



Groundwater potential assessment as a preliminary step to solving water scarcity challenges in Ekpoma, Edo State, Nigeria

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Abstract

Water scarcity is a major challenge around the world, particularly in Ekpoma community, Edo State, Nigeria. The population depends on water vendors and reservoir tanks as a means of water supply. This study aims to make an assessment of groundwater potentials for effective and sustainable water resources management in Ekpoma. Seven criteria were considered to determine groundwater potentiality including slope, rainfall, land use, drainage density, distance to lineament, soil, and geology. According to their impact on groundwater, the parameters were grouped into fuzzy membership categories. The groundwater potentiality map was generated by overlaying the fuzzy members. Of the 101.2 km² area of Ekpoma, the high, medium, and low potential zones cover 7.9, 6.4, and 85.7% of the total area, respectively. High and medium groundwater zones were identified mostly on the outskirts of the built-up areas. These groundwater potential areas were discovered to be predominant around the lineament areas suggesting that lineament plays a major role in the potential for groundwater in the study area. Reservoirs can be assigned in these high potential areas. Conclusively, the generated groundwater prospective map can be exploited for hydrological policy making and also by water supply engineers to predict the availability of groundwater.

Keywords GIS · Groundwater potential · Water scarcity · Fuzzy logic · Nigeria

Introduction

Water is a significant universal resource that sustains life (Ajibade et al. 2020a; Akosile et al. 2020; Ilori et al. 2019), supports human needs and economic development (Opafola et al. 2020; Ugya et al. 2018; Sinha et al. 2012) and as a result of its free existence in nature, is habitually not

reckoned with, taken for granted and neglected, especially in developing nations (Ajibade et al. 2015). Meanwhile, water scarcity has been argued to be one of the fastest-growing pandemics in the world currently. Nigeria has abundant water resources, which the government at all levels have failed to utilize to ensure sustainable and adequate access to a safe, portable, and affordable water supply to the populace. (Gusikit and Lar 2014; Kolawole 2015; Longe et al. 2010). The issue of water scarcity is substantially overwhelming,

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based on the fact that Nigeria represents the eight most populous nations in the world with a total population of over 180 million people. Nigeria's water sector confronts momentous challenges with 71 million people still living without access to better water services and just 61% of Nigerians having access to improved water (World Bank Group 2017; Adewumi et al. 2020). Nearly half of the population has access to basic water, merely 31% has access to improved water on-premises, and a meagre 7% has access to piped water on-premises (World Bank and UNICEF 2015a; b). For this reason, the bulk of those with the right to use better water must tour long distances to utilize these sources, which probably influences their consumption rates. Groundwater is a component of the natural water cycle that exists in underground strata. Groundwater is formed when surface water from rainfall seeps into the earth and fills the pores of the soil and rock fragments. Groundwater flows through the aquifer layer towards points of discharge, such as wells, rivers, lakes, and oceans (Okoli et al. 2017). The importance of groundwater as a supply source to the socio-economic development of a country is tremendous (Bera and Bandyopadhyay 2012; Sunmonu et al. 2012). Some states in Nigeria such as Benue, Cross River, Taraba, Kano, and Kogi make use of rivers as a means of water supply for agricultural irrigation and industrial use (Miller et al. 2006). Due to the problem of pollution and contamination, these river water cannot be used for domestic purposes as they are not hygienic for human consumption. There is a need for an alternative means to supply water for domestic use which can be achieved using groundwater. Water infrastructure improvements will enhance the social well-being and public health (Joseph 2012).

Geographic Information System (GIS) is a tool that facilitates the integration, management and analysis of large data volume, to delineate groundwater potential (Ahmed et al. 2010; Jaiswal et al. 2003). Remote sensing (RS) has been widely accepted as an effective complementary tool for mapping natural resources across the world. The integration of RS and GIS has been utilized to determine groundwater potential by employing the weighted linear combination (WLC) technique to integrate these criteria (land use, soil, slope, rainfall, elevation, lithology, lineament density, drainage density, etc.) within the GIS to generate potential groundwater zones via ranking each category of these parameters (Al-Shabeeb et al. 2018; Chaudhary and Kumar 2018; Dinesan et al. 2015; Gumma and Pavelic 2013; Waikar and Nilawar 2014). Elewa and Qaddah (2011) integrated enhanced thematic mapper plus (ETM+) images, GIS, watershed modelling system (WMS), and weighted spatial probability modelling (WSPM) to delineate the groundwater prospective areas in Egypt's Sinai Peninsula. Khan and Jhariya (2019) used DRASTIC model by modifying it into four types namely DRASTIC, Modified DRASTIC-Lu,

DRASTIC AHP, and Modified DRASTIC-Lu AHP to assess the groundwater vulnerable zone. This modification was achieved by adding the LULC parameter in the real DRASTIC model and also applying the AHP technique to ascertain the rating and weight.

Moreover, Al Saud (2010) used GIS and RS by processing high-resolution satellite images with the aid of ERDAS IMAGINE software to recognize terrain elements controlling the subsurface rock behaviour for the purpose of delineating groundwater prospect zones. With a combined approach of using RS and GIS, these researchers (Barik et al. 2017; Venkateswaran and Ayyandurai 2015; Prasad et al. 2008) employed the topographic map to prepare a base map and generate thematic maps for the creation of groundwater prospective map by incorporating the study area's geology, slope, drainage-density, geomorphology, and lineaments map. The identification of groundwater potential areas by using IRS-1D (LISS III) and Landsat Thematic Mapper (TM)/Enhanced TM (ETM+) digital data, and digital elevation models (DEMs) from the Shuttle Radar Topography Mission (SRTM) were analysed alongside with other collateral data to extract various thematic maps (geomorphology, land use/land cover, soil, drainage density, river gradient, lithology, lineament, and slope maps) necessary for groundwater modelling in a hard rock terrain (Sinha et al. 2012; Srivastava and Bhattacharya 2006; Vijith 2007). The advent of RS and GIS presents immense possibilities for analysing, manipulating, and producing valuable spatial data comprising the geology, hydrogeology, geomorphology, and the identification of groundwater prospective areas as highlighted in the report of Lakshmi and Reddy (2018) and Sener et al. (2018). Akinluyi et al. (2021) acquired the groundwater potentiality mapping of the hard rock terrain of Ondo State, Southwestern Nigeria, by employing the remotely sensed data and electrical resistivity data.

Furthermore, fuzzy logic is a phenomenon based on the concept of fuzzy sets, which are an extension of crisp Boolean sets that combine Lukasiewicz's (1970) idea of having grades of membership with a multi-valued logic. It allows partial membership between 0 and 1 (i.e. [0, 1]) to denote the degree to which an entity fits into a specific class. The use of negation of attribute expectations as cut-off values to highlight characteristics of significant attributes and deemphasize low ratings of unimportant attributes distinguishes this strategy (Qiu et al. 2014). It has been employed also as a supporting tool with GIS in making essential decisions. Khorram et al. (2015) used a model that combined GIS with fuzzy logic based on multi-criteria assessment techniques. To manipulate and present spatial data, the ESRI Arc GIS 10 term method was used. All standardized maps were overlaid using the fuzzy AND operator. The fuzzy set theory was applied to standardize criteria employing various fuzzy membership functions while the AHP was used to

determine the relative importance of the criteria (Donevska et al. 2012). Recent studies reported excellent outcomes on groundwater prospect evaluation via the integration of GIS and RS technologies with fuzzy-logic based decision-making approach (Halder et al. 2020; Ahmad et al. 2020; Taheri et al. 2020; Qadir et al. 2020). However, regional studies based on the usage of geospatial techniques for the delineation of groundwater potential in Nigeria are very limited. In this study, the demarcation of groundwater potential zones in Ekpoma, Edo State, Nigeria using fuzzy logic integrated with GIS was carried out.

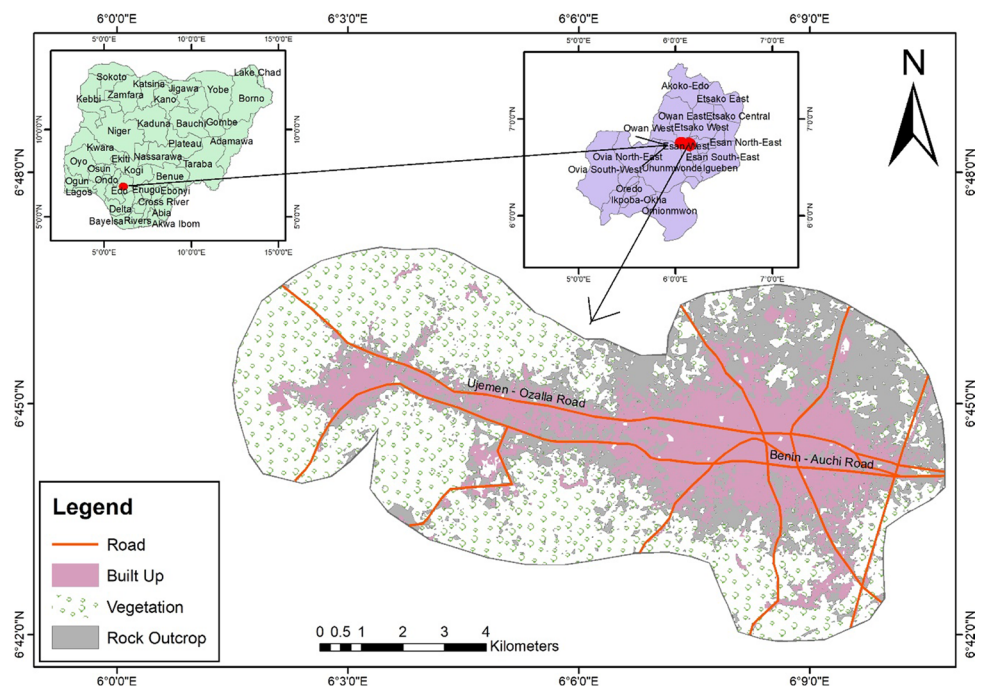
Historically, Ekpoma is called "a town on a hill" or "a dry land" because of the prevalence of water scarcity in the community. Ekpoma is situated on the apex of a partly flat-undulating Esan Plateau which is mainly lacking in water retaining aquifers and there is no presence of highlands which may serve as feasible catchment basins for surface rivers like those observed in areas with groundwater sources or potentials (Alens 2017). The geological features of Ekpoma do not permit the downward flow of rainwater to recharge the aquiferous units as a result of thick deposits of laterites (Salufu and Ujuanbi 2015) which offers unfavourable hydro-geological condition for groundwater to occur. About 90% of the residences in Ekpoma have underground tanks used for the storage of rainwater during the wet season (James 2016). The provision of water in Ekpoma was observed to be inadequate. There are no provisions by the government to supply water to households, even when they have a readiness to pay for the services (Toolkit 2006). During the dry season, the residences of the community have to depend on commercial tanker water supply which is usually at an expensive

rate (Turay et al. 2014). This is as a result of the continuous prevalence of water scarcity in the community. There is a need for adequate groundwater potential assessment for the purpose of siting boreholes to supply water for Ekpoma community in order to solve the problem of scarcity. Remote sensing and GIS are dependable, economical, and time-saving tools and have been widely used for conserving and managing water resources recently. Thus, this research aims to make an assessment of groundwater potential in Ekpoma, Edo State, Nigeria using GIS and RS. Seven conditioning factors including slope, rainfall, land use, drainage density, distance to lineament, soil, and geology are considered. Thematic layers were created for each factor using remotely sensed data in a GIS environment. The factors are assigned scores based on their impact on groundwater potentiality. Groundwater potentiality in Ekpoma was determined by overlaying all weighted factor thematic layers.

Description of the study area

Ekpoma is a big town in Edo State Nigeria. It is the head office of Esan West Local Government Area. Ekpoma runs from longitude 6°00' E to 7°00' E and latitude 5°42' N to 5°48' N (Fig. 1). According to the National Population Commission (NPC) census of 2006 and National Bureau of Statistics (NBS), the population of Ekpoma is 127,718, but the estimated projected population assuming the same growth rate for 10 years is currently approximately 167,300 (NPC 2006). The estimate terrain elevation above sea level is 363 m. The soil type is generally dystic nitosol with

Fig. 1 Study area map of Ekpoma



geology of clay, clayey sandstone, and shale. The natural rain vegetation in Ekpoma can be characterized as a rain forest with a tropical climate. Ekpoma's climate is categorized as tropical and the Koppen–Geiger climate classification is Aw. The annual average temperature is 26.1 °C and the annual average rainfall ranges between 1666 and 2025 mm.

Generally, the relief scenery of Edo State and Nigeria is dominated by basement complex and sedimentary rocks. Therefore, Ekpoma relief is covered by sedimentary rocks of the Miocene Pleistocene Age at the surface level, which are relatively stabilized underneath by the basement complex rocks (Alens 2017). Moreover, the geologic formation is mainly underlain by Bende-Ameki formation with the exception of few areas located in the extreme boundary line where formation transition occurs to either Imo Shale or Ogwashi-Asaba. This geologic characteristics of Bende-Ameki formation promote unfavourable hydrogeological condition for the absence of groundwater in Ekpoma town (Orobator and Odjugo 2015).

Materials and methods

Acquisition of data

The United States Geological Survey (USGS) website (<https://www.earthexplorer.usgs.gov>) provided the Landsat 8 imagery for Ekpoma. The imagery was acquired on January 27th 2016. This imagery was utilized to create a map of land use/land cover (LULC). The Global Land Cover Facility website (<https://www.glovis.usgs.gov>) provided imagery from the Shuttle Radar Topography Mission (SRTM) for Ekpoma. This imagery was employed to produce study area's slope, lineament and drainage as criteria for determining groundwater potential. The Nigeria Geological Survey Agency provided a scanned geological map for Edo State. The soil type in Ekpoma was obtained from the Harmonized World Soil Database viewer. The rainfall data for 30 years (1989–2018) were acquired from ERA-interim satellite data. The data were used to generate the rainfall spatial distribution over Ekpoma using inverse distance weighting.

Methods

The advances in GIS and RS technologies have been widely applied in groundwater potential mapping using multi-hydrogeological factors as the criteria. Previous studies have widely considered conditioning factors such as LULC, lineament, soil type, rainfall, geology, and topographical attributes (Hussein et al. 2017; Agarwal and Garg 2016; Al-Shabeeb et al. 2018; Bagyaraj et al. 2013). Therefore, in this study, seven conditioning factors were considered to determine the groundwater potentiality in Ekpoma, Nigeria.

These factors include slope, rainfall, drainage density, lineament density, land use, soil, geology. The fuzzy membership function, which assigns values between 0 and 1 to the various criteria based on their impact on groundwater potentiality was applied (i.e. each factor was put into fuzzy membership classes). Each criterion was assigned fuzzy membership according to their impact on groundwater potential. Traditional overlay analysis, such as suitability models, can be solved using fuzzy logic. (Isalou et al. 2013). The overlay technique of fuzzy logic is used for dealing with imprecisions in spatial data attribute and geometry. The fuzzy logic overlay determines the likelihoods of membership in all sets based on the various fuzzy membership groups provided for the several requirements (Ajibade et al. 2019; Khorram et al. 2015). A suitability map is the end result. Reclassification was performed for the several thematic layers and weighting of the thematic layers was assigned based on previous studies. Figure 2 depicts the flow chart for the methods used for the data analysis while Fig. 3 reveals the flowchart showing the developed fuzzification logic system used.

Conditioning factors, results and discussion

This section highlights the results of each criterion and the final overlay map and discusses the steps taken and their relevance to the study. To achieve uniformity, the criteria maps were all scaled to a 15 m resolution before being assigned fuzzy membership.

Slope

The slope is the extent of change in altitude and referred to as one of the crucial parameters that affect the process of groundwater recharge. The SRTM Digital Elevation Model (DEM) with a 15 m resolution was used to generate the slope map using a surface analysis tool in the ArcGIS 10.2 environment. The slope ranges between 0° and 33.19°. Slope affects the rate of infiltration into the underlying groundwater table indicating zones with a suitable location for groundwater potential. The regions with higher or steeper slope result into a high rate of runoff which does not allow enough time for infiltration to recharge groundwater during rainfall (Ajibade et al. 2020b; Kumar and Krishna 2018; Ghosh et al. 2016) and such steep slopes are elevated zones characterized by hilly terrain (Olabode 2019). Places with lower or gentle slope degrees are flat or almost flat decelerating the velocity of runoff. The runoff rate from areas with lower slope offers sufficient time for the water to infiltrate into and recharge the underlying groundwater. Fuzzy values closer to 1 were assigned to the lower slope and higher slopes values closer to 0. Fuzzy MS small was used to assign the slope into a member as it

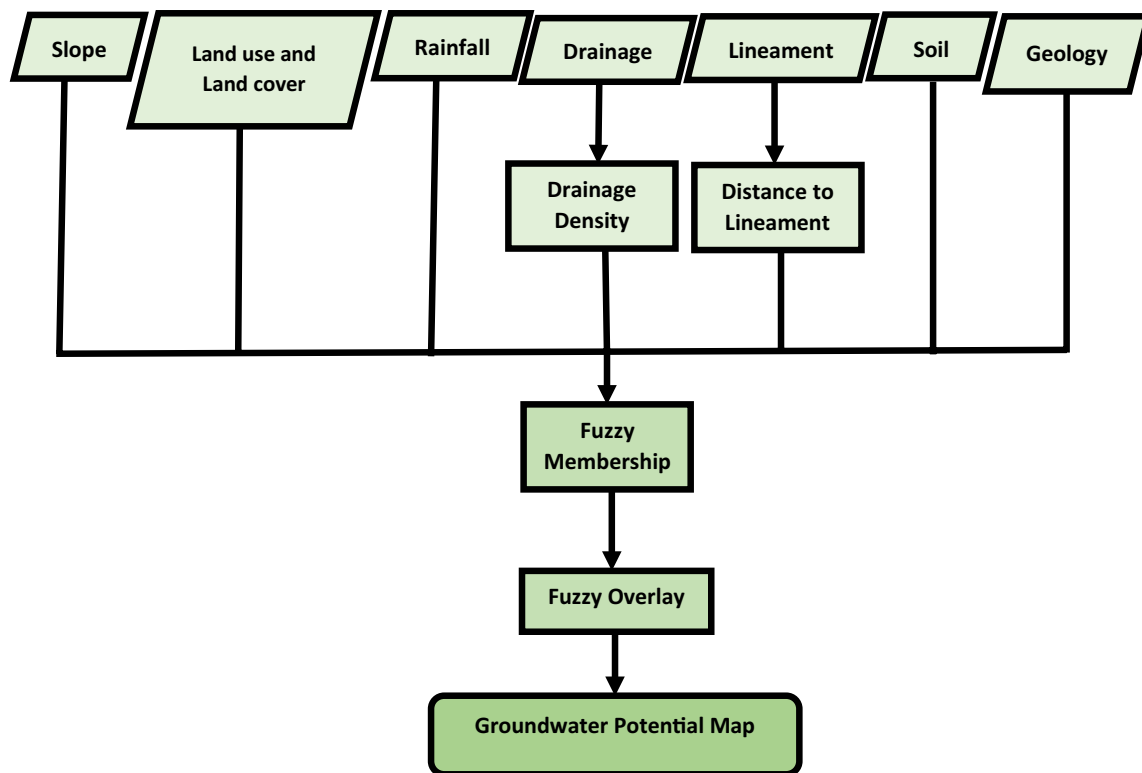


Fig. 2 Data analysis and methodology flow chart

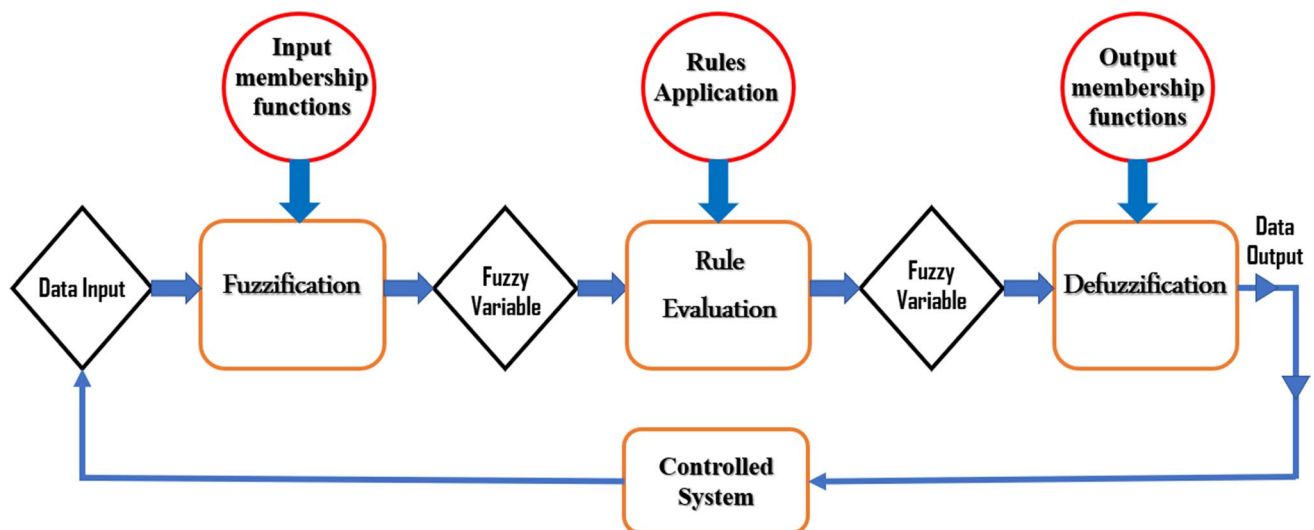


Fig. 3 Flowchart showing the developed fuzzification logic system

is very low slope degrees which are flat or almost flat that enhances groundwater recharge more which is similar with the gentle slope obtained in the study by Mageshkumar et al. (2019) representing zones with good groundwater prospect. Figure 4 exhibits the map of slope distribution in Ekpoma, Edo State.

Land use land cover (LULC)

Land use is relevant to groundwater because it has a major effect on both its quality and recharge rates, especially in an arid environment. It is a prime indicator of spatial impact extents which give a comprehensive understanding

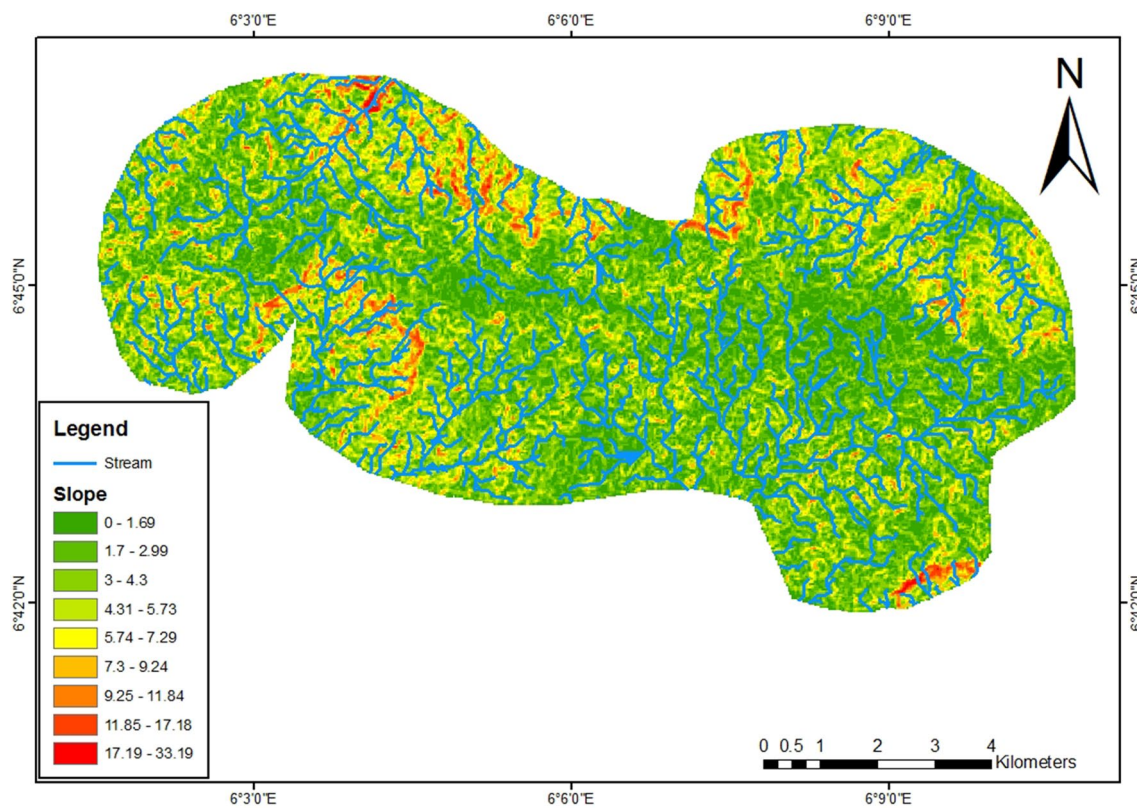


Fig. 4 Slope map of the study area

of a variety of ways land artificially used at present and in the future (Adewumi et al. 2016, 2017). It gives information that helps in taking necessary actions to manage the natural ecosystem and resources (Singh et al. 2018). Also, it affects the runoff, evapotranspiration, and rate of infiltration into the underlying surface (Aladejana et al. 2016; Aluko and Igwe 2017). The study area's Landsat 8 imagery was subjected to supervised classification, and this was applied to create the map of the study area's LULC. The supervised classification was performed on the composite layer using the maximum likelihood classifier to generate the land use map of Ekpoma (Eastman 1999). Four land use classes were generated for the area: rock, bare surface, built up and vegetation. The land cover map was reordered to make it suitable for the analysis. Rocky areas are impermeable; they enhance high runoff and no infiltration. The rocky areas were classified as zero since they would not permit infiltration for recharge of groundwater because of the presence of paved surfaces. Built-up areas and vegetation were reclassified and ranked as two. Built-up areas experience low infiltration as some of the areas are covered with houses depicting urban expansion (Daramola et al. 2018; Waikar and Nilawar 2014) and paved surface which enhances high runoff. Vegetation areas including

farmland, grassland, or forested area were also ranked as two. Forested area has canopy cover which could limit the amount of rainfall reaching the surface. Agricultural practices also alter the soil surface and sometimes cause thin soil cover which could also reduce the rate of infiltration into groundwater. Bare surfaces were ranked the highest with a value of four. They have exposed surfaces which allow direct drops of rainfall on them which encourage the easy penetration of water, thereby, recharging the underlying aquifers and providing an indication of groundwater accessibility. The soils are loosed by the rainfall and allow for better porosity and infiltration of rainwater to recharge the groundwater. These changes observed in this study can be solely attributed to the anthropogenic activities that have occurred over time. In validating the land use map, the Kappa coefficient, which is a measure of how the classification results compare to values assigned by chance, was utilized. The higher the kappa coefficient, the more accurate the classification is (Anand 2017). The kappa coefficient value of 0.93 was obtained, indicating high accuracy. Figure 5 depicts the various land use/land cover features of Ekpoma. Figure 6 indicates the reclassification of the land use/land cover type according to groundwater potential suitability.

Fig. 5 Land use/land cover map of Ekpoma

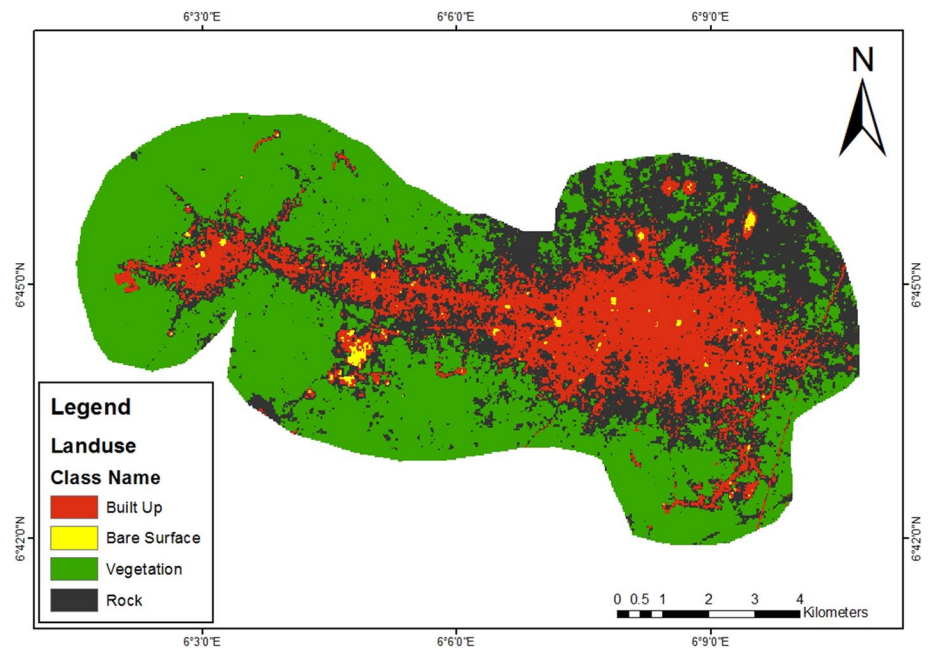
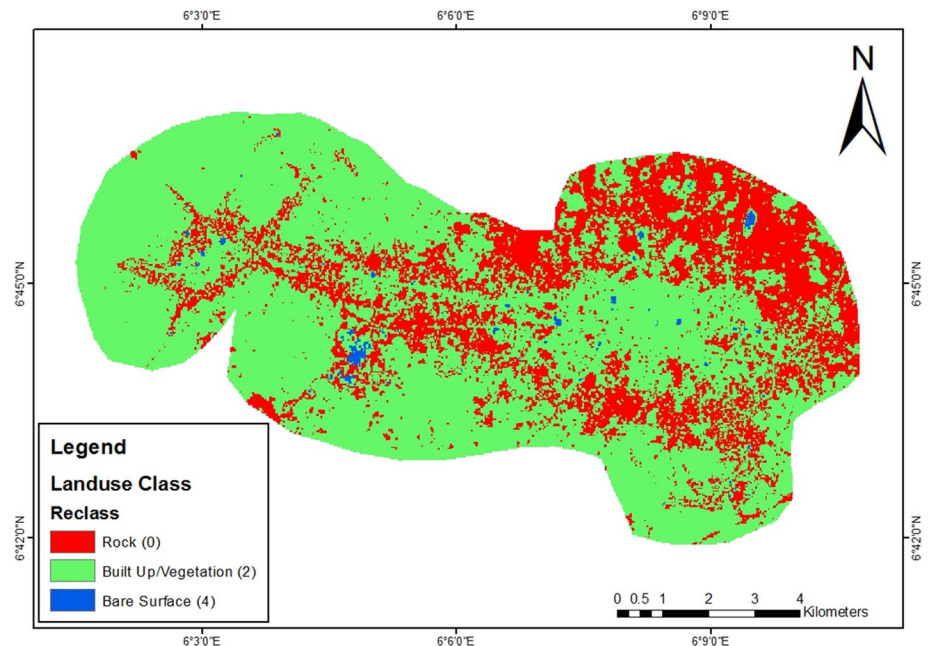


Fig. 6 Land use/land cover reclassification map of the study area



Rainfall

Rainfall represents the main water source in the water cycle and the most influential element in the groundwater recharge of an area. It determines the quantity of water that would infiltrate into the groundwater system (Hussein et al. 2017; Agarwal and Garg 2016). In this study, the rainfall data of 30 years were utilized. The average annual rainfall for the 30-year period in Ekpoma ranges from 141.4 to 147.5 mm. Groundwater recharge depends largely on the infiltration rate which is influenced by the

rainfall intensity and duration. If there is low intensity and long duration of rainfall, it enhances the infiltration rate, contributing more to the groundwater table while short-duration rain with high intensity influences high surface runoff and less infiltration rate. Furthermore, the results reveal that the high and moderate potential areas are situated in the southwest and southeast, respectively, with dense vegetation. Fuzzy large was used to assign fuzzy membership to rainfall values. Therefore, higher rainfall areas are ranked important and given values of 1 while

lesser rainfall values are ranked lesser and given values close to 0. Figure 7 shows the rainfall map of Ekpoma.

Drainage density

The drainage map was first generated from the SRTM imagery using the ArcGIS's hydrology analysis tool and this involved generating flow direction and accumulation maps which were then used for creating a stream network. Thereafter, the line density tool in ArcGIS was used to generate the drainage density map. Areas with high drainage density enhance surface runoff and inhibit infiltration as the underlying ground is saturated with water. Areas with low drainage density promote high infiltration and encourage low surface runoff indicating less saturation. Drainage density indicates rock permeability and infiltration capacity and therefore determines the water recharge capacity of an area. It is regarded as an inverse function of permeability (Agarwal and Garg 2016). Based on the factors influencing the availability of groundwater sources, zones with highly permeable rocks have high infiltration to groundwater, and minute quantity of water is conveyed in rivers as surface water while where low permeable rocks have low infiltration and are characterized by increased surface water runoff (Misi et al. 2018; Aroprovo et al. 2012). Low drainage density is thus linked to higher recharge and groundwater capacity as reported by Balachandar et al. (2010) and Magesh et al. (2012). Fuzzy small was used to assign the drainage density into fuzzy membership where areas with low drainage density were ranked highest and are classified as 1, areas with high drainage density were ranked lowest and classified as 0. Figure 8 represents the drainage density map of Ekpoma.

Lineament Density

A lineament is a landscape feature that denotes a geological structure beneath the surface such as a fault, fold, veins, and joints. The earth movement leads to the development of lineaments, which are the frail areas of bedrock, accountable for the infiltration of surface runoff into groundwater (Magesh-kumar et al. 2019). The study area's lineament was extracted from the SRTM imagery using PC GEOMATICA (Fig. 9). The lineament density map was generated in ArcGIS environment. The process involved using the generated stream network to perform an automatic lineament extraction to create the lineament density map. Previous studies have revealed a close relationship between lineament and groundwater flow. Lineament represents fracture zones, increased secondary porosity and permeability, resulting in increased groundwater occurrence and movement. Some researchers studied relationships between groundwater potentiality and the number of lineaments within specifically designated areas stating that lineament density areas are vital indicators for groundwater potential or recharge (Qadir et al. 2020; Senanayake et al. 2016; Ndatuwong and Yadav 2014; Rashid et al. 2012). The areas close to the circumference of the map (Fig. 9) are dominated mostly by moderate groundwater potential sites and few high potential sites representing a small portion of Ekpoma which indicate areas that will allow the building of large groundwater structures. Moreover, the major portions of Ekpoma are depicted with low lineament density, thereby suggesting a possible construction of small artificial groundwater recharge structures to detain the runoff water. Fuzzy MS Large was used to assign the lineament density into fuzzy membership where areas with high

Fig. 7 Rainfall map of Ekpoma

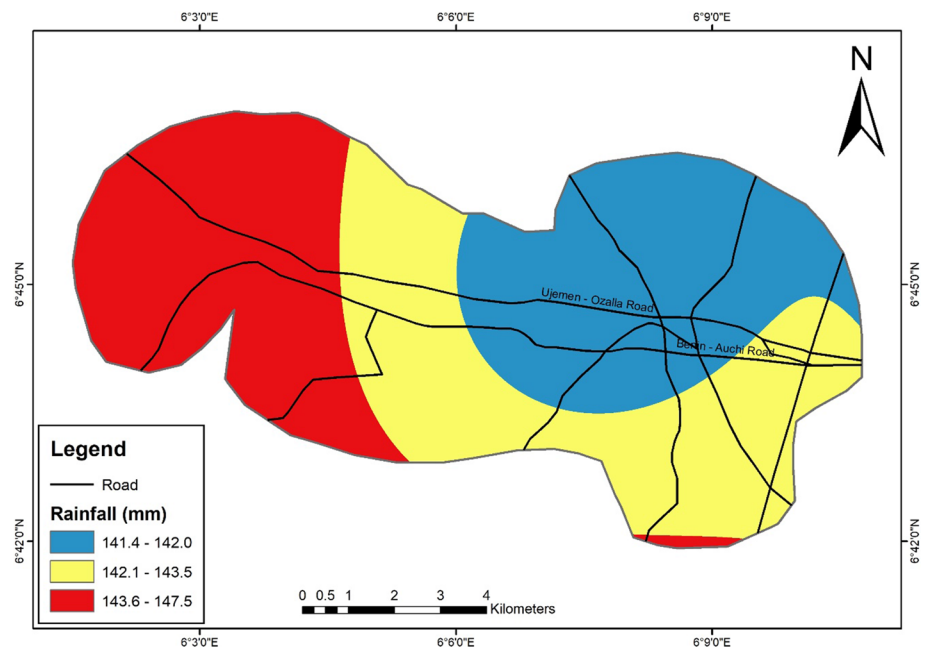
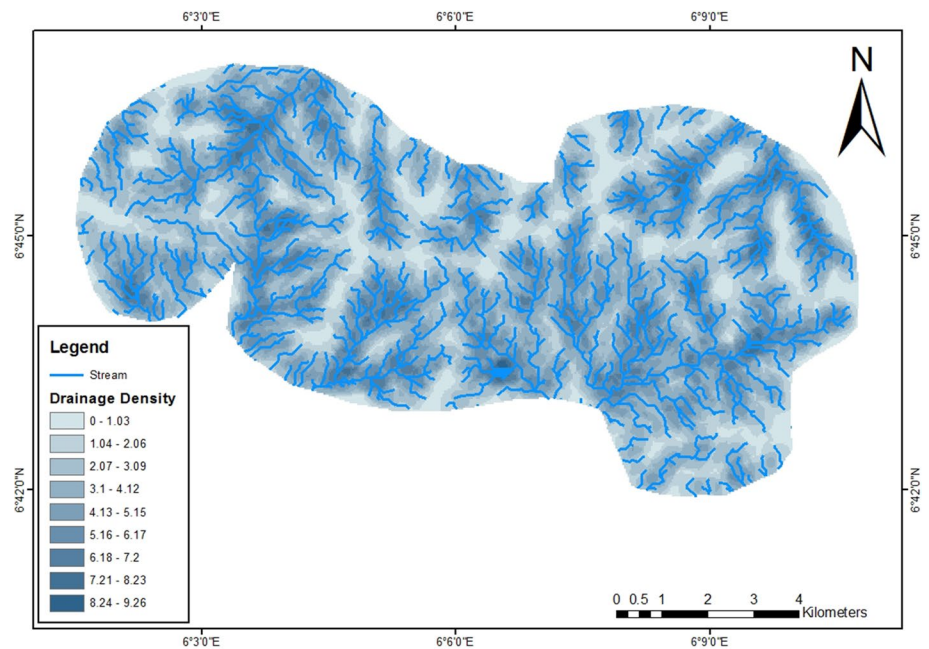
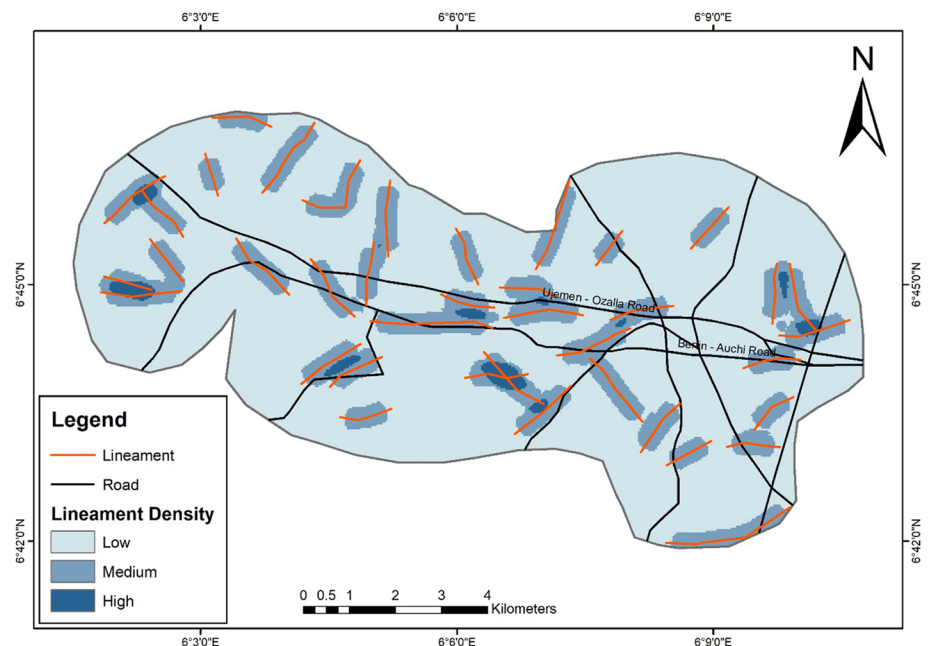


Fig. 8 Drainage density map of Ekpoma**Fig. 9** Lineament density map of Ekpoma

lineament density were ranked the highest which is 1 and areas with low lineament density were ranked lowest which is 0. Lineament structures are indicators of high porosity and permeability (Qadir et al. 2020).

Soil

The availability and recharge of groundwater depend on the types of soil, infiltration rate, permeability, and percolation (Kadam et al. 2020; Jasrotia et al. 2016; Das 2017). Soil data for the study area were taken from the HWSO. The soil

data were then digitized to convert it into a shapefile and subsequently rasterized and reclassified using ArcGIS 10.2. The singular soil type discovered in the study area according to the Food and Agriculture Organization (FAO 1990) soil classification is called dystric nitosol. It is also called Tropudults (dystric) according to the US Soil Taxonomy. They are one of the best and most fertile soils of the tropics. They can tolerate P-fixation and acidity and when there is a decrease in organic carbon, they are likely to erode. They have moderate resilience and moderate to low sensitivity. In this study, a high amount of sand and silt than

clay is found in the study area; therefore, it has a poor water holding capacity. From Fig. 10, it is glaringly vivid that the Ekpoma's soil is majorly composed of sandy soil but specifically, it contains sandy, sandy-clayey, and sandy-loam which are associated with Ogwashi-Asaba, Bendel-Ameki and Imo shale formations, respectively. These are sandy, deeply weathered soils formed from unconsolidated sediments of sandstone (Aweto 1987; Orobator and Odjugo 2015), which are made up of over 90% massive, porous, coarse sand with clay/shale interbeds having high groundwater retention capacity especially the Benin-Ameki formations. Thus, making it suitable for groundwater as it allows infiltration into the soil for groundwater recharge. Soil properties always aid the downward flow of surface water into the groundwater table and they are associated to permeability, infiltration, and percolation rates. (Sedhuraman et al. 2014) which are major indicators of potential areas (Jose et al. 2012). These highlighted characteristics of the soil in Ekpoma support infiltration and can function as a potential groundwater recharge area. The soil type was then converted to raster format and reclassified giving it a value of 4. The value 4 given to the soil type serves as a ranking to signify the suitability of the soil for groundwater potential.

Geology

One of the most critical factors which crucially play a part in the occurrence and distribution of groundwater is geology. The geological map for Edo State published by the Nigeria Geological Survey Agency (NGSA) was downloaded. The image was georeferenced and the study area was gotten by digitizing using ArcGIS. The extracted geology was

rasterized and reclassified based on the impact of each geologic formation on groundwater potentiality and assigned a value of 4. The ranking was based on the type of geology in the area implying high retention capacity to hold groundwater. The underlying geology of the study area contains clay, clayey sandstone, and shale (Fig. 11). This geology type is a good underlying rock type which would hold the water that infiltrates from the surface in the groundwater recharge which corresponds to Nejad's research (Nejad et al. 2015). The porosity of the underlying rock significantly affects the storage capacity of the rock formation (Savita et al. 2018). Figure 11 represents the geological map of the study area.

Groundwater potential

Fuzzy membership tool reclassifies the input data (criteria maps) to a 0–1 scale according to the possibility of being a member of a specified set—in this case, contributors to groundwater potential. The criteria used to check the study area's groundwater prospect assigned to classes of 0 and 1 using fuzzy membership where 0 value areas are the parts of the map that do not favour groundwater recharge while 1 are the parts favouring groundwater recharge. The criteria and their fuzzy membership classes are depicted in Table 1.

Figure 12 represents the groundwater potential map obtained after the overlay process and Table 2 highlights the area coverages of the groundwater potential classes. Ekpoma covers an area of 101.2 km². The groundwater potential map as shown in Table 2 indicates that high potential areas cover 7.99 km² (7.9%), medium potential areas cover 6.45 km² (6.4%) and low potential areas cover 86.76 km² (85.7%). It can be observed that over 85% of the entire study area

Fig. 10 Soil map for the study area

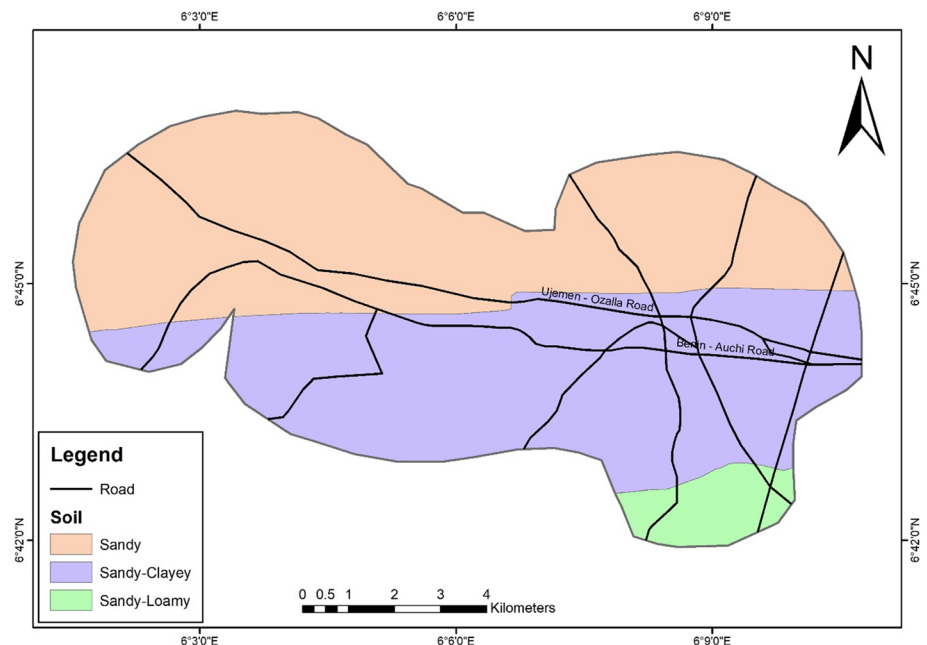
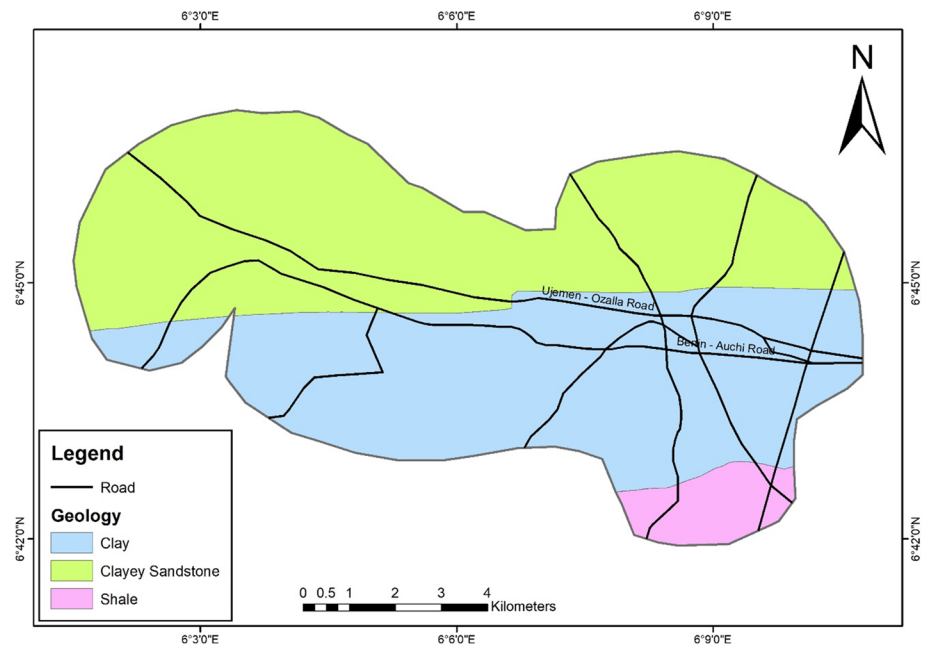


Fig. 11 Geology map of the study area**Table 1** Fuzzy membership classes assigned to different criteria

Criteria	Value	Fuzzy membership
Slope	0–33.19	Fuzzy small
Drainage density	0–9.26	Fuzzy small
Lineament density	Low, medium and high	Fuzzy MS large
Land use	Bare surface, built-up, rock, and vegetation	Fuzzy large
Soil	Dystric Nitosol	Fuzzy near
Geology	Clay, clayey sandstone and shale	Fuzzy near
Rainfall	141.4–147.5 mm	Fuzzy large

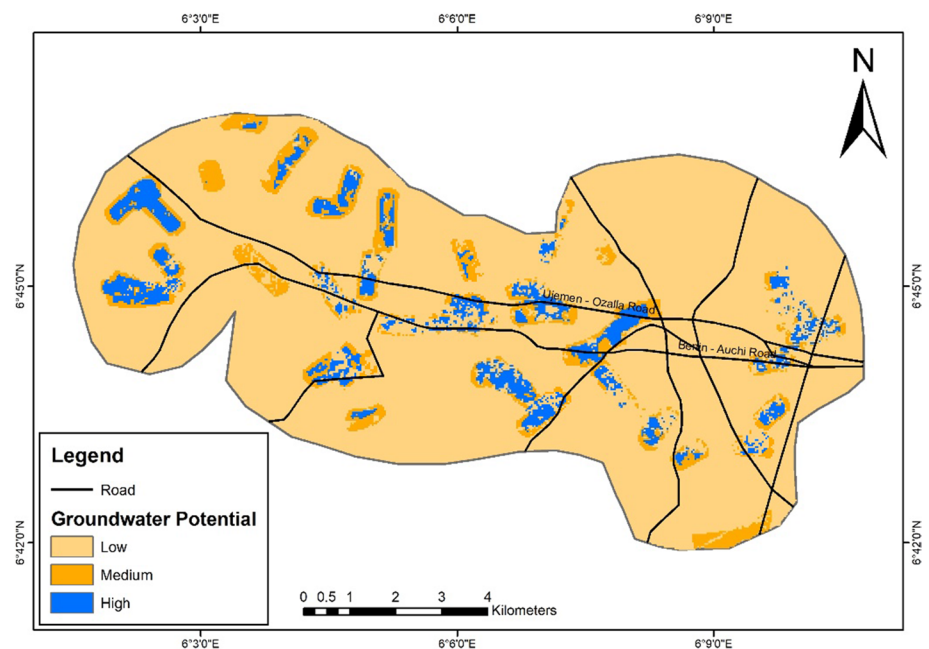
Fig. 12 Groundwater potential map in Ekpoma

Table 2 Criteria and their fuzzy membership

Groundwater potential class	Area coverage (km ²)	Percentage (%)
Low	86.76	85.7
Medium	6.45	6.4
High	7.99	7.9

is characterized by low groundwater potential. By identifying the few medium and high vulnerability areas, sustainable groundwater abstraction frameworks can be developed around these areas for efficient water provision.

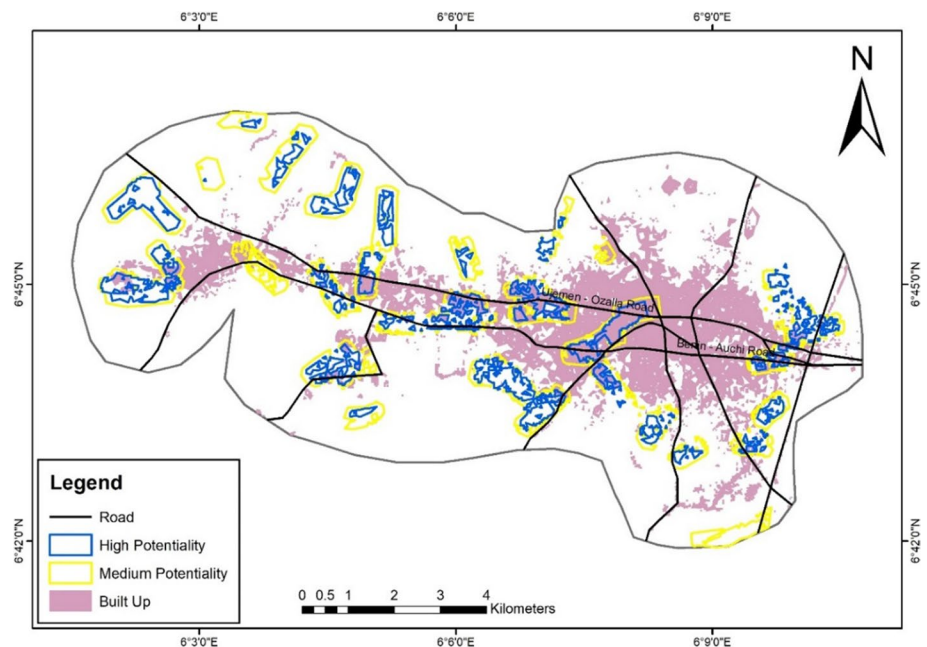
In order to identify these areas in real time, the medium and high groundwater potential areas were overlaid with the land use map of the built-up areas. Figure 13 shows the high and medium risk potential areas with respect to built-up. It can be observed that these medium and high groundwater potential areas are positioned across the study area in such a way that every region can receive sufficient supplies of water if these spots are effectively managed. Similarly, when the groundwater potential map is compared with the lineament map (Fig. 9), it can be observed that the high and medium groundwater potential areas mostly coincide with high and medium lineament density areas, implying that lineament plays a pivotal role in the potential for groundwater in the study area. Previous research studies in Nigeria make use of AHP and other methods that have the constraint of expert bias when assigning weight to factors. The weighing method is discreet which does not provide a clear picture of reality. The fuzzy logic removes the bias and weight assignment is continuous such that a closer picture to reality is achieved.

Fuzzy logic solves the problem of generalization. It provides specific details for each unit factor considered. The findings of this study have implications for future research on groundwater resource assessment and sustainability, agriculture, basin management, and other groundwater relationship studies. The fuzzy logic approach is significant and offered compatible results which can be applied in other localities of comparable hydrologic characteristics with suitable alterations.

Conclusion

Groundwater is one of the crucial natural resources for any economic development (e.g., agriculture, aquaculture, industry, domestic water demand), and it plays an essential part in human health as well as the terrestrial and aquatic ecosystems. In this research, seven conditioning factors were identified to have an influence on groundwater potential mapping. The effects of each factor on groundwater potential were evaluated and classified employing the use of fuzzy logic. The classified factors were then overlaid to give the final groundwater potential map, which shows areas of low, medium, and high groundwater potential. The groundwater potential areas were discovered to be predominant around the lineament areas. This study has shown the efficient and effective application of GIS and fuzzy logic in groundwater assessment as a support system for decision and policymakers. This approach could be used to solve the problem of water scarcity as well as to respond to water resource emergencies. Contrary to the general belief that Ekpoma is a town on a hill so there must be water scarcity, it has been shown

Fig. 13 Map of the high and medium groundwater potential overlaid on built-up



by this research study that this is only an assumption. The results indicated that groundwater potentiality exists outside the inhabited areas. The study's outcome serves as a precursor to water resource planning and management in Ekpoma at large. Field observations can be carried out using this study as a baseline to evaluate the quantity of water resources available in the high potential areas. Finally, reservoirs can be built in the high potential areas and distributed to the community using underground pipe networks thereby solving the water scarcity problem.

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Declarations

Conflict of interest The authors declare that they have no conflict of interest.

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- Appendix V: Major tropical soils and their susceptibility to land degradation
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