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DRAINAGE NETWORK EXTRACTION AND WATERSHED DELINEATION USING REMOTE SENSING AND GEOGRAPHIC INFORMATION SYSTEM OF IMO STATE, NIGERIA.

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Abstract

This study focused on drainage network extraction and watershed delineation using remote sensing and geographic information system Imo state Nigeria and then carried out extraction some of the hydrologic characteristics of the study area. Five major watersheds were delineated which were named WS1, WS2, WS3, WS4, and WS5, with the largest watershed basin having an area of 1744.86km^2 to 567.01km^2 for the smallest basin. The perimeter of watershed basins varies from one basin to another, where the circumference of the largest watershed basin reaches about 338.54 km, and the smallest basin about 187.53km. The longest flow length of the streams is very important in quantifying the volume of available surface water, the carrying capacity of the stream channels, and the urban floodplain extent as well. Figure 8 and 9 shows the watersheds and their drainage networks which is dendritic type, with the longest flow length ranges from 105.82km in WS1 to the smallest 40.21km in WS5. Analysis of land use and soil characteristics the study area was also done which could be used for watershed management.

Keywords: *Watershed; stream network; GIS; remote sensing; DEM; topographic map*

1.0 INTRODUCTION

The importance of drainage network and watershed in ecosystem cannot be over emphasize. Investing in the maintenance of healthy watersheds can significantly lower costs associated with water treatment and flooding. Healthy watersheds provide many ecosystem services including, but not limited to: nutrient cycling, carbon storage, erosion/sedimentation control, increased biodiversity, soil formation, wildlife movement corridors, water storage, water filtration, flood control, food, timber, and recreation, as well as reduced vulnerability to invasive species, the effects of climate change and other natural disasters.[1]

The role of watersheds in nutrient cycling is important for stabilizing the environment at local and global scales [2]

Watershed Management refers to the management and conservation of surface and groundwater resources, which includes surface and groundwater resources, conservation, regeneration, and judicious use of all resources. [3]. Watershed Management is an adaptive, comprehensive, integrated multi-resource management planning process that seeks to balance healthy, ecological, economic, and cultural/social conditions, within a watershed. It serves to integrate the planning of land and water [3].

A watershed is an area that supplies water by surface or subsurface flow to a given drainage system or body of water, be it a stream, river, wetland, lake, or ocean. It is considered as the basic unit of water supply and the basic building block for integrated planning of land and water use. The characteristics of the water flow and its relationship to the watershed are a product of interactions between land and water (geology, slope, rainfall pattern, soils, and biota) and its use and management [4]

Drainage networks are important data structures for modeling the distribution and movement of surface water over the terrain. Numerous tools and methods exist to extract drainage networks and watersheds from digital elevation models (DEMs).

The application of GIS to watershed delineation is increasingly gaining relevance. Accurate delineation of a watershed plays an extremely important role in the management of the watershed.

Watershed modeling is an ideal application for GIS which allows the simulation of hydrologic processes in a more wholistic manner, compared to many other models [5, 6]. A key component of watershed modeling is the watershed area that contributes flow to the point of interest [5]. Each stream or river is bounded by a watershed divide and is defined by the highest elevations surrounding the stream. Watershed, catchment, and drainage basin are terms that are used interchangeably to refer to, 'the topographic area that collects and discharges surface stream flow through one outlet' [7].

This study is aimed at drainage network extraction and watershed delineation using "DEM of Imo state area of Nigeria and to document the important flow characteristics of each sub-catchment in a GIS environment using the 30m SRTM DEM as input data and ARCGIS 10.4 to delineate. In order to achieve this, the drainage routes were marked out in the GIS environment, and the DEM cells that contribute to each drainage route delineated in the same polygon as a sub-catchment.

1.2. LITERATURE REVIEW

Hayder H Kareem, Aseel A Alkatib, and Waseem H. Mahdi (2021). Watershed basins delineation using GIS and Digital Elevation Model (DEM) to the region NI-38-14 Karbala-Al-Najaf Plateau, Iraq. Remote Sensing and GIS technology was used to calculate the morphometric properties and output them in the form of tables and cartographic models. The water networks of the geographical plateau NI-38-14 located between the administrative borders of the provinces of Al-Najaf and Karbala in Iraq are devised by extracting a topographic map of the area and calculating the areas of the watersheds and their perimeters. The topographic map showed great variations in the level of the earth's surface, as the heights of the area ranged between 20m and 120m. The number of watersheds extracted in the Karbala-Al-Najaf plateau is 150 watersheds with different areas, the large area is about 4882 km^2, while the small area is about 1 km^2, and between those areas, there are various areas. The largest recorded watershed circumference reached 580km in area (4882 km^2), while the lowest recorded perimeter is 8km for the area (1 km^2)[8].

Solomon et al (2012) studied the extraction of Drainage Pattern from ASTER and SRTM Data for a River Basin using GIS Tools. The river drainage pattern is extracted from digital elevation data using D8 algorithm available within ArcGIS, hydrology toolbox. Study area is the Cauvery basin spanning across three states of Southern India viz., Tamilnadu, Karnataka, and Kerala. Watershed is delineated by using ArcGIS 10 by the normal delineation procedure which is described in detail and plugins like Arc SWAT and Hydro tools are used to get the best results. Google earth is used as a reference to visually inspect the ridges and boundaries. The basis for assuming the limiting threshold value is discussed. All the aforementioned work is done for ASTER and SRTM data separately and the results are compared. The number of sub-watersheds resulting for limiting threshold value obtained by trial and error method is shown. The threshold value for deciding on the required drainage density is arrived at by trial and error method where the watershed boundary derived from digital network matches the digitized boundary most accurately. Threshold value for flow limitation in ASTER (30-meter resolution) is higher than SRTM (90-meter resolution) due to the difference in resolution. Correspondingly, drainage density is notably higher in ASTER for scarcely distinguishable watershed boundary obtained as a result. [9].

Bal Gopal Guru, Janhabi Meher (2016) Delineation of Mahanadi River Basin by Using GIS and Arc SWAT. Therefore in the present work, Mahanadi river basin lying within Odisha (drainage area approximately 65000 sq. km.) has been delineated in to five sub-basins based on the five CWC-operated discharge sites in Odisha. In the present work, Arc-Swat has been used to delineate the watershed with the help of the (digital elevation model) DEM. It was observed that number of sub-watersheds into which the study area is being depicted relies on number of outlets and density of drainage. The soil data is being found out by the help of the soil map in the grid pattern and was determined by the calculation and viewed in the attribute table after delineation. In the present work, the DEM is taken of the study area and being delineated by the assistance of the Arc SWAT and small watersheds are being shaped according to the release of the water in the study zone. By the assistance of these small watersheds, we can get a concrete idea for the flow of water direction and the occurrence of the slope in the watershed [10].

2.0 DESCRIPTION OF STUDY AREA

Imo State is a state in the South-East geopolitical zone of Nigeria, bordered to the north by Anambra State, Rivers State to the west and south, and Abia State to the east [11]. It takes its name from the Imo River which flows along the state's eastern border, which takes its course from the Okigwe/Awka upland. It lies within latitudes 4°45'N and 7°15'N, and longitude 6°50'E and 7°25'E. Imo State has many rivers. The main rivers in the state are Imo, Otamiri, and Njaba. The major lakes are in Oguta and Abadaba in Obowu local government area [12].

Geographically, the State is divided between the Niger Delta swamp forests in the far east and the drier Cross–Niger transition forests in the rest of the State. Other key geographical features are the state's rivers and lakes with the Awbana, Imo, Orashi, and Otamiri rivers along with the Oguta Lake in western Imo State [13]. Imo State covers an area of 5,530 square kilometers. Imo State shares boundaries with Enugu and Ebonyi States to the north, Anambra State to the west, Rivers State to the south and in the North and Rivers State to the South, Cross River, and Akwa Ibom States to the east.

The main streams draining the state are Imo, Otamiri, Njaba, and Orasi rivers, all of which have very few tributaries. With the exception of Imo River, which runs through the area underlain by the Imo Shales, other rivers rise within the coastal plain sands. Generally, river valleys constitute the major physical features, which are often marshy. The vegetation is tropical rainforest.

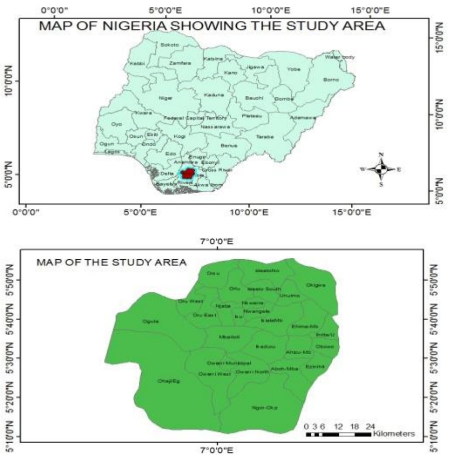


Figure 1: Show the map of the study area.

3. MATERIALS AND METHODS

The primary data used for this study is the 2020 Shuttle Radar Topography Mission (SRTM) digital elevation model (DEM) of 1 arc-second (approximately 30 m) resolution. It is an elevation data obtained from one of the most famous and largest sites that provide Digital Elevation Models (DEM) which is USGS Earth Explorer (earthexplorer.usgs.org), as it provides DEMs in the Shuttle Radar Topography Mission-SRTM format with a resolution of (10m, 30m, and 90m) through which it is possible to extract the raw data stored for the area to be studied [14], on a near-global scale to generate the most complete high-resolution digital topographic database of Earth. While delineating watersheds or defining stream networks, we proceed through a series of steps.

The flow chart shown below are the steps for delineating drainage network and watershed.

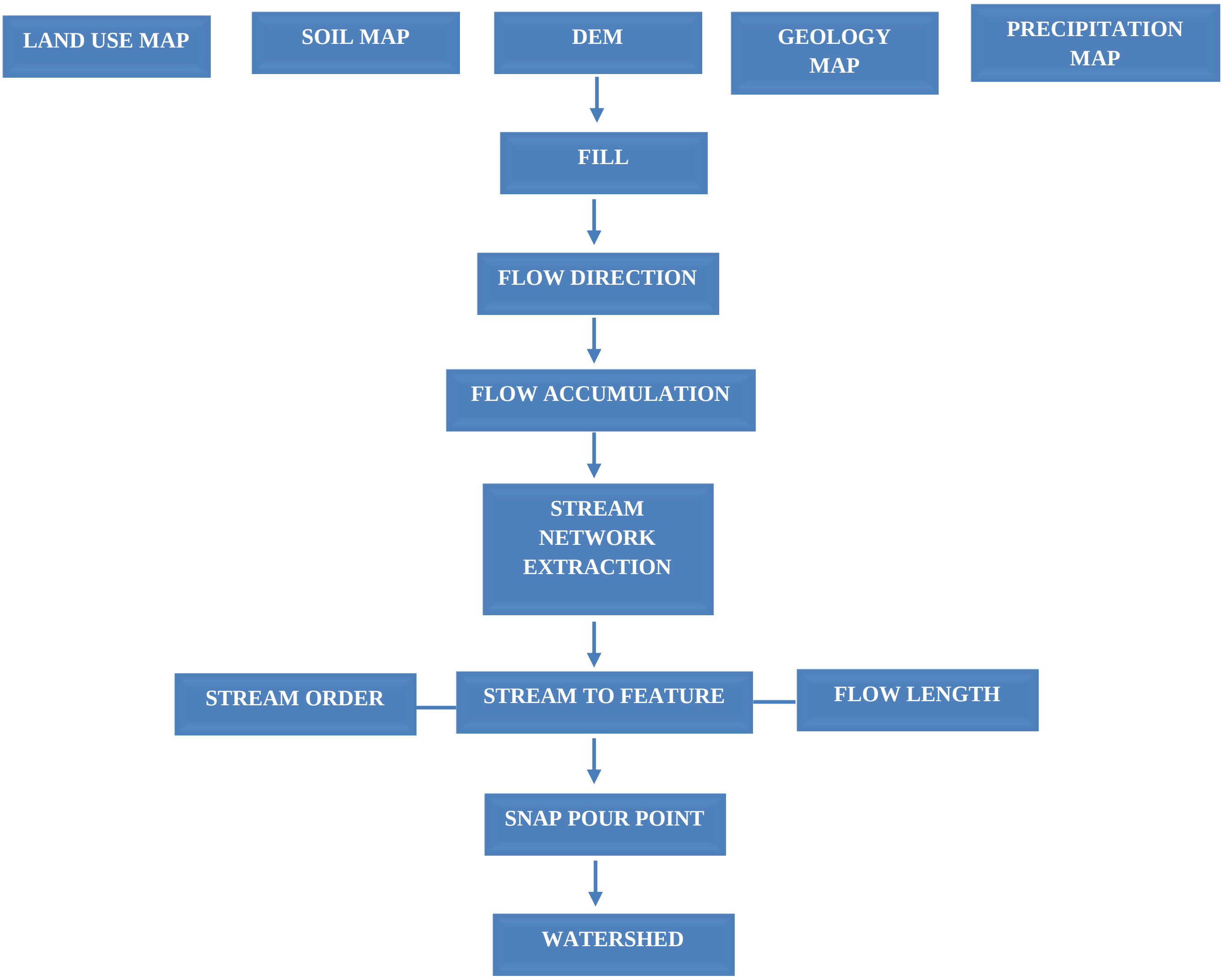


Figure 1: Flow chart of steps to delineate watershed.

3.1.1. DEM Acquisition

The first input required for watershed analysis is DEM. Digital Elevation Models (DEMs) are a type of raster GIS layer. In a DEM, each cell of raster GIS layer has a value corresponding to its elevation (z-values at regularly spaced intervals). DEM data files contain the elevation of the terrain over a specified area, usually at a fixed grid interval over the "Bare Earth".

3.1.2. Fill

Fills sinks in a surface raster to remove small imperfections in the data. A filled DEM or elevation raster is void of depressions. A depression is a cell or cells in an elevation raster that are surrounded by higher elevation values, and thus represents an area of internal drainage. Although some depressions are real, such as quarries or glaciated potholes, maybe imperfections in the DEM. Therefore, depression must be removed.

A common method to remove depression is to increase its cell value to the lowest overflow point out of the sink. This results in flat surface.

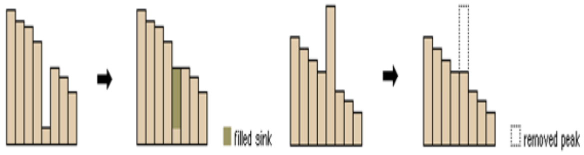


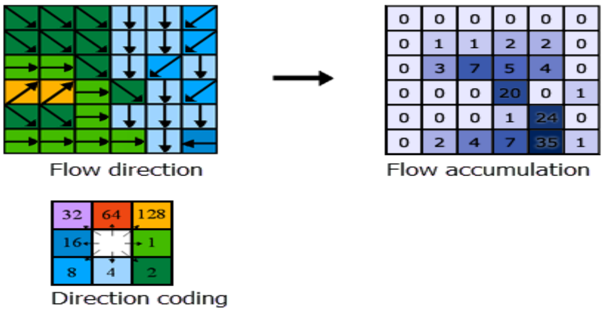
Figure 2: Shows sink being filled and peak being removed

3.1.3. Flow Direction

A flow direction raster shows the direction water will flow out of each cell of a filled elevation raster. A widely used method for deriving flow direction is the D8 method, used by Arc GIS. In D8 method, assigns a cell's flow direction to the one of its eight surrounding cell's that has the steepest distance-weighted gradient. D8 method produces good results in zone of convergent flows and along well-defined valleys. It fails to represent adequately divergent flows over complex slopes and ridges. Another algorithm is well used in calculation of flow direction is D ∞ (infinity).

A grid of D8 flow directions which are defined, for each cell, as the direction of the one of its eight adjacent or diagonal neighbors with the steepest downward slope.

Flow Direction Coding: 1 -East, 2 - Southeast, 4 – South, 8 – Southwest, 16 – West, 32 - Northwest, 64 - North, 128 – Northeast.



0	0	0	0	0	0
0	1	1	2	2	0
0	3	7	5	4	0
0	0	0	20	0	1
0	0	0	1	24	0
0	2	4	7	35	1

32	64	128
16		1
8	4	2

Figure 2: Shows D8 coding direction

3.1.4. Flow Accumulation

A flow accumulation raster tabulates for each cell the number of cells that will flow to it. The tabulation is based on the flow direction raster. A flow accumulation raster can be interpreted in two ways.

- Cells having accumulation values generally correspond to stream channels, whereas cells having an accumulation value of zero generally corresponds to ridgelines.
- If multiplied by cell size, the accumulation value equals to drainage area.

3.1.5. Stream Network

Stream network can be derived from a flow accumulation raster. The derivation is based on a threshold accumulation value. A threshold value of 500, for example, means that each cell of the drainage network has a maximum of 500 contributing cells.

A higher threshold value will result in a less dense stream network and fewer internal watersheds than lower threshold value.

Threshold values between 100 to 500 cells seem to best capture the stream network in the area.

3.1.7. Area-wide Watersheds

This is final step to delineate watershed for each stream section. Inputs required for area-wide watershed delineation are flow direction raster and stream link raster. A denser stream network will have more but smaller watersheds

3.1.8. Point-Based Watersheds

Delineation of individual watersheds based on point of intersection (pour point) follows the same procedure as for delineation of area-wide watersheds. The only difference is to substitute a point raster for a stream link raster.

Point-based watersheds delineation is based on the point of interest. This point of interest may be stream gauge stations or dams. They may also correspond to surface drinking water system intake points of interest are called pour point or outlets.

If pour point is not located directly over a stream link, it will result in a small, incomplete watershed for the outlet.

3.2. SOIL MAP

Soil map is a geographical representation showing diversity of soil types and /or soil properties (soil PH, textures, organic matter, depth of horizons etc) in the area of interest. The soil map is prepared from world soil map FAO SOIL portal at 1: 5000000 scale. Generally, soil maps are used to simply identify soils and their properties but sometimes require for specific purposes such as determining the suitability of a soil for a particular crop or the land drainage capabilities of an area.

3.3. GEOLOGY MAP

Geologic maps represents the distribution of different types of rock and surficial deposits as well as location of geologic structures such as faults and folds. Geologic maps are primary source of information for various aspects of land use planning, including the siting of building and transportation systems, resource identification, natural hazard avoidance, and critical for growing the economy.

3.4. LAND USE LAND COVER

Land cover data are used as basic information for sustainable management of natural resources, they are increasingly needed for the assessment of impacts of economic development on the environment. Land use refers to the purpose the land serves, for example, recreation, wildlife habitat or agriculture. Land cover maps provide information to help managers best understand the current landscape. To see change over time, land cover maps for several different years are needed. The land use land cover from figure 5 and summary of land use category from **Table 1** shows eight different category with the Trees occupying almost three quarter of the entire study area and built area taking almost one-quarter of the whole area.

Table 1: Shows land use category of the study area.

S/N	Land Use Category	Percentage
1	Water	0.4%
2	Trees	72.8%
3	Flooded Vegetations	0.03%
4	Crops	0.57%
5	Built Area	23.7%
6	Cloud	0.017%
7	Shrubs	0.013%
8	Bare Ground	2.5%

3.5 PRECIPITATION

Precipitation maps allows you to see the amount distribution, type, and probability of precipitation over a large area. The amount of precipitation is usually expressed in millimeters (mm). The map in figure 4 show the precipitation within the indicated period of 2000 to 2020 years.

3.6 STREAM SEGMENTS

Streams, including those that don‘t flow all of the time, make up the majority of the country‘s waters. They could be a drizzle of snowmelt that runs down a mountainside crease, a small spring-fed pond, or a depression in the ground that fills with water after every rain and overflows into the creek below. They protect against floods, filter pollutants, recycle potentially-harmful nutrients, and provide food and habitat for many types of fish.

4.0 RESULTS AND DISCUSSION

The result of watershed delineation and flow patterns of Imo State, Nigeria is presented below with tables, figures, and maps for illustration.

These are very important tools in flood mitigation, erosion control, urban area planning, urban development monitoring and management, engineering design of drainage facilities, the studies of distribution of water-borne diseases, sediment transportation, and agriculture. The drainage lines indicate the natural routes through which runoff flow.

The study of the area, perimeter of drainage basins, and dimensions of watershed basins includes the study of the total area of Watershed basins and their dimensions, which are the stream order and length, longest flow length, which indicates parts of the characteristics of these basins and the calculation of some morphometric characteristics related to the formal characteristics of drainage basins and their networks in the area basins.

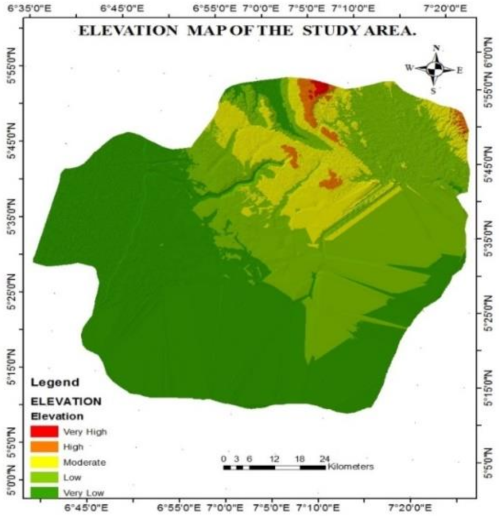


Figure1: Shows the Elevation map of the study area.

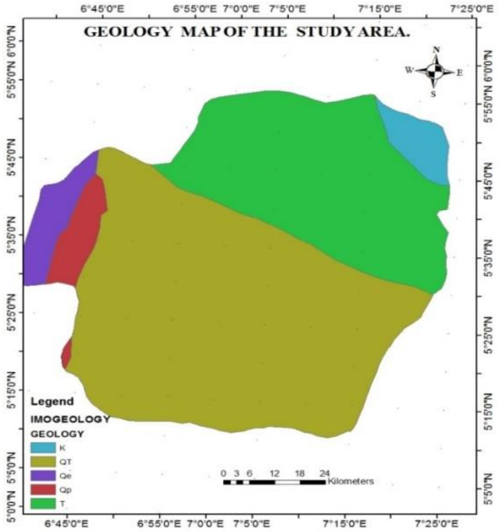


Figure2: Shows the Geology map of the study area.

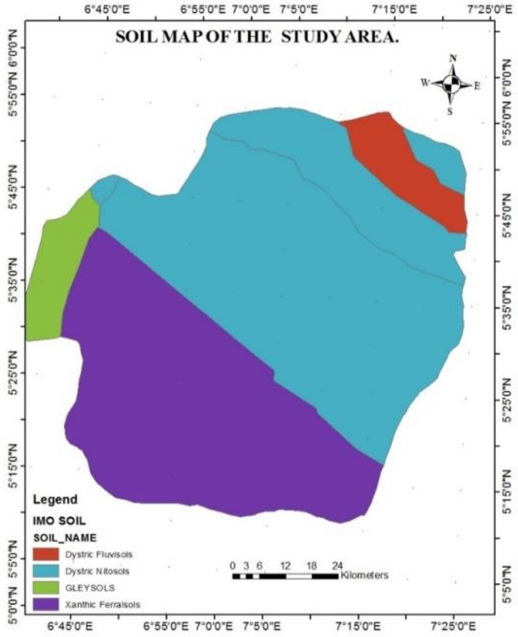


Figure3: Shows the Soil map of the study area

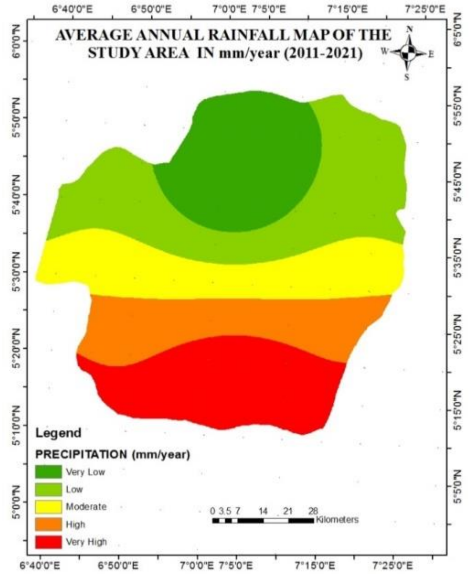


Figure4: Shows the Precipitation of the study area

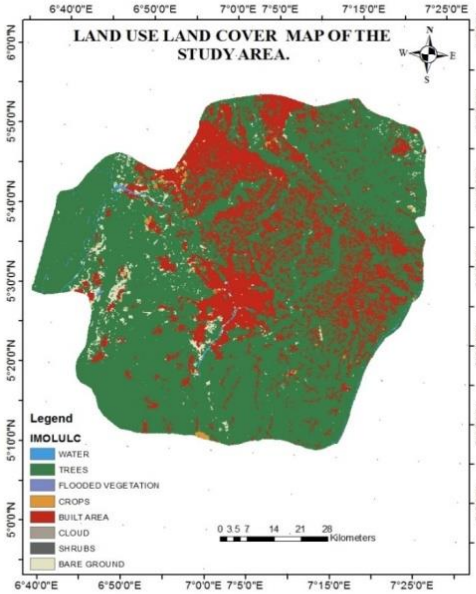


Figure5: Shows the land use land cover map of the study area.

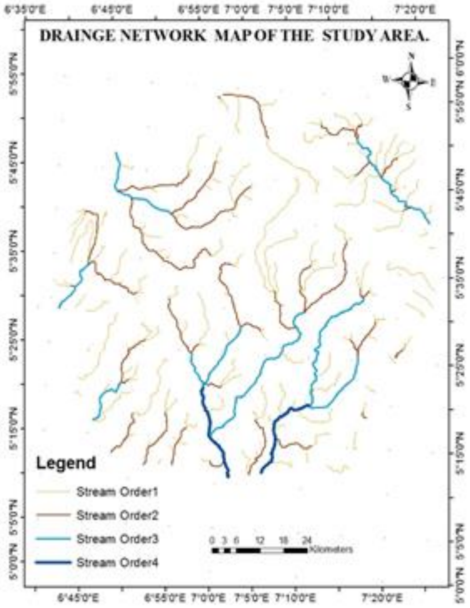


Figure6: Shows the Drainage network of the

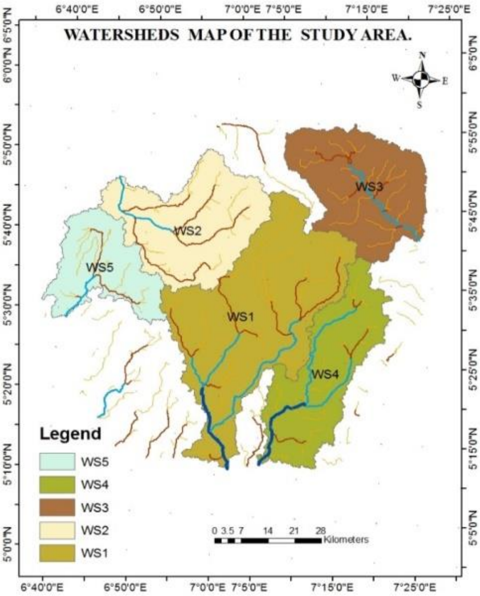


Figure7: Shows the Watershed of the study area.

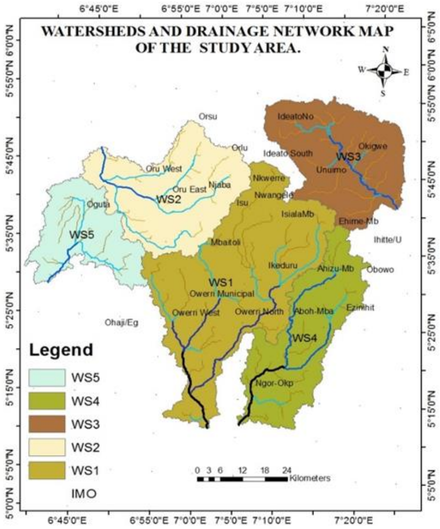


Figure8: Shows the Watershed and Drainage of the study area

Table 2.0 Hydrologic Characteristics of the Watersheds

Watershed	Area (km^2)	Perimeter(km)	Stream Order	Stream Order Length(km)	Longest Flow length(km)
WS1	1744.86	338.54	1	191.63	105.82
			2	109.52	
			3	77.35	
			4	25.54	
WS2	983.31	213.89	1	83.65	61.20
			2	107.42	
			3	26.38	
WS3	927.00	174.34	1	147.85	52.11
			2	36.28	
			3	35.09	
WS4	890.07	252.50	1	108.36	76.90
			2	32.84	
			3	61.28	
			4	25.70	
WS5	567.01	187.5	1	8.76	40.20
			2	17.10	
			3	14.35	

From **Table 2.0,** Five major watershed were delineated which were named WS1, WS2, WS3, WS4, and WS5, with the largest watershed basin having an area of 1744.86km^2 to 567.01km^2 for the smallest basin. The perimeter of watershed basins varies from one basin to another, where the circumference of the largest watershed basin reaches about 338.54 km, and the smallest basin about 187.53km. The longest flow length of the streams is very important in quantifying the volume of available surface water, the carrying capacity of the stream channels, and the urban floodplain extent as well. **Figure 8 and 9** shows the watersheds and their drainage networks which is dendritic type, with the longest flow length ranges from 105.82km in WS1 to the smallest 40.21km in WS5.

SOIL INTERPRETATION

The soils of Imo state belongs to four soil group – Dystric Fluvisols, Dystric Nitosols, Gleysols, Xanthic Ferralsols. **Figure 3 and Table 3. 0** shows the distribution of these soil associations in the study area.

Dystric Fluvisols (4.55%) is distributed in the watershed spreading from the northeast region. Dystric Nitosols (53.3%) is present in the mountainous region of the eastern part of the watershed, GLEYSOLS (4.45%) in the western area of Imo, and Xanthic Ferralsols (37.7%) is found in the southwestern part of the area.

A soil's characteristics, such as type, depth, and saturation, control the volume of water that flows over (as runoff), drains through, or is absorbed by the soil. Bedrock geology, depth, and configuration also affect the volume of water that can infiltrate the soil to the bedrock and be stored in an aquifer. In addition, vegetation type and density can impact runoff volume and the amount of water that plants absorb and transpire.

Fluvisols are very young soils with weak horizon differentiation and are predominantly brown (aerated soils) and/or grey (waterlogged soils) in colour. Their texture can vary from coarse sand in levee soils to heavy clays in basin areas. Fluvisols are wet in all or part of the profile due to stagnating groundwater and/or flood water from rivers or tides. Gleysols is prolonged saturation with water, associated with lack of aeration, poor rooting conditions for most crops, and poor conditions for soil fauna.

Table 3.0

SOIL	PERCENTAGES
GLEYSOLS	4.45%
Dystric Fluvisols	4.55%
Dystric Nitosols	53.3%

Xanthic Ferralsols	37.7%

Most Ferralsols are clayey (a consequence of advanced weathering) and have strong water retention at permanent wilting point while the presence of micro-aggregates reduces moisture storage at field capacity.

Nitosols are free-draining soils and permeable to water (50–60 percent pores). They are well-drained soils with a clayey subsurface horizon that is deeply stretched and has typical nutty or polyhedric blocky structure elements with shiny ped faces

5.0 CONCLUSION AND RECOMMENDATION.

This study also gives information about the physical characteristics of the watershed. This is very important in urban planning, resources allocation, and flood control. The delineation of drainage areas, watersheds, or basin boundaries is an important process that can impact investigations of local and regional ecology, epidemiology, hydrology, flood modeling, urban planning, and political boundaries. Stream network features are commonly used to designate watershed outlets, and thereby identify contributing areas that drain to each outlet.

The study highlight some hydrologic features and a comprehensive assessment of Imo state watersheds distribution, movement, and properties of the waters of the earth in order for proper management of water resources and a comprehensive evaluation of characteristics of the watersheds in the study area is recommended.

Acknowledgments

Special thanks to USGS Earth Explorer for providing the DEM data from the site, the International Union of Soil Sciences (IUSS) FAO-UNESCO Soil Map of the World for providing soil map, and Esri land cover, for providing data land use analysis, which was required in order to develop this work.

COMPETING INTERESTS

Author have declared that no competing interests exist.**ORCID**Festus Eebo https://orcid.org/0000-0002-7371-5344?lang=en

AUTHORS' CONTRIBUTIONS

This work was carried out in collaboration between all authors. Author Festus Olusola designed the study, wrote the framework, and wrote the first draft of the manuscript, the GIS analysis, and wrote the first draft of the manuscript. Author Odunayo and Gabriel managed the literature searches and geospatial analysis of the study was performed by the three authors. All authors read and approved the final manuscript

REFERENCES

1. Benefits of Healthy Watersheds | US EPA.United state environmental protection agency. https://www.epa.gov/hwp/benefits-healthy-watersheds
2. Allan, J.D. and Castillo, M.M. (2007) Stream Ecology: Structure and Function of Running Waters. 2nd Edition, Chapman and Hall, New York. http://dx.doi.org/10.1007/978-1-4020-5583-6
3. Watershed Management & Its Importance, universal group of institutions.https://universalinstitutions.com/watershed-management-and-its-importance/
4. SLM 310 Watershed Hydrology.pdf – NOUN https://nou.edu.ng/coursewarecontent/SLM%20310%20Watershed%20Hydrology.pdf
5. Poyer E. Using GIS to Delineate Watersheds. [Online].Available:www.edc.uri.edu/nrs/classes/nrs409509/509_2010/Poyer.pdf [Accessed
6. 25/05/2015]
7. Tripathi CN, Gosain AK. Micro watershed modeling in India using GIS technologies and agricultural policy environmental extender (APEX) model. A case study. International Journal of Engineering Research and Applications. 2013;3(2):1640-1648
8. Mays LW. 2005 Ed. Water Resources Engineering. John Wiley & Sons Inc. New Jersey; 2005.
9. Hayder H Kareem et al 2021, Watershed basins delineation using GIS and Digital Elevation Model (DEM) to the region NI-38-14 Karbala-Al-Najaf Plateau, Iraq. *Journal of Physics: Conference Series. 1973 (2021) 012188.*doi:10.1088/1742-6596/1973/1/012188.
10. Gokul V., Ambica A., An experimental study on high strength concrete with replacement of fine aggregate using welding slag, International Journal of Applied Engineering Research, v-9, i-22, pp-5570-5575, 2014.
11. Bal Gopal Guru, Janhabi Meher, Delineation of Mahanadi River Basin by Using GIS and ArcSWAT. International Journal of Engineering Science Invention ISSN (Online): 2319 – 6734, ISSN (Print): 2319 – 6726, 2016.
12. "Imo | state, Nigeria | Britannica". www.britannica.com. Retrieved 12 March 2022.
13. "Nigeria's 36 States and Their Slogans". nigerianfinder.com. Retrieved 12 March 2022.
14. "What are the two lakes in Imo State?". big board scouting. 22 July 2022. Retrieved 3 September 2022.
15. R. E. Daffi1* and I. I. Ahuchaogu2, Delineation of River Watershed and Stream Network Using ILWIS 3.7.1 Academic, *Asian Journal of Environment & Ecology 4(4): 1-8, 2017; Article no.AJEE.35972*
16. Karra, Kontgis, et al. "Global land use/land cover with Sentinel-2 and deep learning." IGARSS 2021-2021 *IEEE International Geoscience and Remote Sensing Symposium. IEEE, 2021.*