imagine software. Prior to classification, we fused the two imageries to tap into the higher spatial resolution of the Quick bird imagery and the spectral resolution of the Landsat. The ISODATA method allows the pre identification of land uses classes which were later verified during field work (Ground truthing).

Lineament mapping

Lineaments are fractures and faults that indicate the conduits for groundwater flow. In this study, lineaments were identified using the SRTM DEM as the main data source and supplemented with the topographic maps and quick bird high resolution imagery using the PCI Geomatica software. Morphological features were identified by looking out for the combination of topographic gradients, shades and curvatures. A high filter edge enhancement was applied to improve on contrast and it was combined with multi-illumination direction shaded relief images derived from the SRTM DEM (Richards and Richards, 1999; Campbell, 2002). GIS overlay techniques was then used on these two sets of multi-illumination shaded relief image generated by combining eight separate relief images with light coming from the following sources (directions) (0°, 45°, 90°, 135°, 180°, 225°, 270°, 315°). The first set of images combined 0°, 45°, 90° and 135° light sources, while the second set combined 180°, 225°, 270°, and 315° light sources. The first set of shaded relief images was finally adopted for Ona-Ara study area lineament mapping based on better contrast/lineament enhancement. While employing these automated lineament extraction approach offered by GIS, we further extracted and cleaned up the results to eliminate other linear features like transportation networks and rivers that may be mistaken for lineaments/fractures and faults by overlaying the transportation and river network on the lineament map to further distinguish it from geological discontinuity. Through this we improved the accuracy of the findings that will guide its use in the hydrogeophysical survey (Figure 3).

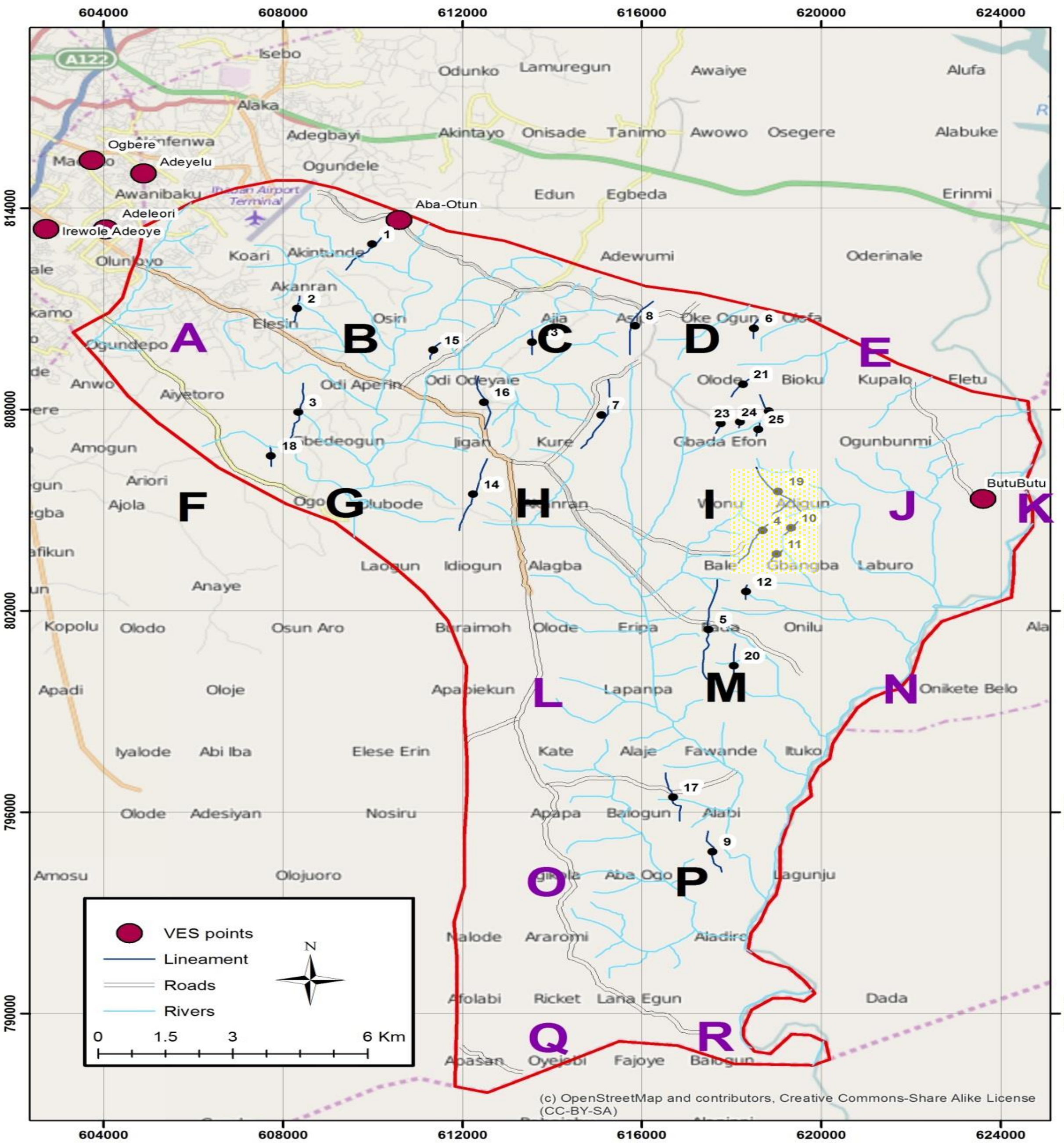


Figure 3. GIS delineated lineament map of Ona Ara LGA showing study area.

Hydrological and Drainage Basin Network Analysis

River network was delineated in topographic maps, Quick bird imagery and SRTM DEM data complemented by river network data set. Watershed of the area was delineated with the aid of Arc Hydro and HEC HMS extension of ESRI ArcGIS. These tools were also used for identification of four pour points. Pour point is the location of a river where water discharge is measured. Four watersheds (1, 2, 3 and 4) were automatically delineated from the selected pour points downstream using available SRTM DEM and Arc Hydro tool in ArcGIS environment. The measurement tools offered in ESRI ArcGIS software was used to measure river lengths, areas and densities and a ranking mechanism to rank delineated watersheds in terms of their groundwater potentials and sustainability.

Geophysical survey

The VLF – EM served as a reconnaissance tool for quick detection of lineaments while the Electrical Resistivity method served in imaging of the subsurface to confirm presence, depth of emplacement and thickness of identified lineaments.

VLF–EM prospecting

The materials used were ABEM WADI, Garmin eTrex GPS and recording materials. A reconnaissance with the VLF-EM data acquisition along three (3) traverses deployed approximately at right angles to the lineament of interest was carried out. In order to achieve this, the ABEM WADI was employed. The WADI measures the field strength and phase displacement around a fracture zone (lineament) in the rock and records directly the real and imaginary components. The ABEM WADI also directly filters the raw components generating real time filtered plots of the perturbations thereby enabling on-site assessment of acquired data for anomalously conductive zones.

Data acquisition and interpretation

The data for this study were acquired by utilizing a transmitter with frequency of 15.1 kHz and power of 500 kW located in Bordeaux, France; although the WADI carries out Karous – Hjelt filtering of data in real time. Data were acquired at intervals of 10 m along the deployed traverses while recording the raw real and imaginary components. This was to enable a more detailed filtering of the data by varying spacing between data points to develop 2D equivalent current density sections beneath the traverses. A geographic coordinate of each data station was recorded using a hand-held GPS unit, such that any station along the traverse can be readily identified on the map of the study area. Field data were interpreted through filtering with the Karous – Hjelt (KH) filtering method and presented as 2D contoured and colour coded sections making use of the KHFFILT software developed by Markku Pirttijarvi of the Department of Geosciences, University of Oulu, Finland. On interpreted sections, highly conductive zones are depicted as hot (red) while regions with very low conductivity are depicted as cold (blue / black).

Vertical Electrical Sounding (VES)

The Vertical Electric Sounding (VES) locations were firstly chosen at random (the randomized sampling was done at the political wards in the study area) in nine locations of the LGA. Sequel to the delineation of probable lineaments from remote sensing using GIS techniques, a ground confirmation exercise was attempted to test the application of GIS in groundwater exploration. The closeness to the lineaments obtained from remote sensing exercise was attempted using a hand-held GPS unit. The materials used were: PASI 16GL Earth Resistivity Meter, Garmin eTrex GPS and recording materials were used for VES.

Data acquisition and interpretation

PASI 16GL Earth Resistivity Meter was used for data acquisition. Results of the VES were presented as bi-log plots with obtained apparent resistivities on the ordinate and half current electrode spacing on the abscissa. Thereafter, quantitative interpretation of the VES curves was attempted manually by partial curve matching using 2-layer master and auxiliary curves of Mooney and Orellana (1966). Finally, automated forward inversion of the VES data was carried out using the WingLink software.

RESULTS AND DISCUSSION

Remote sensing and GIS analysis

Land use and land cover

Figure 4 shows the major land use types/classes

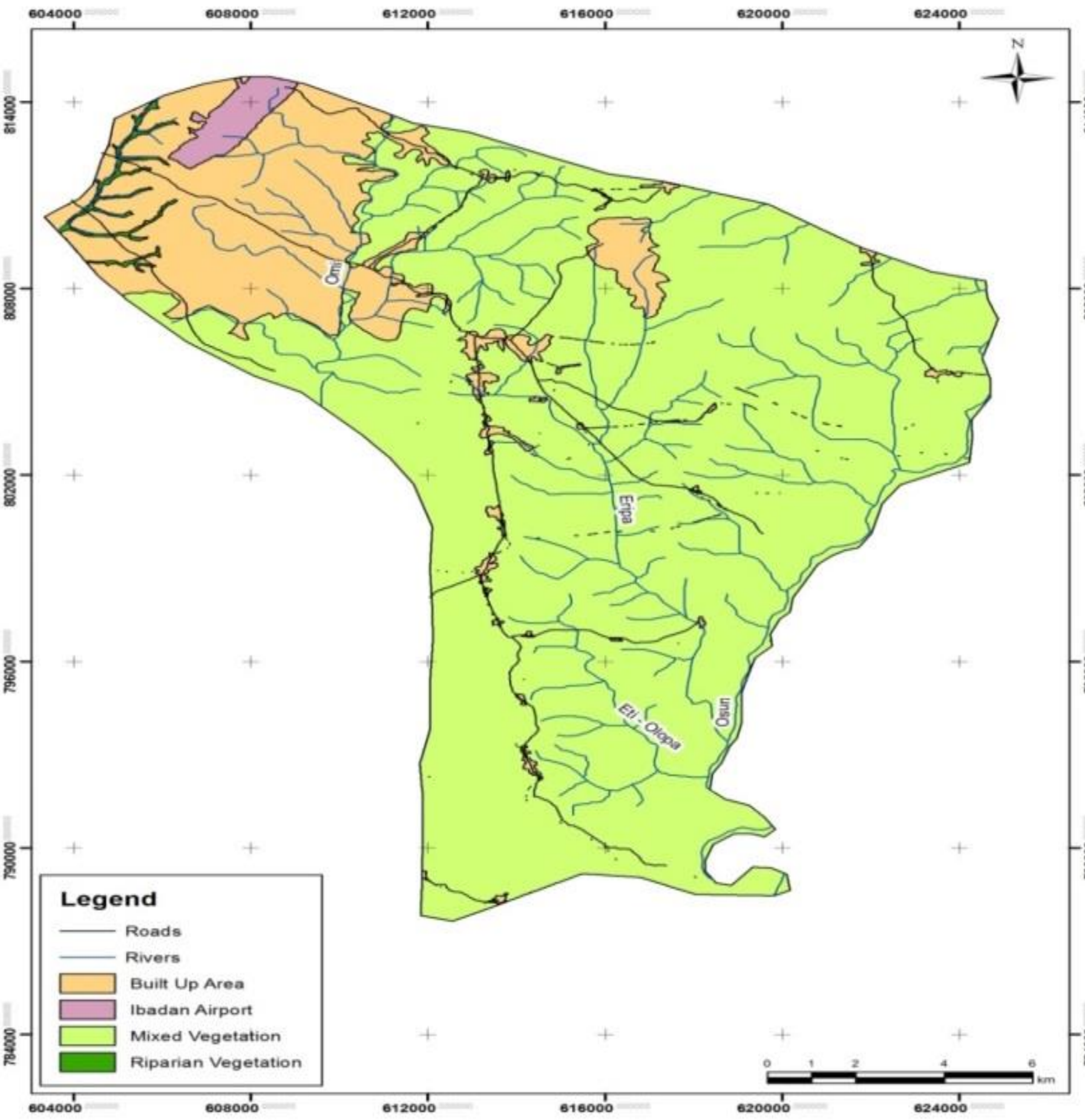


Figure 4. Land use types in Ona Ara Local Government Area.

identified within the Ona-Ara Local Government Area. Four major land use types/classes identified were the built up area (human settlement), Ibadan airport, mixed vegetation (forest and savannah) and riparian vegetation. The mixed vegetation is the largest land use class with an area of 233.7 km^2 and it accounts for 81.2% of the LGA. The built up area (BUA) consists of residential and commercial human settlements with an area of 49.3 km^2 which make up 17.1 % of the LGA; while the Ibadan airport and riparian vegetation land use classes are characterized by an area of 3.5 km^2 and 1.3 km^2 representing 1.2 and 0.5% respectively. Many of the roads in the LGA tend to connect the contiguous settlement to the North West of the scattered ones. A few scattered human settlements and commercial activities have developed along the major roads.

Hydrological and drainage basin analysis

The study area is dissected by five principal river systems which include Osun, Omi, Eripa, Eti – Olopa, Ogundepo and their tributaries (Figure 5). The respective lengths of the principal rivers are 21.3, 12.1, 15.4, 8.3 and 5.1 km within the LGA.

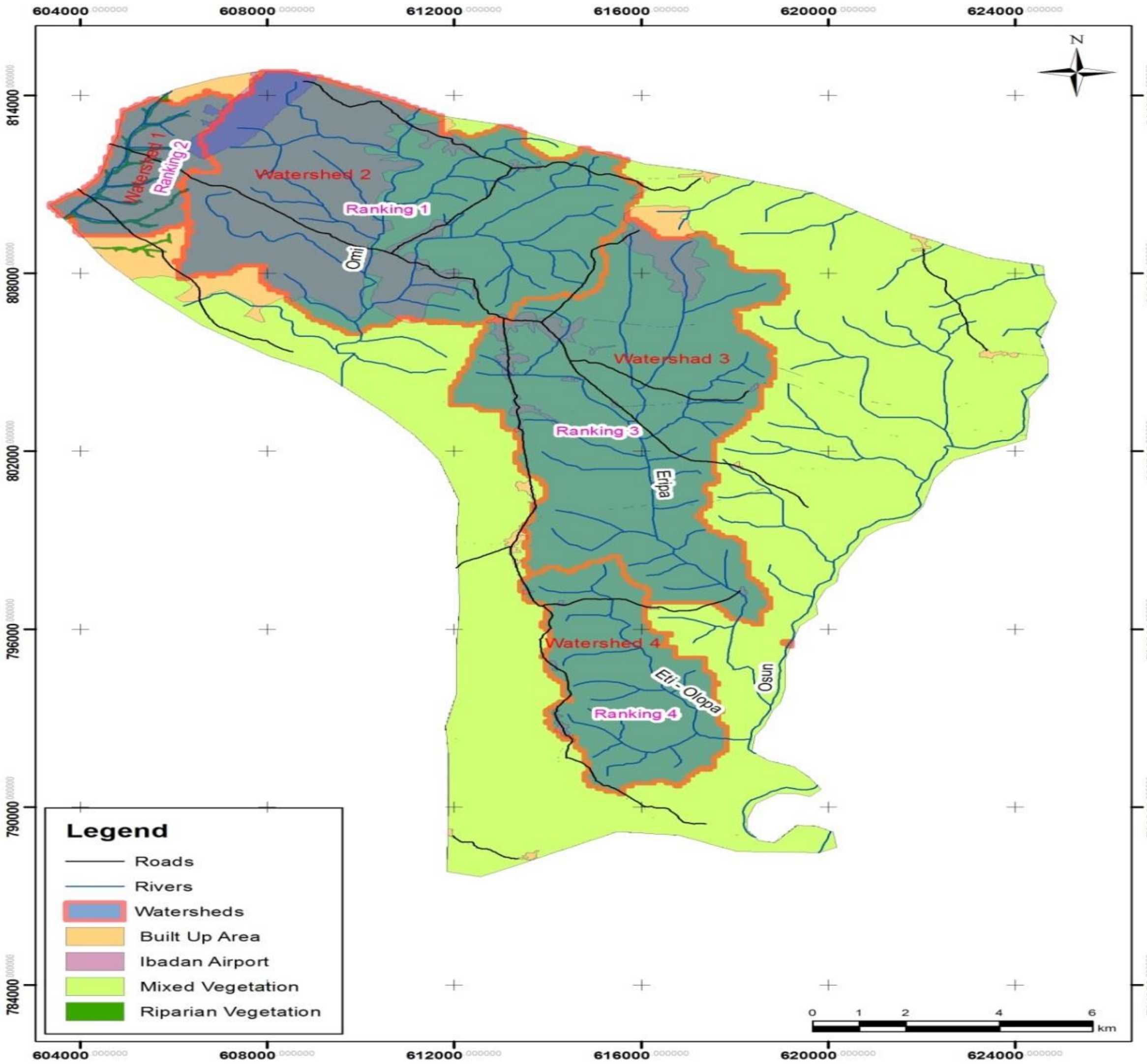


Figure 5. Principal watersheds in Ona-Ara Local Government Area.

Within this catchment area, Osun River has the longest river stretch or reach; while Ogundepo River has the shortest river stretch. This implies that Osun River will have a high volume of discharge as stream length has an important relationship with surface flow and discharge.

Watershed characteristics

Watersheds usually show different drainage characteristics as indicative of land use, soil types, geology and geomorphology which are closely related to groundwater availability. Watershed analysis was necessary to assess watershed potential for groundwater recharge/runoff generation to serve as a guide for proposed groundwater exploration and exploitation. The watersheds characteristics are presented in Table 1, while the Land use types in the watersheds and its ranking within the study area are given in Tables 2 and 3, respectively.

In addition to geomorphological feature such as lineament, drainage basin pattern, density and shape are important clues to potential groundwater recharge especially in basement complex rocks. The delineated watersheds (Table 1) have drainage densities that ranged from 1.0 to 1.2 km/km^2. The most permeable watershed is watershed 1 characterized by the least drainage density. Watershed 2 has the highest drainage density indicating more runoff generation. The watershed looks most compact/circular with

Table 2. Land use types by watershed.

Area (km^2)	Built up area (BUA)	Ibadan airport	Riparian vegetation	Mixed vegetation
Section 1	8.57	0.44	1.08	0.00
Section 2	28.97	2.97	0.00	26.74
Section 3	4.03	0.00	0.00	51.99
Section 4	0.25	0.00	0.00	20.85

Table 3. Watershed ranking.

Area (km^2)	Built up area (BUA)	Ibadan airport	Riparian vegetation	Mixed vegetation	Ranking
Section 1	8.57	0.44	1.08	0.00	2
Section 2	28.97	2.97	0.00	26.74	1
Section 3	4.03	0.00	0.00	51.99	3
Section 4	0.25	0.00	0.00	20.85	4

tendency towards synchronized peak flow. In addition, Watershed 2 has the highest built up area with 29 km^2 followed by Watershed 1 with 8.6 km^2 (Table 3). The Ibadan airport covers 3.0 km^2 within watershed 2 with the remaining 0.4 km^2 falling into Watershed 1. The geology, hydrogeology and lineament mapping are considered as equal. Closeness to built-up area/infrastructure can be an important consideration with reference to cost when siting boreholes for the LGA. Watershed 2 is therefore a good location for future boreholes because it has the highest number of built up area, hence the most populated watershed out of the four. Also, the borehole will be very useful for both domestic and commercial purposes unlike watershed with a low number of built up area.

Apart from Watershed 1, all other watersheds have a good mixed vegetation cover. Watershed 3 has the highest area of mixed vegetation followed by Watershed 2 and then Watershed 4. Vegetation cover with reference to the mixed type can increase rainfall infiltration and groundwater recharge. As a result, Watershed 2 has the most representative land use type within the study area, although the watershed has the highest drainage density amongst the delineated watersheds. Drainage density figures in the study area are generally low indicating permeable watersheds. It is hoped that lineaments will be in this watershed. Watershed 2 is therefore ranked 1 and should be the focus of geophysical investigations for groundwater abstraction.

Lineament mapping

The lineament map of the study area as manually extracted from the SRTM DEM is provided in Figure 6. Lineament analysis involves the extraction of parameters which have strong influence on geological structures that serves as conduit for groundwater flow. Consequently, lineament direction, length frequency, lineament intersections and lineament density were obtained during the analysis.

This reveals that the direction of lineaments in the catchments is trending towards northeast-southwest (NE–SW). This direction is significantly not different from the drainage direction of the area under investigation. This is a good indicator as direction of aquifers tends to align with surface water bodies (Abdullahi et al., 2013). Lineament length range suggests slightly greater variability in catchment 3 having 8.33km. Lineaments in catchments 2 and 3 are mainly parallel. However, a lineament intersection outside the catchments was observed close to catchment 3. Lineament densities and frequencies are generally low across catchments in the project area. The result of the analyzed lineament/fracture indicates varying lengths of lineaments, which are feasible points of groundwater potential evaluation especially when they intersect or are of high densities.

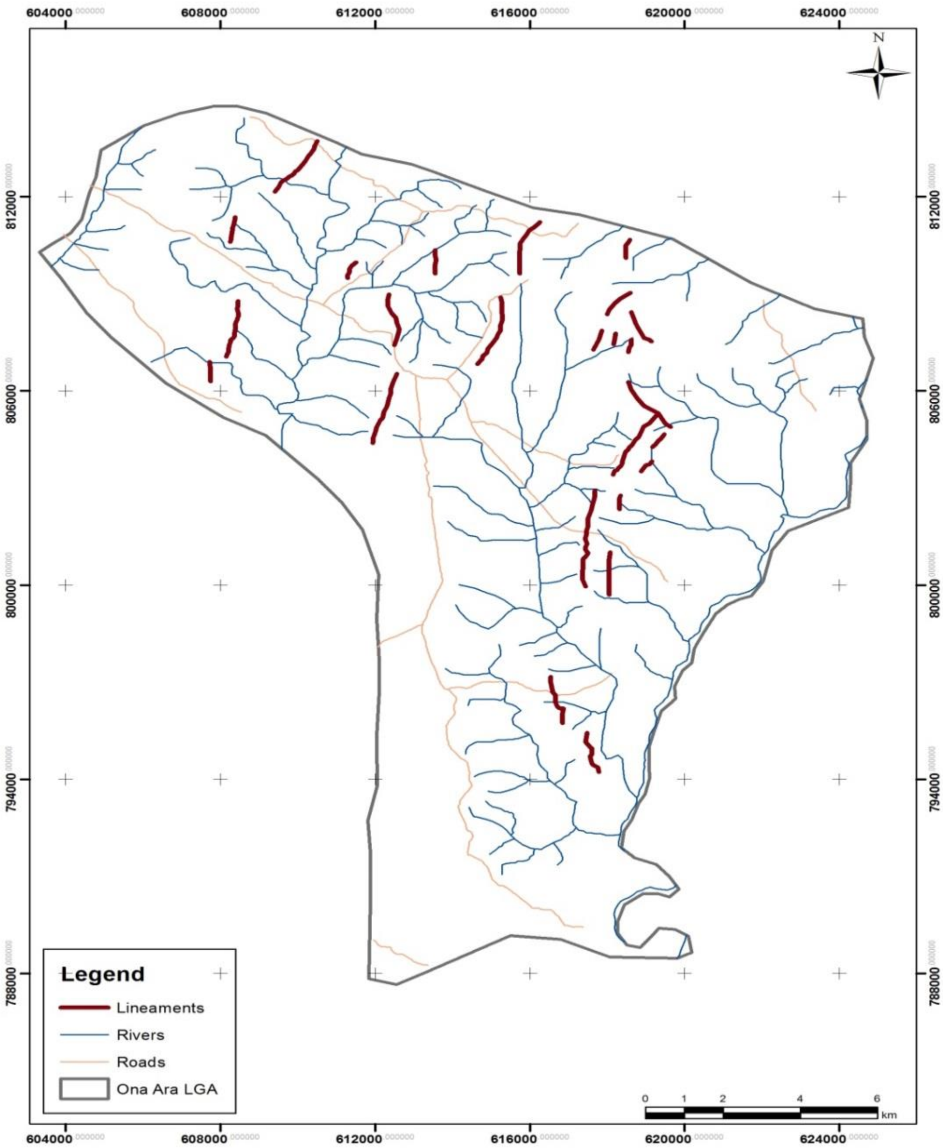


Figure 6. Lineament Map of Ona-Ara LGA in Oyo State, Nigeria.

Geophysical survey (VES and VLF-EM)
Randomized VES locations

Vertical electric sounding (VES) location carried out in nine locations has been mapped and presented in Figure 7. The VES locations chosen at random seem not to be in close alignment with the lineaments identified using RS/GIS techniques. A randomized position selection method was used for selecting VES position which is often used by the government agencies in siting wells in rural communities. The interpretation of the nine randomized VES conducted in the study area reveals the presence of six geoelectric layers. These geoelectric layers falls into four groups and these are top soil, lateritic soil, slightly weathered basement, weathered and fresh basement. The resistivity of the top soil ranges between 16 and 470 ohm-m while the thickness varies between 0.8 and 1.7m. The resistivity of the lateritic layer varies between 46.4 and 156.1ohm-m while the thickness varies between 2.0 and 3.7m. The resistivity of the weathered basement ranges between 11 and 371.2 ohm-m while the thickness varies between 1.4 and 11.5m. The resistivity of the fresh basement ranges between 95 and 4273 ohm-m while the thickness varies between 6.2 and 18.4m. The resistivity of the slightly basement

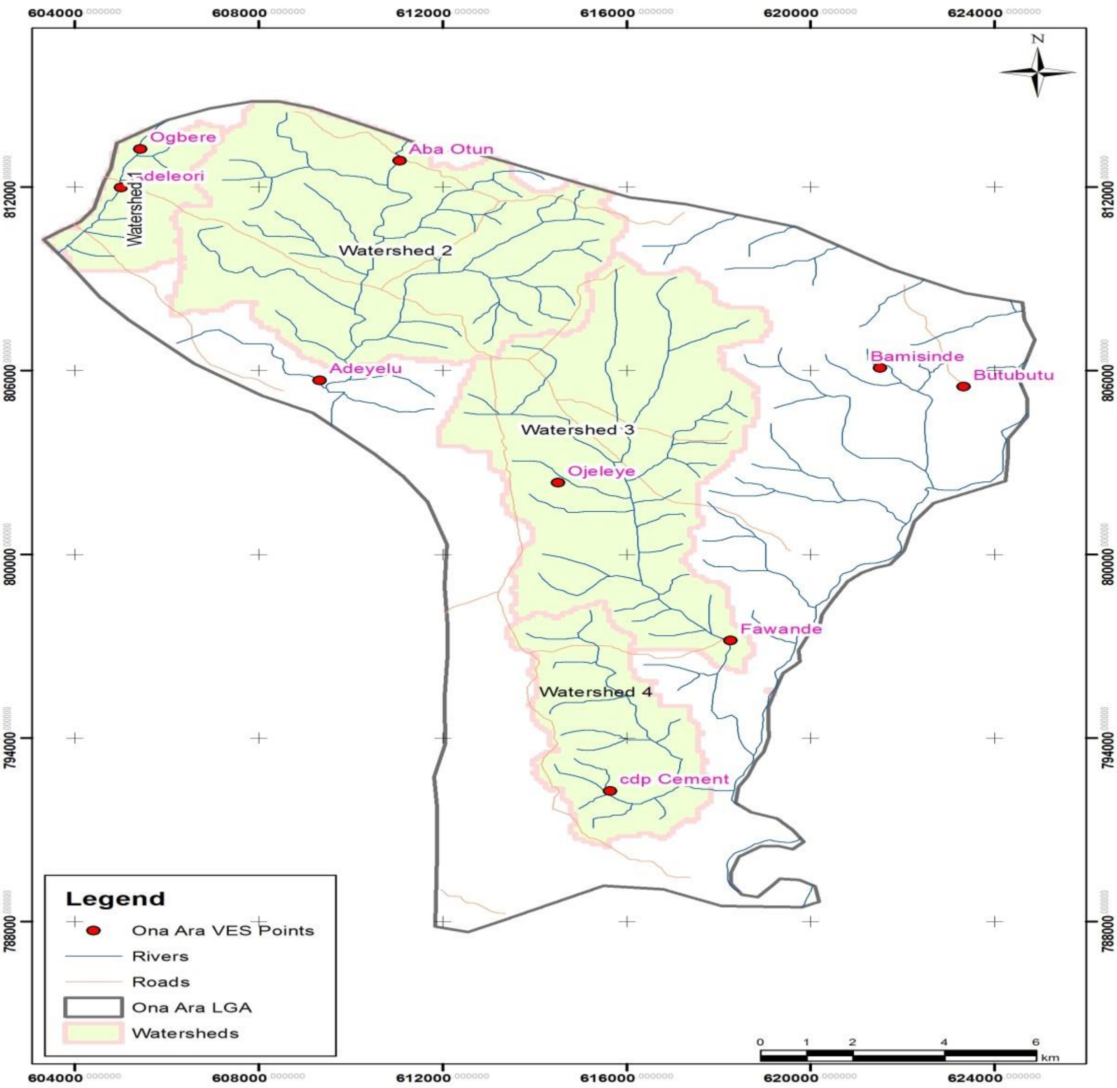


Figure 7. VES mapping using randomized position selection method.

which was only observed in one out of the nine locations is 2329m while the thickness is 6.4m.

VES at GIS Delineated Locations

The interpretation of VES conducted at three of the locations where lineaments were delineated by GIS and remote sensing analysis reveals the presence of seven geoelectric layers. These geoelectric layers fall into five groups and these are top soil, weathered basement, fresh and fractured basement. The resistivity of the top soil ranges between 39 and 77 ohm-m while the thickness varies between 0.5 and 0.9m. The resistivity of the weathered basement ranges between 27 and 200 ohm-m while the thickness varies between 0.7 and 9.0m. The resistivity of the fractured basement ranges between 177 and 6870 ohm-m while the thickness varies between 13.0 and 57.6m. The resistivity of the fresh basement ranges between 242 and 9430 ohm-m while the thickness varies between 20.9 and 97.4m.

VLF-EM

Traverse 1 (Lineament 19)

This traverse spans 300 m trending approximately E-W and is deployed to intercept lineament 19. On this section, multiple conductive zones (lineaments) were identifiable with two being very significant at lateral distance of about 50 m and at 125-170 m (Figure 8a). However, considering the point of interception of the first

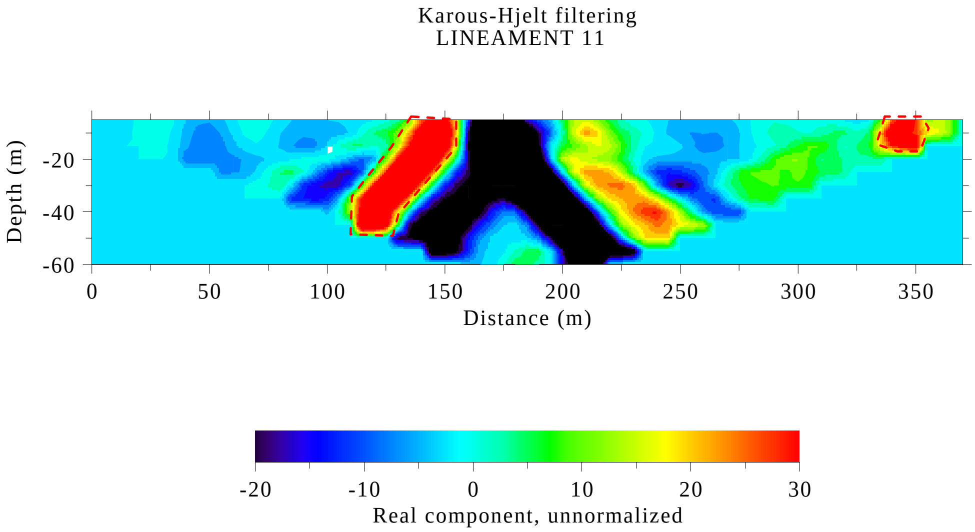


Figure 8. VLF-EM of traverse (a) Traverse 1 (Lineament 19) (b) Traverse 2 (Lineament 4) (c) Transverse 3 (Lineament 11).

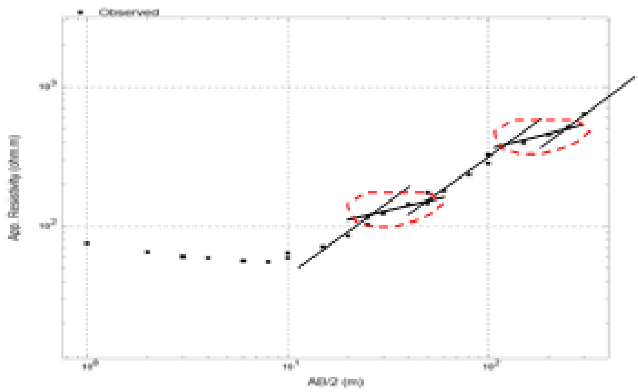
lineament, that is, close to the start off point of the traverse, its attitude cannot be fully deciphered. However, the second lineament dips westwards and is mostly developed at lateral distance of 150 m. Consequently, VES was conducted on the second lineament while varying current electrode separation between 2 and 600 m. On qualitative examination of the VES curve generated at this station, two fractured horizons are readily observed (Figure 9a). The quantitative interpretation of the data set yields 7 geo-electric layers from ground surface to a depth of about 155 m. The summary of the layers with geo-electric parameters is presented in Table 4. The first observed fracture is delineated at depths between 24 and 37 m, while the second is delineated between 97 and 155 m.

Traverse 2 (Lineament 4)

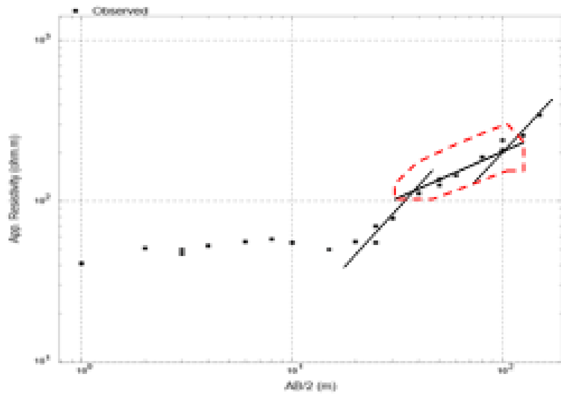
This traverse spans 350 m trending approximately E-W and is deployed to intercept lineament 4. On this section, a major lineament is identifiable at lateral distance of between 150 and 200 m dipping eastwards (Figure 8b). Consequently, VES was conducted at lateral distance of 180m while varying current electrode separation between 2 and 300 m. Owing to space constraints, the half Schlumberger array was employed. On qualitative examination of the VES curve generated at this station, a fractured horizon is readily observed (Figure 9b). Quantitative interpretation of the data set yields 6 geo-electric layers from ground surface to a depth of about 68 m. The observed fracture is delineated at depths between 38 and 68 m.

Traverse 3 (Lineament 11)

This traverse spans 370 m trending approximately NW-SE and is deployed to intercept lineament 11. However, there was difficulty in intercepting this lineament owing to inaccessibility. Nevertheless, the traverse was taken as close as possible to the GIS identified lineament (Figure 8c). On this section, multiple conductive lineaments are identifiable with two being incredibly significant: the first at lateral distance of between 110 and 150 m and the second at distance of about 345 m. However, considering the proximity of the second lineament to the GIS identified lineament it was chosen for the Vertical Electrical Sounding. The VES was conducted while varying current electrode separation between 2 and 600 m. On qualitative examination of the VES curve generated at this station, a fractured horizon is observed (Figure 9c). Furthermore, the probe terminated within this horizon as its extent could not be ascertained owing to space limitation for wider current



(a)



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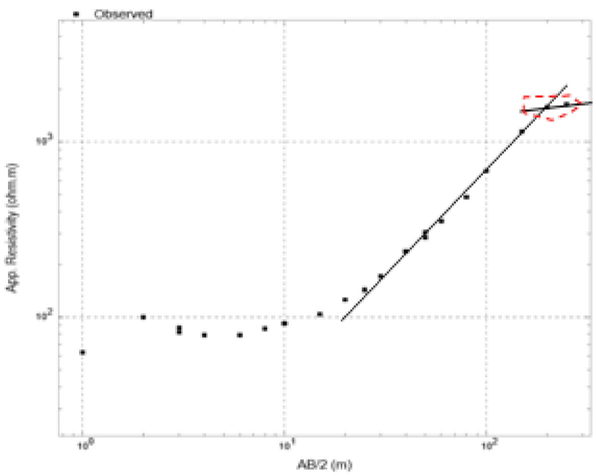

(c)

Figure 9. VES Curve of Traverse (a) Traverse 1 (Lineament 19) (b) traverse 2 (Lineament 4) (c) Transverse 3 (Lineament 11).

electrode (Figure 8 (a) and b). Quantitative interpretation of the data set yields 7 geo-electric layers from ground surface to a depth of about 84 m. The observed fracture is delineated at depth beyond 84 m.

Ground confirmation of GIS identified lineaments in the study area was attempted using the Electrical Methods of geophysical prospecting. The VLF-EM and Electrical Resistivity via Vertical Electrical Sounding were employed within the "I" designated grid of the map with the survey area measuring approximately 3 by 2 km (Figure 10). Three traverses were deployed across lineaments 19, 4

Table 4. Lithologic description of VES at GIS delineated lineament locations.

Transverse	Layer	Resistivity (Ωm)	Thickness (m)	Depth to layer base (m)	Lithology
Traverse 1	1	77	0.9	0.9	Topsoil
	2	52	9.0	9.9	Weathered basement
	3	328	14.0	23.9	Fresh basement
	4	177	13.0	36.9	Fractured basement
	5	1320	60.5	97.4	Fresh basement
	6	731	57.6	155.0	Fractured basement
	7	2540	-----	-----	Fresh basement
Traverse 2	1	39	0.7	0.7	Topsoil
	2	60	4.8	5.5	Weathered basement
	3	27	6.3	11.8	
	4	242	10.8	22.6	Fresh basement
	5	1537	15.3	37.9	Fresh basement
	6	645	29.9	67.8	Fractured basement
	7	7692	-----	-----	Fresh basement
Traverse 3	1	50	0.5	0.5	Topsoil
	2	200	0.7	1.2	Weathered basement
	3	51	3.2	4.4	
	4	89	4.3	8.7	Partially weathered basement
	5	528	12.2	20.9	Fresh basement
	6	9430	63.5	84.4	
	7	6870	-----	-----	Fractured basement

and 11 and VLF-EM was conducted along the traverses. On each traverse, a point of anomalous conductivity corresponding to a probable lineament was further investigated for presence of fractures using the VES. Consequently, a total of six lineaments were delineated from the VLF-EM survey and three of them were confirmed using the VES technique. Coordinates of the delineated lineaments are given in Figure 10 indicating the traverses on which they were delineated.

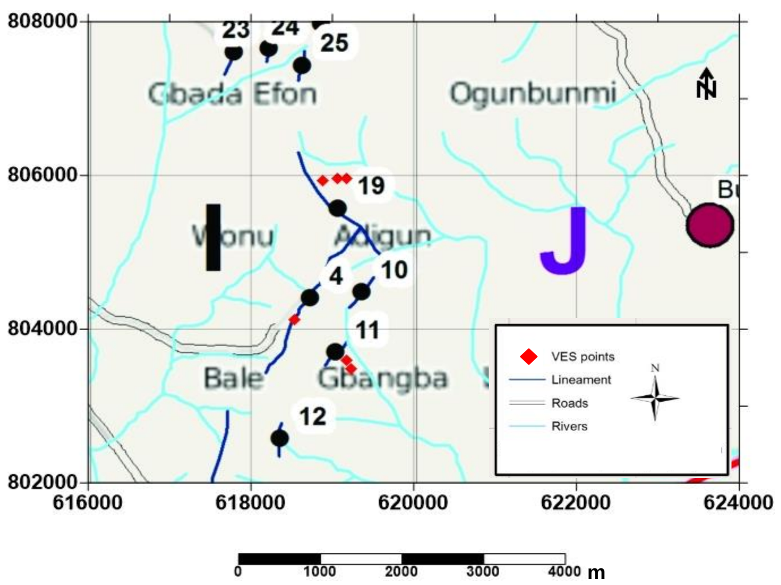

Figure 10. Map of the study area showing the inferred lineaments.

Comparison of Geophysical Survey at Randomized locations and GIS delineated lineament locations

Out of the nine randomized VES locations, it was observed that it was only in one location (Fawande) that a slightly fractured zone was readily observed as aquiferous unit in the basement complex terrain. Aquiferous units are mainly found in the thick and porous weathered overburden (saprolite zone) and the fractured part of the bedrock (Schemang, 1993; Aboh and Osazuwa, 2000; Mallam 2004). Also, the zones with thick overburden corresponding to basement depression have been identified with weathered / fractured basement as potential layer for groundwater development.

From the results of VES and VLF-EM carried out of the GIS delineated lineament locations, it was observed that fractured zones were readily observed in all the three locations as the use of GIS and remote sensing guides in the location where geophysical survey should be carried out to have a good groundwater potential yield in the study area.

A comparison of the VES obtained from soundings at randomized VES stations to that of GIS delineated VES station shows remarkable difference in resistivity structure. Thus, groundwater exploration at the GIS delineated lineament VES station is expected to have a high groundwater yield.

CONCLUSION

The study has focused on the effectiveness of remote sensing and GIS and geophysical survey in the identification and delineation of groundwater potential zones in Ona-Ara Local Government Area of Oyo State, Nigeria. The spatial distribution of various zones of groundwater potential obtained generally shows regional prototypes related to land use/cover, geology, landforms, and lineaments. The exceptionally good and good zones are distributed along the lineaments and valleys with and without structural control, highlighting the importance of lineaments and geomorphological units for groundwater investigations. The fractured zones were readily observed from the Vertical Electronic Sounding Curve of areas or regions where lineaments were identified while there was a low success rate at Randomized Vertical Electrical Sounding locations. Also, it was observed that shallow nature of facture was observed at the point where fractures were observed during randomized VES. RS and GIS tools are less time consuming and cost effective, which provide sufficient support in groundwater studies where the region lacks previous hydrogeological investigations and data. The overall results demonstrate that remote sensing and GIS are a potential tool in locating groundwater reservoir areas and this can help in solving the complex geohydrological problems associated with groundwater occurrence and its development. The integrated map could be useful for various purposes such as sustainable development of groundwater as well as identification of priority areas for implementation of water conservation projects and programmes in the area.

REFERENCES

Abdullahi, B. U., Rai, J. K., Momoh, J., and Udensi, E. E. (2013). Effects of Lineaments in Groundwater Occurrence. *International Journal of Environment* 8(1): 22-32

Aboh, H. O., and Osazuwa, J. B. (2000). Lithological Deductions from Regional Geoelectric Investigation in Kaduna State Nigeria. *Nigerian Journal of Physics* 12: 1-7

Adiat, K. A. N., Olayanju, G. M., Omosuyi, G. O, and Ako, B. D. (2009). Electromagnetic Profiling and Electrical Resistivity Soundings in Groundwater Investigation of a Typical Basement Complex – A Case Study of Oda Town Southwestern Nigeria. Ozean J. Appl. Sci. 2(4): 333-359.

Ariyo, S. O., and Adeyemi, G. O. (2009). Role of Electrical Resistivity Method for Groundwater Exploration in Hard Rock Areas: A Case Study from Fidiwo/Ajebo Areas of Southwestern Nigeria. Pac. J. Sci. Technol. 10(1): 483-486.

Bobba, A. G., Bukata, R. P., and Jerome, J. H. (1992). Digitally processed satellite data as a tool in detecting potential groundwater flow systems. *Journal of Hydrology*, *131*(1–4), 25–62.

Campbell, J. B. (2002). Introduction to Remote Sensing. CRC Press.

Chandhary, B., Kumar, B., Saroha, K., Yadar, G., Singh, M., Sharma, A., Pandey, M., and Singh, P. (2001). Integrated Ground- water Resources Mapping in Gurgoan District (Haryana) India, Using Remote Sensing and GIS Techniques

Hubbard, S., and Rubin, Y. (2005). Introduction to Hydro geophysics, Springer, Netherlands, 3-22

Khan, M. A., and Moharana, P. C. (2002). Use of Remote Sensing and Geographical Information System in the Delineation and Characterization of Ground Water Prospect Zones, Jour. India. Soc. Rem. Sen, 30(3): 131-141

Magesh et al. (2012). Delineation of Groundwater potential zones in Theni district, Tamil Nadu, using Remote Sensing, GIS and MIF techniques. Geoscience Frontiers 3(2) 189 -196

Mallam, A. (2004). Fresh Basement: Revealed from Resistivity Method. Zuma, *Journal of Pure and Applied Science* 6(1):6-9.

Manimaran, D. (2012). Groundwater geochemistry study using GIS in and around Vallanadu Hills, Tamilnadu, India, Res. J. recent sci, 1(6), 32–37

Meijerink, A. M. J. (2000). Groundwater. In G. A. Schultz and E. T. Engman (Eds.), *Remote sensing in hydrology and water management* (pp. 305–325). Berlin: Springer.

Nag, S. K., and Ghosh, P. (2013). Delineation of groundwater potential zone in Chhatna Block, Bankura District, West Bengal, India using remote sensing and GIS techniques. *Environmental earth sciences*, *70*(5), 2115-2127.

Nag, S. K., and Kundu, A. (2016). Delineation of Groundwater Potential Zones in Hard Rock Terrain in Kashipur Block, Purulia District, West Bengal, using Geospatial Techniques. *International Journal of Waste Resources*, *2016*.

NPC (2006). National Population Commission Report of Census 2006.

Phukan I., Ravindran K. V. and Banerjee D. M. (1999). Delineation of Groundwater Prospect Zones using Remote Sensing and Geographic Information System in the West Garo Hills District, Meghalaya, “Geoinformatics: Beyond 2000”, an International Conference on Geoinformatics for Natural Resource Assessment, Monitoring and Management, Jointly Organized by Indian Institute of Remote Sensing (National Remote Sensing Agency) Dehradun, India and ITC (International Institute for Aerospace Survey and Earth Sciences) The Netherlands, 203-211

Richards, J. A., and Richards, J. (1999). Remote Sensing digital image analysis. Springer.

Sankar, K. (2002). Evaluation of Groundwater Potential Zones Using Remote Sensing Data in Upper Vaigai River Basin, Tamil Nadu, India, Jour. India. Soc. Rem. Sen, 30(3), 119-129

Saraf, A. K. and Choudhury P. R. (1998). Integrated Remote Sensing and GIS for Groundwater Exploration and Identification of artificial recharge sites, Intl. J. Rem. Sen, 19(10), 1825-1841

Shahid, S., and Nath, S. K. (2002). GIS integration of remote sensing and electrical sounding data for hydrogeological exploration. *Journal of Spatial Hydrology*, *2*(1), 1–10.

Shemang, E. N. Jnr. (1993). Groundwater Potentials of Kubanni River Basin, Zaria, Nigeria from DC Resistivity Study. Water Resources 4(1and2):36-42

Singh, A. K. and Prakash, S. R. (2002). An integrated approach of remote sensing, geophysics and GIS to evaluation of groundwater potentiality of Ojhala sub-watershed, Mirjapur district, U.P., India (Online). Available from http://www.GISdevelopment.net (accessed 25 June 2003).

Srivastav, P., and Bhattacharya, A. K. (2000). Delineation of groundwater potential zones in hard rock terrain of Bargarh District, Orissa using IRS, Jour. India. Soc. Rem. Sen, 28(2-3), 129–140

Todd, D. K., and Mays, L. W. (2005). *Groundwater hydrology* (3rd ed.). New Jersey: John Wiley and Sons.

Waikar, M. L., and Nilawar, A. P. (2014). Identification of Groundwater Potential Zone using Remote Sensing and GIS Technique. International Journal of Innovative Research in Science, Engineering and Technology (An ISO 3297: 2007 Certified Organization) Vol. 3, Issue 5, www.ijirset.com

Srivastava, P. K., and Bhattacharya, A. K. (2006). Groundwater assessment through an integrated approach using remote sensing, GIS and resistivity techniques: a case study from a hard rock terrain. *International Journal of Remote Sensing*, *27*(20), 4599-4620.

Preeja, K. R., Joseph, S., Thomas, J., and Vijith, H. (2011). Identification of groundwater potential zones of a tropical river basin (Kerala, India) using remote sensing and GIS techniques. *Journal of the Indian Society of Remote Sensing*, *39*(1), 83-94.

Elbeih, S. F. (2015). An overview of integrated remote sensing and GIS for groundwater mapping in Egypt. *Ain Shams Engineering Journal*, *6*(1), 1-15.

Yeh, H. F., Lin, H. I., Lee, S. T., Chang, M. H., Hsu, K. C., and Lee, C. H. (2014). GIS and SBF for estimating groundwater recharge of a mountainous basin in the Wu River watershed, Taiwan. *Journal of Earth System Science*, *123*(3), 503-516.

Raju, G. S. (2015). Identification of ground water prospecting zones using remote sensing and gis techniques in Chintakommadinne Mandal, YSR District, AP, India. *International Journal of Research in Engineering and Applied Sciences*, *5*(10): 88-97.