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ORIGINAL ARTICLE

Potential dam sites selection using integrated techniques of remote sensing and GIS in Imo State, Southeastern, Nigeria

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Abstract

Water is an essential natural resource that is vital for sustaining every form of life existence. Availability of groundwater is spatially and temporally dependent upon the terrain of an area. In order to improve efficiency and effectiveness in water availability, supply and use, the construction of water harvesting structures across streams/watersheds is gaining drive in recent years. The increase in demand for water has led to the construction of water storage dams for various purposes such as community and industrial use, irrigation, flood control, hydropower and river canalization. Safety is the key consideration than cost and capacity as the failure of a dam often results to severe loss of lives and properties, hence the need to consider some important criteria for suitable dam siting. In this study, potential sites for construction of dams in Imo State, Nigeria, have been identified by using geographical information system and remote sensing techniques which were integrated with fuzzy logic to achieve the study objectives. Climatic and geophysical factors such as rainfall, runoff, stream order, soil type, geology type and land use were considered. These factors assigned fuzzy membership classes according to their contribution in locating suitable dam sites. The fuzzy members for all the factors were combined using the fuzzy overlay technique to produce the suitable dam site selection map. Majority of the selected sites were located in the northwestern part of Imo State which is characterized by high elevation and gentle slope.

Keywords Dam · Site selection · GIS · Fuzzy logic · Remote sensing · Water

Introduction

Water is an indispensable natural resource essential for the sustainability of life existence (Opafola et al. 2020; Akosile et al. 2020; Ilori et al. 2019; UN Water 2015; Ajibade et al. 2015). However, there are existences of uneven distribution of water resource, in both temporal and spatial scales, leading to the persistence of different levels of flood and drought across the world (Dai 2016). The paucity of water resources has turned out to be a significant problem in recent

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time as a result of populace surge, unceasing climate alteration and current utilization inclinations. By 2020, amid 75 and 250 million persons in Africa are likely to be opened to serious water hassle, agricultural production with food obtainability would be strictly reduced and production from rainfed farming would possibly diminish by about 50% in various areas (IPCC 2014). It is estimated by the United Nations Environment Program that above 2 billion people will live under conditions of nonstandard water hassle by 2050 (Adham et al. 2016). There has been increasing universal water utilization in domestic, industrial and agricultural areas (Danilenko et al. 2010). The United Nations via its millennium development goals (MDGs) and sustainable development goals (SDGs) stressed universal and provincial collaboration to ascertain water concerns then resolve them cooperatively (UN Water 2015). Viable water resource management facilitates healthier economic growth plus poverty mitigation.

Water storage is identified as an important factor for economic and social development (for both rural and urban population) in almost every single country around the world (Ahmadullah and Dongshik 2015; Rezaei et al. 2017). Many developing countries have inadequate water supply as their major challenge due to prevalent dry climate, and precipitation is greatly inconsistent or seasonal. In such circumstances, there is a need to store water in rainy season in view of meeting demands in the dry season. Meanwhile, as a result of problems associated with sedimentation and evaporation, surface water reservoirs are not considered viable; hence, groundwater is normally the dependable source of water resource. However, it is always common that as the end of the dry season approaches, ground water aquifers deplete (Nilsson 1988). Thus, the development of viable water supply management calls for immediate consideration (Rockström and Falkenmark 2015). Hence, careful and effective selection of appropriate sites for dams and professional construction of the dams can be a promising solution to the issues of water scarcity.

A dam is primarily known to be a barrier built across a river or stream to control flow or obstruct the flow of water and raise its level to form a reservoir which could be for various purposes such as electricity generation and general water supply (which could be agricultural, domestic, municipal and industrial). The economic advantages of dams prevail over the disadvantages and costs, as a result, providing a worthy motive for the construction of dams around the world (Jozaghi et al. 2018). In water supply management, selection of the most suitable location for dam construction is one of the most complex and divisive decisions. Thus, for selection of the best dam sites, a clear-cut study over the interest area bearing in mind factors affecting this selection is highly necessary to be conducted. Nevertheless, this practice is costly and time-consuming (Noori et al. 2018). With improvements in modern computing and information technologies, defining competitive solutions in terms of cost, time and a variety of other objective variables is significantly simplified (Jozaghi et al. 2018).

In hydrology, the application of remote sensing and GIS techniques is currently one of the most effective approaches (Abushandi and Alatawi 2015). In recent times, the use of remote sensing has been noteworthy in providing valuable datasets to examine hydrological variables and morphological variations over large areas at various spatial and temporal scales (e.g., mean squared relative error (MSR-E), tropical rainfall measuring mission (TRMM), global satellite mapping of precipitation (GSMAP), advanced spaceborne thermal emission and reflection (ASTER), synthetic aperture radar (SAR) and several others) especially in areas where ground data are unavailable. Over 2 decades, many scholars have focused on satellite imagery applications in hydrology (Kite and Pietroniro 1996; Liu et al. 2003; Forzieri et al. 2008; Abushandi and Merkel 2011; Mahmoud 2014; Abushandi and Alatawi 2015). Forzieri et al. 2008) applied GIS and remote sensing techniques to assess the suitability of sites for the installation of small dams for water harvesting purposes in arid areas. And in the selection of the dam sites, criteria are well defined mutually in a qualitative and numerical method. The assignment of sites for small water collecting structures across streams and watersheds is productively done using remote sensing and GIS methods. To comprehensively describe the data obtained, various thematic layers such as land use and land cover, geomorphology and lineaments were applied. These layers together with geology and drainage were combined using GIS techniques to derive suitable sites for water harvesting. Moreover, the storage and transmittance of groundwater in the study area were calculated (Kumar et al. 2009). It is worthwhile to note that GIS is strongly used in the selection of dam site; however, its ability and effectiveness in a region may differ with locations (Jozaghi et al. 2018). Similarly, Singh et al. (2009) used several remote sensing imageries to select dam sites. In their study, parameters like slope (below 10%), soil infiltration rate (moderate), land use (shrubs and river beds) and soil type (sandy clay loam) were used in selecting the sites. Thereafter, 14 potential dam sites were found which could practicably be used for water collecting and agriculture. Ibrahim et al. (2019) identified and selected viable sites for the possibility of constructing dams, including generating a model builder in ArcMap 10.4.1. This model combined various factors, such as land cover/use, slope, stream order, runoff potential, hydrology and soil quality to ascertain the suitability of the location for rainwater harvesting.

Such facts as terrain surface, drainage network, land use and catchment boundaries which are significant for suitable dam siting can be obtained from remotely sensed images. Particularly, slopes facts from DEM are beneficial for several hydrological studies as well as dam site selection (Sanyal and Lu 2004). Moreover, in recent years, attempts have been made in determining the fitness of these techniques in supporting engineering dam projects by allowing effective, rapid and economic data assortment (Ramakrishnan et al. 2009; Salih and Al-Tarif 2012). Though, remote sensing application in ephemeral streams is limited in comparison with its application in permanent rivers (Abushandi and Alatawi 2015). Studies have proven that apart from ground relevance, remote sensing is also useful in atmospheric variables such as cloud thickness, relative humidity and evapotranspiration (ET) which are imperative for water supply administration as used in such studies as use of MODIS images in ET (Rahimi et al. 2014), soil moisture estimation (Sharma 2006) and GSMaP (Forzieri et al. 2008). This study is based on selecting the best feasible dam sites in Imo State, Nigeria, utilizing criteria namely rainfall, runoff, soil types, geology, drainage network and land use/land cover in the selection procedure. For this purpose, the specific objectives of this research are to integrate GIS and RS in the study area in selecting suitable dam sites, establishing individual weights to the proposed criteria and considering topographical and morphological conditions in dam site selection, generating a suitability map for every condition and carrying out multilayered analysis with the resultant generation of the final dam site appropriateness map. These identified suitable dam sites would help decision-makers to choose the best site for dam(s) construction with the aid of geospatial technologies.

Description of study area

Imo State is one of the five states of the Southeastern region of Nigeria with her capital and major city as Owerri. It occupies the area between the lower River Niger and the upper and middle Imo River. Imo State lies within latitudes 4° 45′ N and 7° 15′ N and longitude 6° 50′ E and 7° 25′ E (Fig. 1). The eastern part of Imo State is bordered by Abia State, on the western part by the River Niger and Delta State, on the

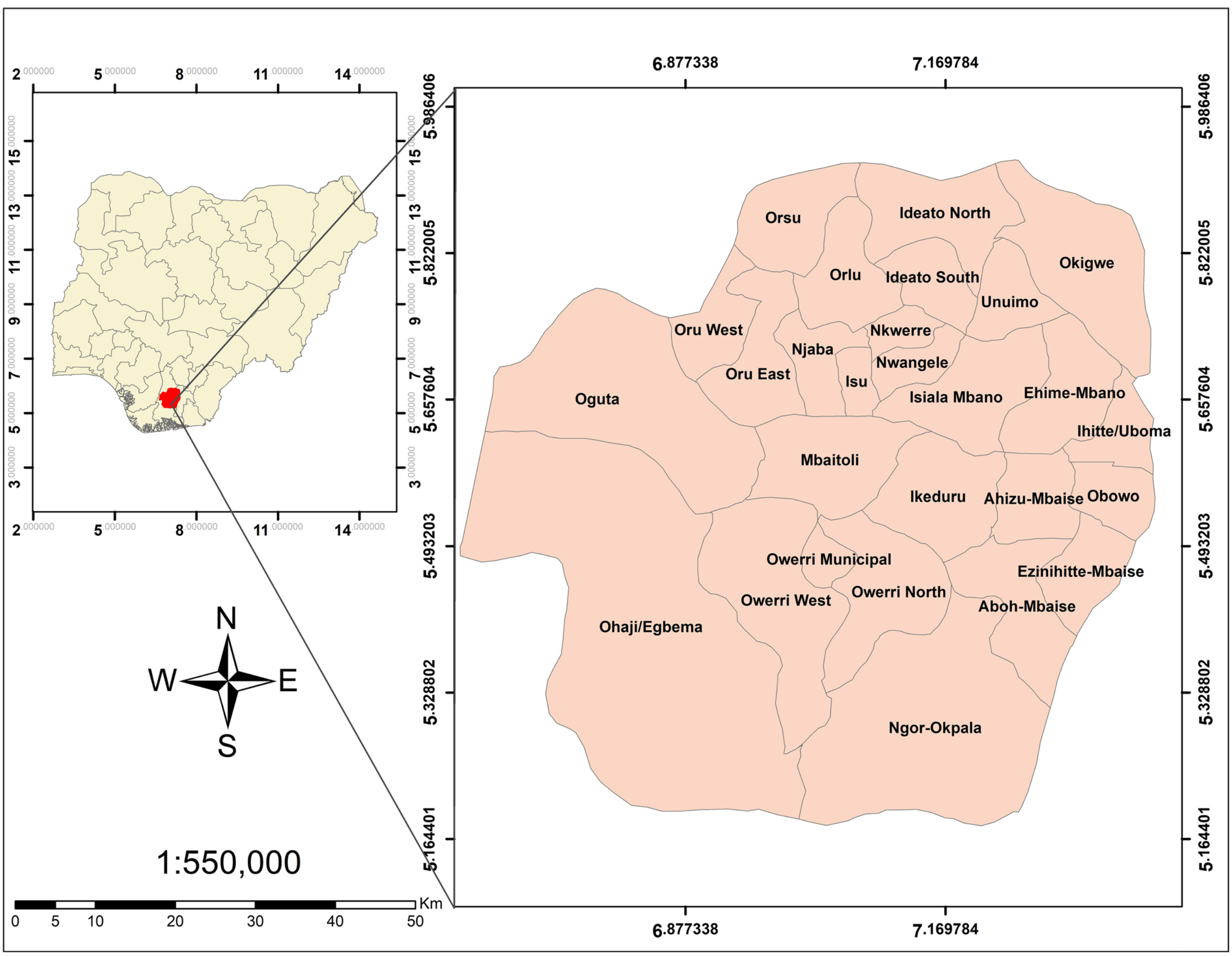


Fig. 1 Study area map

northern side by Anambra State, and Rivers State borders the southern end. A land area of about 5100 km^2 is covered by Imo State. The Benin formation of coastal plain sands lies beneath the state. This formation is affirmed to be deep, porous, infertile and highly leached. Some region like Okigwe has impermeable layers of clay which exist near the surface, whereas the soil consists of lateritic material under a shallow stratum of fine-grained sand in other regions. Rivers in Imo State are few with immense fluvial materials which are categorized by dry gorges that convey surface drainage in times of great precipitation. The remarkable uniformity of the landscape may be accounted for by the lack of any visible tectonic features (faults and fracture zones) as well as by the uniformity of rock formation. Imo, Otamiri, Njaba and Ulasi rivers are the major watercourses draining the state with few tributaries. Other rivers are surrounded by coastal plain sands except for the Imo River that runs within an area underlain by the Imo Shale Formation. Largely, river valleys in Imo State make up the main physical geographies, which are regularly swampy. There are differences in precipitation volume year after year. Rainfall fluctuates from 1990 to 2200 mm annually. Imo State areas have almost equal temperatures. The hottest period spans through January to March, with the mean yearly temperature exceeding 20 °C. The state experiences harmattan that lasts from late December to late February. The average annual relative humidity of 75% is the highest during the rainy season, while it increases up to about 90%. Due to the high temperature and humidity, plants growth is immensely enhanced as peak vegetation of the tropical rain forest can be produced.

Materials and methods

Data acquisition

Digital elevation model (DEM)

Shuttle Radar Topography Mission (SRTM) imagery with a 30-m resolution was downloaded for Imo State from the United States Geological Survey (USGS) Web site. The SRTM data would serve as the DEM data for the study. The DEM cuts across two grids—Path189, Row56, and Path188, Row56 of the USGS grid system. The DEMs for the two grids were downloaded and mosaicked. Afterward, the study area's DEM was clipped from the mosaicked image using the shapefile of the study area. This imagery was used to generate the slope, drainage and lineament of the study area as criteria to determine suitability for siting dams. The Shuttle Radar Topography Mission (SRTM) is a global research effort that acquired digital elevation models on a near-global scale from 56° S to 60° N to come up with truly complete high-resolution digital geographical information of Earth. The void-filled SRTM data where missing data have been pre-filled using spatial interpolation algorithms were used for this study (USGS n.a.).

Soil map

Soil data obtained for the study area are based on the field survey done and published by the Soil Survey Division of the Federal Department of Agricultural Land Resources (FDALR), Nigeria. The data were preprocessed to a format compatible with ArcGIS for analyses. The data was georeferenced and digitized to be stored in a shape file format. This was achieved by obtaining the scanned images; the images were then georeferenced and digitized to be stored in a shapefile format. Finally, the shapefile of the study area was used to extract the soil map for the study area using the clip data management and other geoprocessing tools.

Landcover imagery

The first-of-its-kind continental landcover map of Africa developed by the climate change initiative (CCI) of the European Space Agency (ESA) was used for this study. The Landcover map which has a 20-m resolution is based on a yearlong Sentinel-2 A aggregated data over Africa from December 2015 to December 2016 (Abellavia 2018). Sentinel-2 A was launched in June 2015 by the European Space Agency under the Copernicus Program. It is equipped with a 13-band multispectral imager, and its planned duration is for 7.25 years, i.e., it is expected to be operational till the year 2022 (Sentinel Online n.a.). One of the main applications of the imagery is the area of land monitoring and climate change (Sentinel Online n.a.).

Geological map

The geological map for Imo was acquired from the Imo State Ministry of Environment. The image was georeferenced and digitized to shape file format for easy processing and analysis with the GIS software.

Precipitation data

Precipitation data for Imo metropolis were acquired from the Nigeria Meteorological Agency (NIMET). The data were a rainfall gridded data for Imo State for 30 years from 1986 to 2015 which serves as a climatic period over the area. The acquired precipitation data were used to check the climate variability over the region for a space of 30 years.

Software analysis

Geographical information system (GIS) can be seen as an efficient tool for analyzing, collecting, storing, manipulating, displaying, editing vector and raster data for specific purposes. These can be summarily stated in four ways: data integration, data visualization and analysis, planning and summarizing site activities, and data presentation. In hydrological analysis and modeling, the use of GIS plays a vital role in the assessment and selection of potential dam sites (Ahmadullah and Dongshik 2015).

The study done on the sets was mainly performed using ArcGIS software of version 10.2. ArcGIS is a system that is efficient in works related to maps and geographical information. It can be effectively significant in the areas below:

1. Maps creation and analysis.
2. Gathering geographical data.
3. Scrutinizing mapped facts.
4. Allocation and discerning geographical details.
5. Handling geographical details in a databank.

The system presents a setup for creating maps and geographical details accessible all through an organization, a community and explicitly on the Web. Global mapper is also an efficient preprocessing system. It can accept an extensive array of data presentations as well as exporting the same in the preferred formats. The following measures come to play while using the global mapper:

1. Downloading of altitude facts
2. Imagining of the whole data collections in 2D and 3D.
3. Contour creation.
4. Georeferencing of maps.
5. Conversion and exporting clipped data in preferred formats.

To obtain the preferred result for the project, both softwares were employed in obtaining thematic maps and proposed locations.

Methods

In the selection of a suitable dam site, a variety of methods have been used and the elements deliberated also differ a lot between individual case (Dai 2016). Many studies have applied various techniques in ensuring an effective and efficient selection of suitable sites for dams and other water resource management structures. The conditions for miscellany of appropriate locations for dams are primarily grouped into two, and these are biophysical and socioeconomic criteria. It has been observed that most studies in the 1990s engrossed basically in biophysical conditions such as rainfall, runoff, land use, slope, soil type and drainage network, while most of the studies from 2000 have tried to incorporate socioeconomic criteria with the biophysical parameters as the main benchmarks for selecting suitable sites for water conservation structures (Adham et al. 2016). Food and Agriculture Organization (FAO) states six main factors that would be considered for the evaluation of sites for soil water conservation: climate, hydrology, topography, agronomy, soils and socioeconomics (Adham et al. 2018). It is challenging to define in general a certain number of criteria for dam site selection as the objectives of decision-makers vary in most cases. Decisions vary by purpose from heavy-duty hydropower consumption, like the world's leading power station Three Gorges Dam, to aid giver usage in small villages such as irrigation or aquaculture. In the meantime, decision-makers still encounter hitches in a broad-spectrum dataset of criteria for dam site selection while putting into consideration the local environments, in both environmental and social facets, and decision-makers' propensities between high speed and viable development. On the other hand, criteria such as slope and hydrological conditions are indispensable criteria related to dam site selection, safety and dam construction (Dai 2016). The methodology flowchart employed in this study is as displayed in Fig. 2.

In this study, these criteria were considered in identifying potential sites for dams based on the availability of data, literature appraisal and professional verdict. The recommendations given by the FAO were observed and used rainfall and runoff as considerations for climate, flow direction and accumulation, and drainage as factors for hydrology, slope as a factor for topography, land use and land cover as factors for agronomy, soil texture as a parameter for soils.

The rainfall component was based on the ERA-Interim rainfall data for years 1986 to 2015 obtained for the study area as earlier described. The rainfall amount plays a vital role in the volume of water that flows in a river. Dams tend to be more active during the rainy season when the volume of water is increased than during the dry season when the water volume is low.

Runoff process is a function of hydrological soil group (HSG), land use and antecedent moisture condition (AMC) (Ramakrishnan et al. 2009; Mugo and Odera 2019). Among these runoff determinants, land use may vary slightly but insignificantly, whereas soil types are commonly constant. Rainfall volume, intensity and distribution are significant in determining the runoff volume. The AMC is evaluated by the total rainfall in the 5-day spell preceding a storm. As the soil moisture increases due to rainfall in the early spell, the runoff during storm event increases. Runoff gridded data for Imo State were acquired from ERA-Interim rainfall data for years 1986 to 2015. Runoff affects the flow rate of a river and the force of river water needed to site a dam. Low runoff

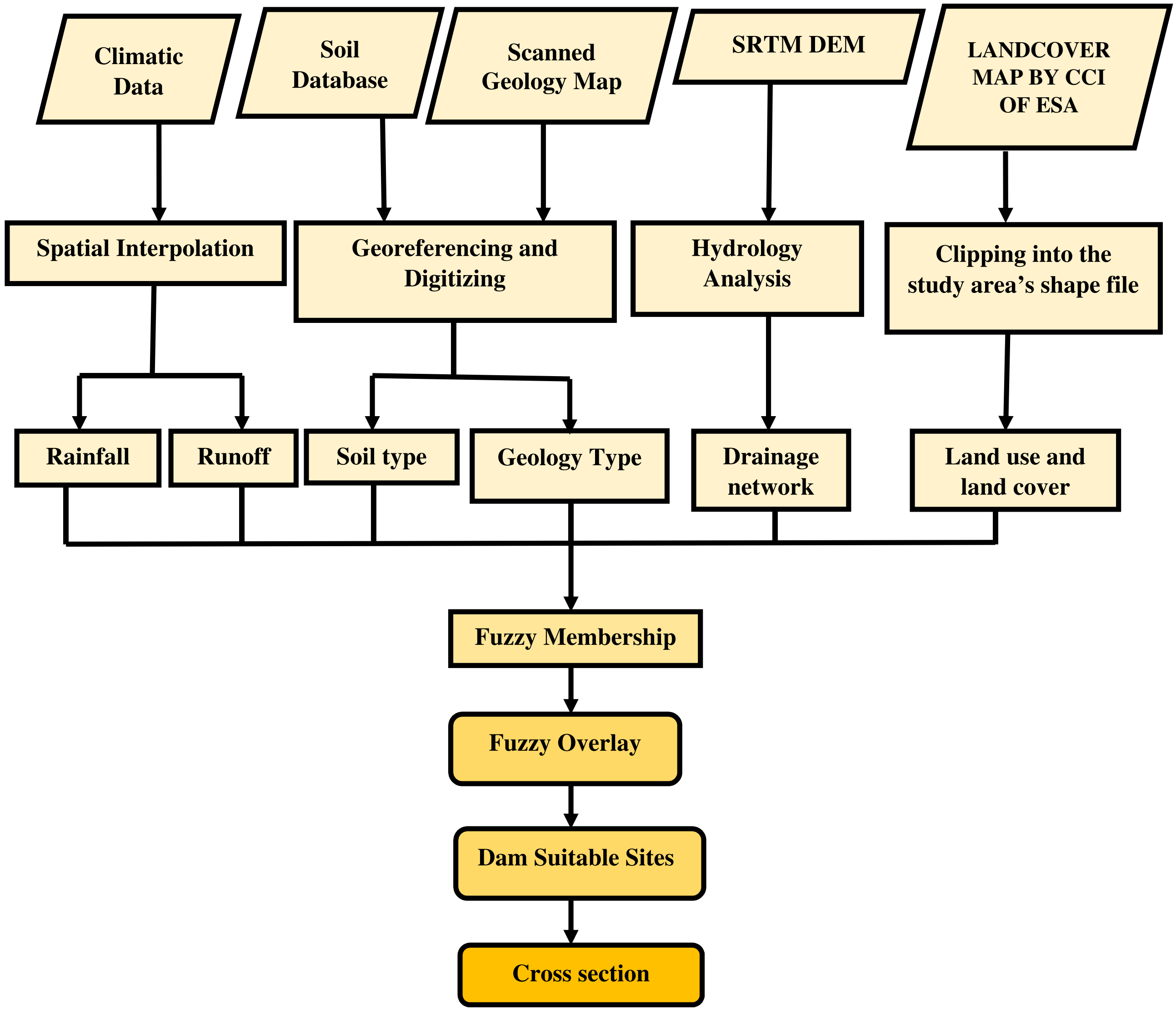


Fig. 2 Methodology flowchart for the study

rate is a disadvantage as river water momentum would not be enough, but high runoff rates are advantageous as the flow rate would increase, thereby increasing river water momentum which would have enough capacity to construct a dam.

Soil data obtained for the study area are based on the field survey done and published by the Soil Survey Division of the Federal Department of Agricultural Land Resources (FDALR), Nigeria, as described earlier. The soil formations identified are explained below:

Recent alluvium Deep well-drained and deep poorly drained soils comprising soil texture types such as sand, sandy loam, loamy sand or sandy clay loam surfaces over sand, sandy clay, sandy clay loam, clay, clay loam or loamy and, sometimes gravelly subsoils.

Lagoonal marshes and back freshwater swamps Deep to moderately deep poorly drained soils; loam to loamy sand, sandy loam, silt or silty loam surfaces over fine sandy loam, silt loam, silty clay loam or sandy clay subsoils.

Coastal plain sands Very deep well-drained soils; loamy sand to sandy loam surfaces over sandy clay loam to sandy clay subsoils

Sandstone and shales Deep, moderately deep and shallow well or imperfectly drained soils; loam, sandy loam, sandy clay loam, sometimes concretionary surfaces over sandy clay loam, clay loam or clay sometimes mottled and concretionary subsoils.

Geological information In the selection of the suitable dam site, it is necessary to have a detailed knowledge of the geology of the dam site and the future reservoir, together with its catchment area. Acquiring such knowledge should be vital in the siting, design and construction of any dam (Razaei et al. 2017). The scanned geology map of Imo State was extracted from a recent research paper (Udoka et al. 2016). The map was georeferenced and digitized in the ArcGIS software environment. The geology was classified based on their permeability properties. Permeable formation types would allow water infiltrate through them, thereby reducing surface runoff. Impermeable formations enhance surface runoff which causes increase flow rate of the river which is vital for siting dams. The six geologic formations in the study area that were identified include Nsukka Formation (Maastrichtian—Paleocene series), Imo Shale Formation (Paleocene—Paleogene series), Bende Ameki Formation (Paleocene—Eocene series), Ogwashi-Asaba Formation (Oligocene—Miocene series), Benin Formation (Miocene—Pleistocene series) and Alluvium Formation (Recent series). These formations have their distinct hydrological properties which are also considered in the selection of suitable dam sites.

The land cover for Imo State was extracted from the 20-m resolution land cover map over Africa using the clip data management tool on ArcGIS. These data were used due to its relatively detailed resolution and the comprehensiveness of its legend. Here, the remote sensing is effective in providing information on actual land use/cover, while GIS facilitates an integrated evaluation on land potentialities to be made (Manugula et al. 2015). For the purpose of this study, the classes we regrouped into the five classes identified as relevant to the dam siting-built up, vegetation, swampy area, bare area and water body.

The drainage networks

In this study, the drainage network was obtained from the DEM of the study area through a series of steps such as the creation of the flow sink, the flow direction, flow accumulation and finally the drainage network in that order. This was achieved with the aid of the wide-ranging tools available in the hydrology toolbox of the ArcGIS software. Since administrative boundaries rarely coincide with hydrologic boundaries as seen in watersheds, the creation of the Fill sink was to delineate outlet points where water collects in a watershed. This output leads to the generation of the flow direction map and each output keeps forming the input for the next map until the drainage network map is achieved.

Flow direction

Water flows downhill. This step follows the fill sink. The voidless fill-sink DEM is used to determine the direction of flow. In this study, the standard D-8 algorithm in which the flow direction is modeled from each pixel to its steepest neighbor was applied. In this algorithm, the values of every central pixel in matrices of 3 by 3 pixels are compared with the values of their corresponding 8 neighbors (Esri n.a.). The direction of the steepest descent from the cells is indicated by the values of the flow direction grid. Thus, slope and the flow width are factors that are considered when delineating flow direction. The flow direction has eight directions pour points. These numbers are used to represent the particular direction in which water flows.

Flow accumulation

Flow accumulation is generated using the flow direction as input. Flow accumulation shows how many contents flow through each cell. In other words, it works out the flow accumulation grid that encompasses the amassed quantity of cells upstream of a cell. The flow accumulation identifies the drainage path. Perpetual or seasonal flow regime of the river at the dam site is crucial. Seasonal rivers have more sediment transport and lower water quality; the management of water resources is difficult as a result of the indefinable discharge of water entering the reservoir. Hence, perpetual flow regimes are suitable for dam construction.

Drainage map

Finally, the flow accumulation map is used for generating the drainage map with stream orders which categories the streams into six types, depending on the volume of water managed handled by the stream. For instance, level 1 connotes temporary runoff paths and gullies which empties into larger streams while level 6 streams are the large streams the smaller streams empty into.

In this study, the socioeconomic component such as distance from urban centers, distance to roads and distance to wells, was based on the landcover information. This was achieved based on the formulation of standards to be considered before siting the dams. These were the standards considered before siting/locating the appropriate dam site:

1. The dam should not be proximate to human activity.
2. It should not be proximate to a fault line.
3. It should principally be located on the river.
4. Steep slopes adjacent to the river best defines the suitable topography.
5. The area with stable rock foundation is best suited for dam location.

Fuzzy membership

In solving customary overlay analysis applications like models for site suitability and selection, fuzzy logic is an efficient overlay analysis technique. Fuzzy logic provides an effective technique for tackling inaccuracies arising in attributes and the geometry of spatial data. Delineation of the classes and measurement of the occurrence are the two key areas from which inaccuracies arise in attribute data. There is a need to eliminate the imprecision caused by those sources of inaccuracies. Hence, it is worthwhile to integrate fuzzy overlay as it helps decision-makers in making productive decisions regarding this fuzziness. Modeling the inexactitudes of the class boundaries is the main emphasis of the fuzzy logic. Fuzzy logic tries to specify the class boundaries. It can be said that fuzzy logic is centered on set theory; as a result, it defines possibilities and not probabilities. The fuzzy overlay uses fuzzy membership classes to delineate suitable dam sites.

The membership of a particular set is done by the fuzzy membership tool which reclassifies the input data into a 0 to 1 scale. 0 designates those locations which are absolutely not members of a set, whereas 1 denotes those locations which are certainly members of a specified set. It is possible to transform the input data by the available number of functions and operators in the ArcGIS Spatial Analyst extension which reclassifies the values into the probable scale of 0 to 1. As earlier stated, that 0 denotes not a member of a specified set and 1 takes the reverse, whereas 0.5 is referred to as the crossover point. Fuzzy values above 0.5 indicate that they may probably be members of the specified set while fuzzy values below 0.5 indicate that they may not be members of the specified set.

Results and discussion

The outcomes of the analyses are presented in this section as follows;

Biophysical characteristics analyses

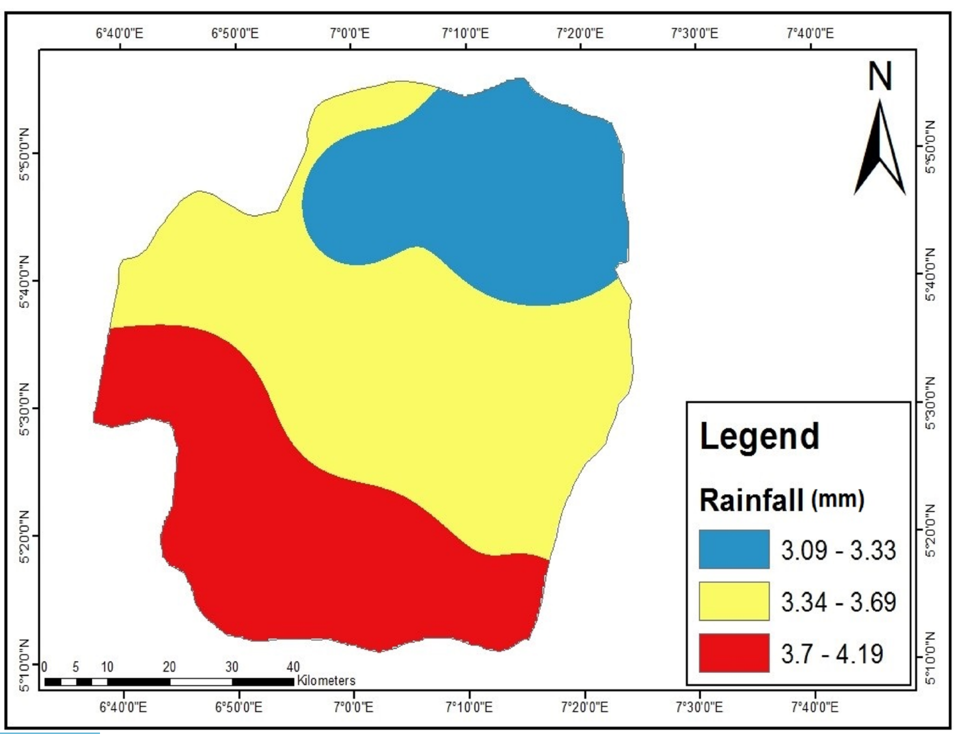
Rainfall

From the spatial analyses of the rainfall data, it was observed that the annual rainfall ranges from 309 mm to 419 mm. The southwestern region of the county receives the highest rainfall through the year while the areas toward the north and northeast of the area receive the lowest annual rainfall through the year. The central regions receive moderate to low rainfall as per the annual average scale shown in Fig. 3. The regions toward the east of the county are characterized by moderate rainfall.

Runoff

The output of the runoff analyses shows that areas toward the south and southwest of the county generate the highest runoff of > 112 mm annually while the northern side of the place generates the lowest runoff ranging from 94 to 100 mm. It could be seen that regions where high rainfall events are experienced, generate higher runoff. Nevertheless, the runoff extent is dependent on land use, land cover,

Fig. 3 Rainfall spatial distribution map



slope and soil type among other hydrologic and structural factors (Mugo and Odera 2019). Figure 4 shows the runoff distribution in Imo State.

Soil texture

As earlier described, the soil types identified in the study area after the extraction process are those typically found in nearly level to gently undulating plains and they comprise recent alluvium, lagoonal marshes, and back freshwater swamps, coastal plain sands, and sandstone/shales. Figure 5 shows the soil type map for Imo State. It can be observed that coastal plain sands cover a large portion of the study area, followed by sandstones and shales, lagoonal marshes and finally recent alluvium in that order. Clay would allow water to be held above the soil, thereby increasing runoff at the surface which in turn would increase the velocity of water above the soil surface.

Geology types

The six identified geologic formations in the study area as earlier listed include Nsukka Formation (Maastrichtian—Paleocene series), Imo Shale Formation (Paleocene—Paleogene series), Bende Ameki Formation (Paleocene—Eocene series), Ogwashi-Asaba Formation (Oligocene—Miocene series), Benin Formation (Miocene—Pleistocene series) and Alluvium Formation (Recent series). The spatial distribution of these formations is illustrated in Fig. 6. It can be observed that the Benin formation, running from the west to the eastern part of the study area, constitutes the largest portion of the geology of the study area. It mainly comprises coarse-grained gravelly sandstones with minor intercalations of shale and clay. This formation type supports dam siting in that the clay component guarantees more runoff while the coarse-grained and gravelly sandstone components guarantee high recharge. In contrast, the Nsukka Formation which is only located in parts of the northern portion of the study area constitutes the least coverage (Fig. 6). The Nsukka Formation comprises more of clays, shale, thin sandstones and coal. The Imo Shale Formation is laid down during the transgressive period that followed the cretaceous. It is an impervious formation characterized by lateral and vertical variation in lithology. The Bende Ameki formation consists of greenish-gray clayey sandstone, shale and mudstones with interbedded limestone. It is a sufficient water-bearing unit of a multi-colored sand member of coarse- to fine-grained and poorly to moderately sorted high porosity and permeability (Onu and Ibezim 2004). The Ogwashi-Asaba Formation consists of a variable series of clays, sands and grits with seams of lignite. It is a moderately water-bearing unit of moderate porosity and permeability. The lighter-clay seams of Ogwashi-Asaba have sandy layers in some horizons (Nwosu et al. 2013; Nwachukwu et al. 2015). The alluvium formation consists of argillaceous particles (Nwachukwu 2016). It is composed of sand, silt and clay.

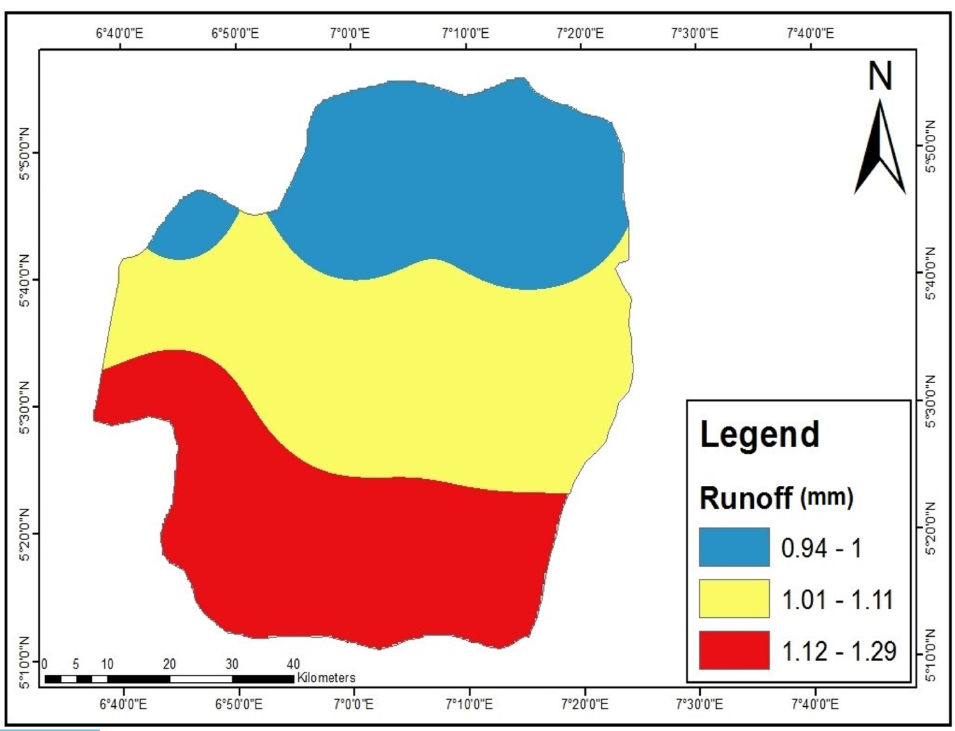


Fig. 4 Runoff spatial distribution map

Fig. 5 Map of soil types in Imo State

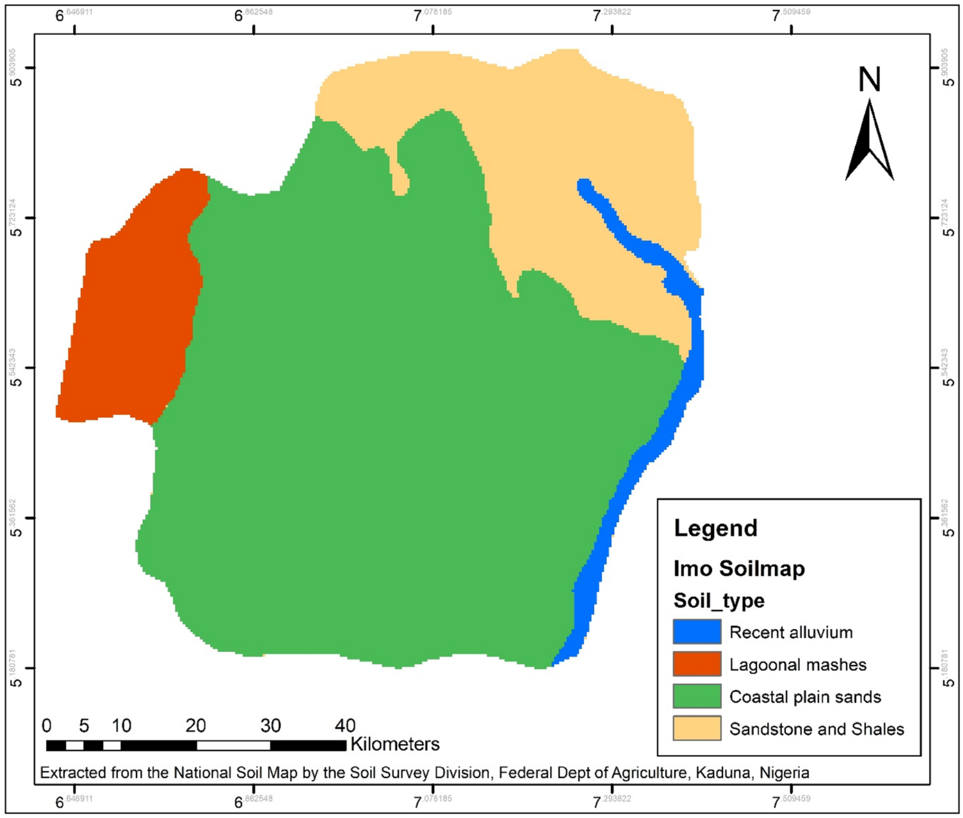
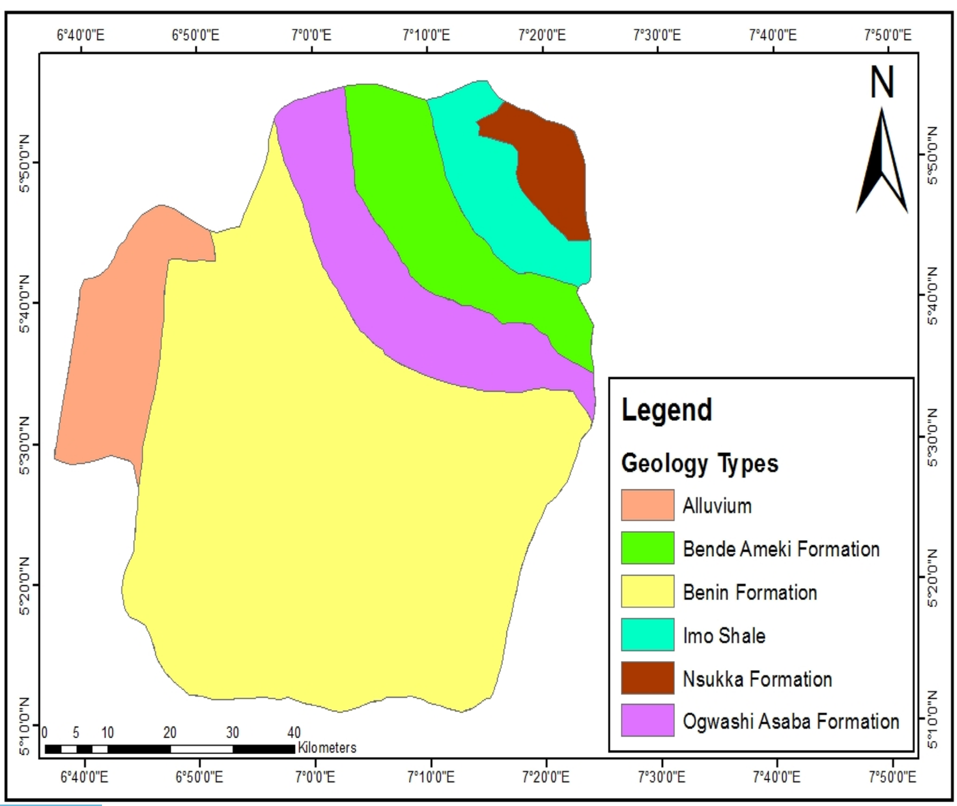


Fig. 6 Imo State geological map



Land use/Land cover

The landcover map of the study area extracted from the continent-scale land cover map and reclassified into the five landcover classes relevant for map siting is depicted in Fig. 7, and the summary of the land cover coverages is presented in Table 1. The vegetation covers comprising tree cover areas, shrubs, grasslands and croplands are the most predominant land cover type in the study area covering 89% of the study area. The second largest percentage coverage is 'built-up' areas with a percentage cover of 9.8% while the other land cover types cover less than 1% of the study area. The vegetation, marsh and bare/rocky areas are of high priority in siting dams or rainwater harvest structures. Built-ups are of low priority as there are lots of human activities in the built-up areas.

Drainage network

The output of the filled sink imagery is a voidless DEM which is used to generate the flow direction. Figure 8 represents the DEM after creating the sinks, and Fig. 9 portrays the direction of flow in Imo State. The flow direction map shows that the majority of the flow is toward the south (S) and west (W) of the study area, especially for the major streams. This is likely because the northern ends have relatively higher elevations, thereby causing water to generally flow south. However, to lesser extents, some surface runoffs flow toward the north (N) and east € before joining larger tributaries. The flows toward the NW, NE, SW and SE are relatively minimal in comparison with the general southwards and eastwards flow. This explains why there is a greater concentration of longer streams toward the southern

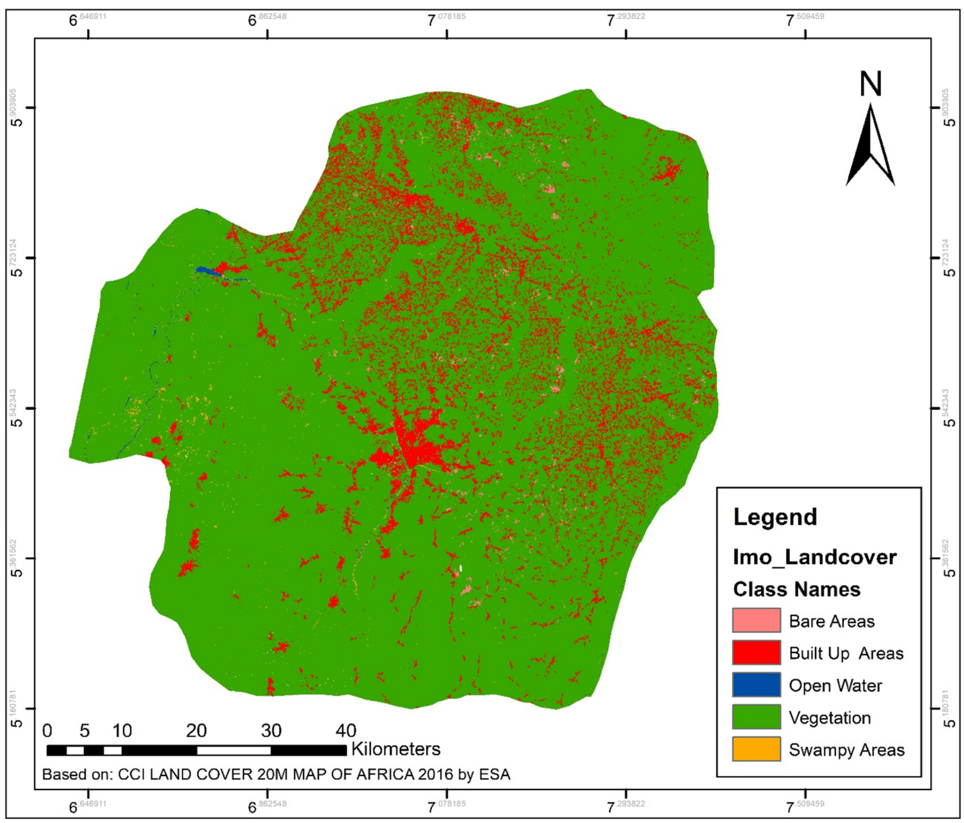


Fig. 7 Imo State land use and land cover map

Table 1 The land cover classes and their percentage coverages (2016)

S/N	Land cover type	Coverage (%)
1	Bare areas (including rocks)	0.7
2	Built-up areas	9.8
3	Vegetation cover (tree, shrubs, grasslands and croplands cover areas)	89.0
4	Swampy areas (vegetation aquatic or regularly flooded)	0.3
5	Open water	0.2

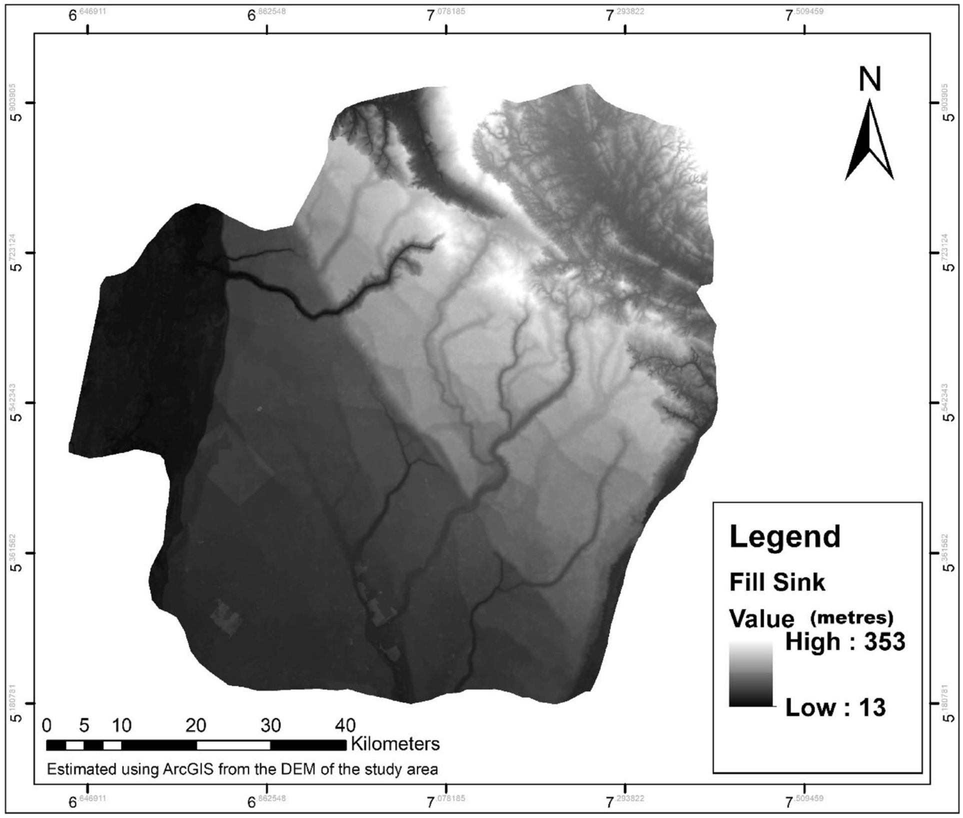


Fig. 8 Map of Imo DEM after sink fill

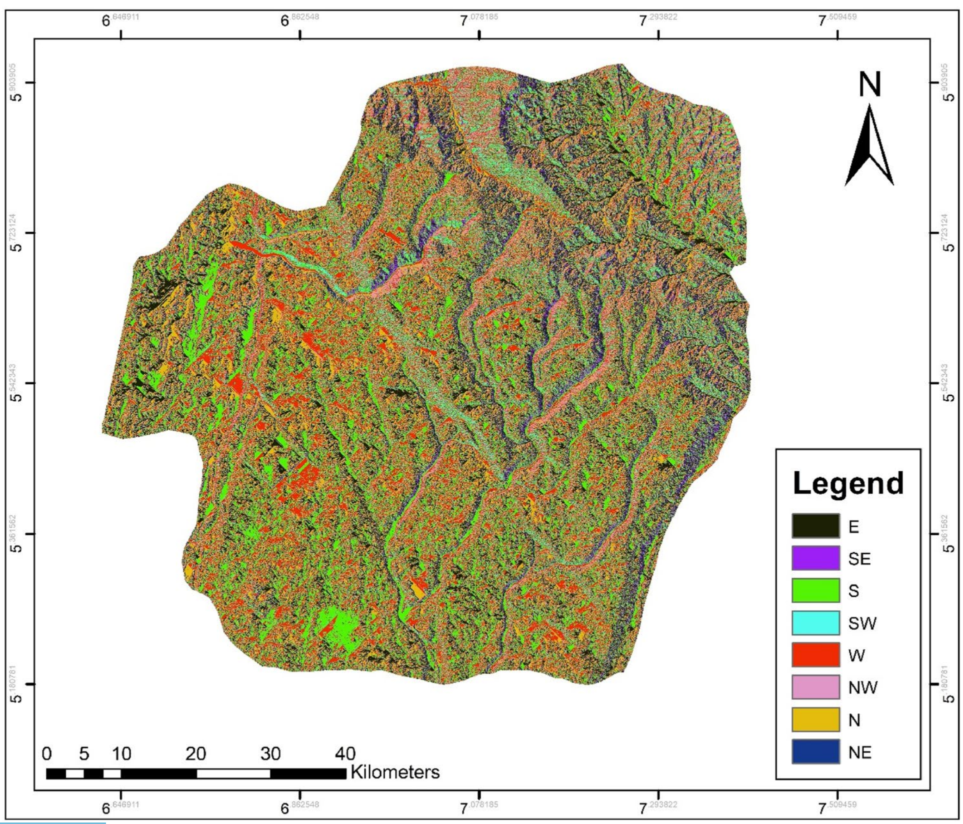


Fig. 9 Flow direction map of Imo State

parts of the study area as observed in the flow accumulation map (Fig. 10).

The drainage network (Fig. 11) was extracted from the flow accumulation map indicating the drainage network pattern and its stream order in Imo State. The extracted drainage network shows the stream order. Stream order is a measure of the relative size of streams. The smallest tributaries are referred to as first-order streams. The first-order to third-order streams are called headwater streams, fourth-order to sixth-order are called medium streams and seventh-order above are called rivers. Imo State has stream orders one to six. Dams would only be suitable in the medium streams since they are large enough for dam construction but not too large as to become infeasible. The stream ordering in Imo State shows that the area is largely provided with the third-order streams draining into the region. The stream orders drain into the four main rivers: Imo, Njaba, Otammiri and Ulasi rivers in the study area. The capacity of third- and fourth-order streams is much higher than the second- and first-order streams. The first- and second-order streams are suitable for rudimentary natural regional uses, whereas the third- and fourth-order streams are suitable for runoff generation and storage capacity for the region. Much of the Western region has a high drainage density which results in high runoff generation within the region. This region is largely characterized by third-order streams and the development of higher-order streams that can be sufficient for dam construction.

Suitable dam site selection

Finally, after assigning fuzzy memberships to each of the six criteria maps, they were overlaid to determine the most suitable sites. The results of the probable dam sites are shown in Fig. 12. Eight sites were identified to be suitable for dam sites (Fig. 12). It is observed that the majority of the selected sites are located in the northwestern part of Imo state and those areas are high elevation areas characterized by gentle slopes.

Conclusion

As urbanization increases in Owerri, the capital city of Imo State, the demand for water resources increases rapidly and these demands have to be met adequately for sustainable

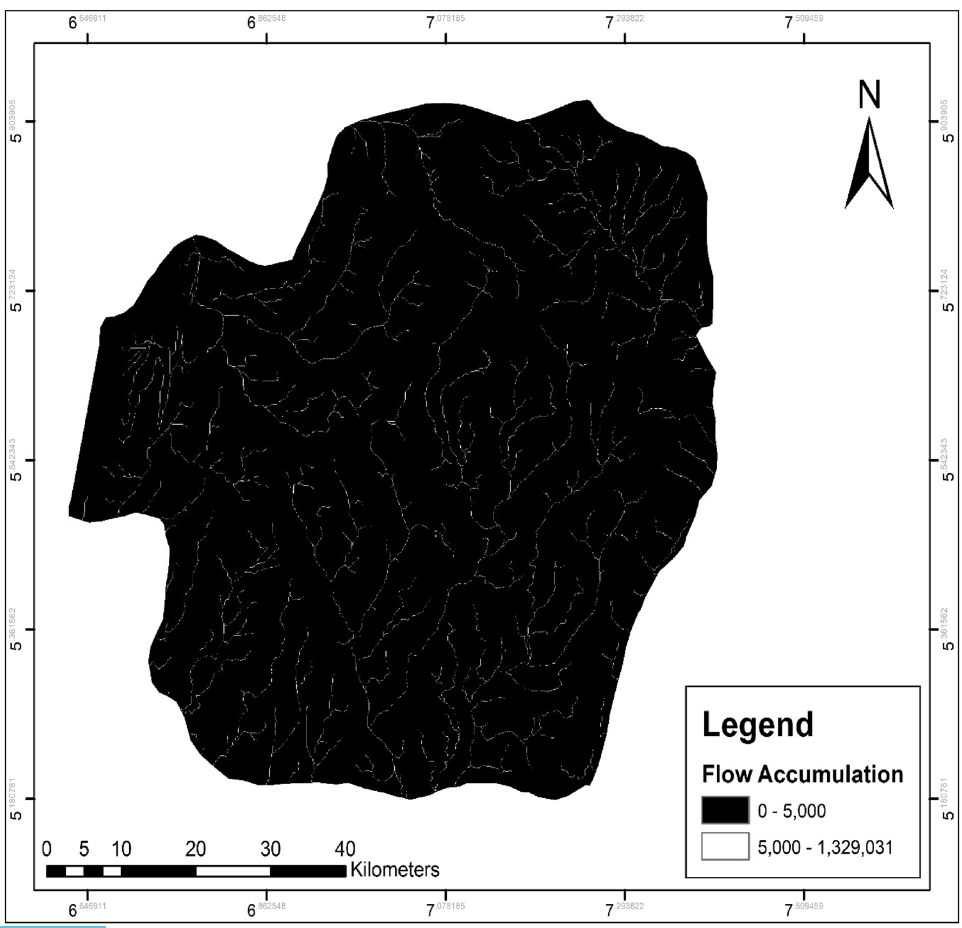


Fig. 10 Flow accumulation map of Imo State

Fig. 11 Imo State drainage map

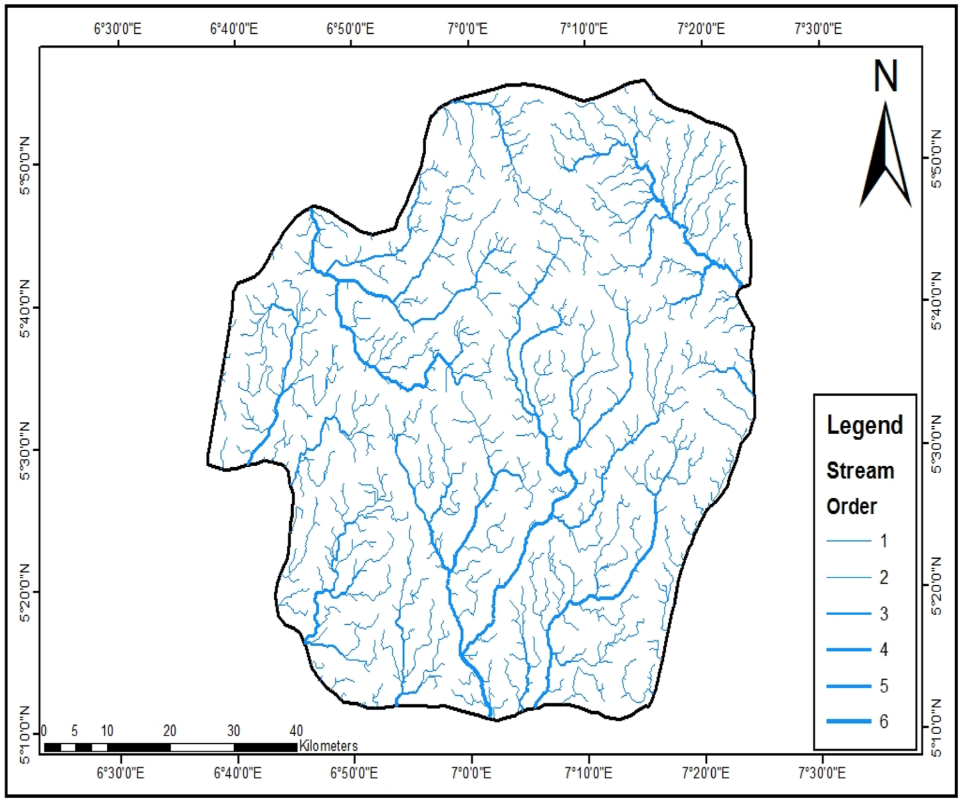
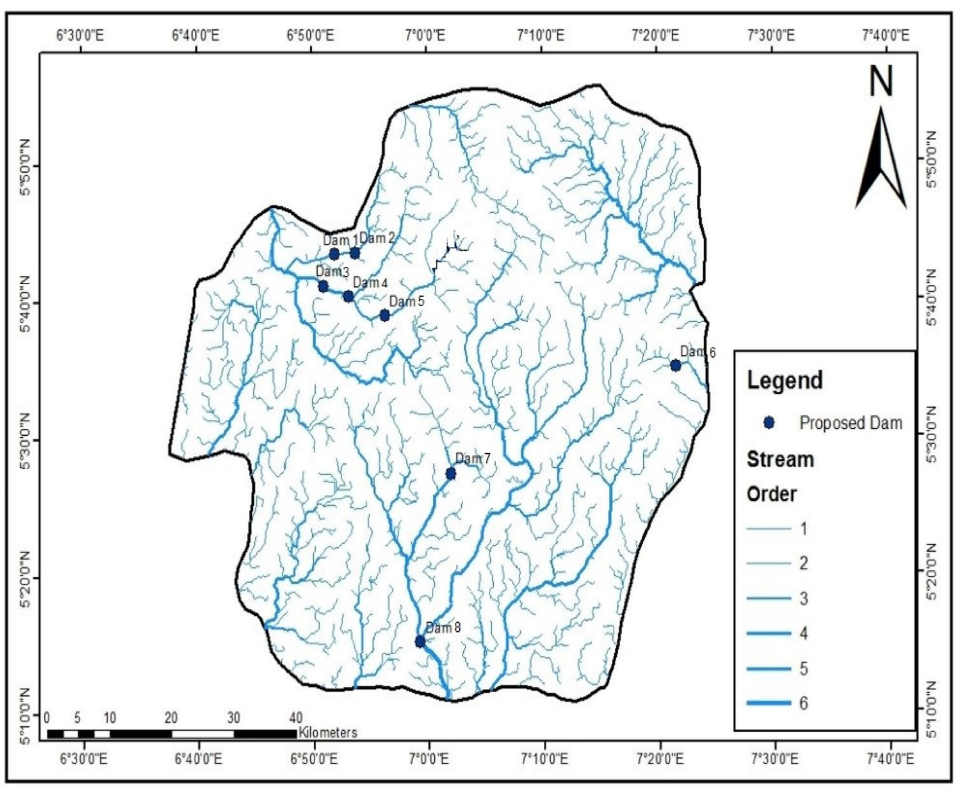


Fig. 12 Selected suitable proposed dam sites



development. Water resource management techniques have to be applied to carter for the increasing domestic and industrial demands of which dam siting is a major part. Dam siting would not only carter for domestic and industrial use, but it would also serve as a source of renewable energy in the form of hydropower. The study has shown that GIS and remote sensing technology are useful for the integration of various criteria information through multi-criteria analysis to identify suitable sites for dam construction for domestic, agricultural, industrial and renewable energy purposes. Climatic and geomorphological factors were considered for adequate information efficiency for siting dams. The information provided by the study would be useful for decision-makers, policy-makers, stake holders and the government in water resource management planning in Imo State to meet the required demand and supply of efficient water resources needs in the state. The information would also aid a sustainable development of water resources management in the state. For future research, however, it is meaningful to integrate more detailed socioeconomic criteria in the decision making for suitable dam sites selection and/or other water management structures. Moreover, to avoid discord with other land usages in the parts which the available GIS and remote sensing data do not pinpoint, closer investigation has to be performed on the nominated locations. The use of other effective methods or their combination can be wonderful as well. These would lead to more accurate results.

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