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Morphometric Analysis of a Drainage Basin using Alos Palsar Dem and Geographical Information System in Ogbese Watershed, Southwestern Nigeria

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ABSTRACT

Water is a critical environmental resource with direct implications for public health, making the understanding of its flow patterns, quantity, and quality essential for effective environmental management. This study focuses on the morphometric analysis of the River Ogbese basin in Ondo State, Nigeria, using geospatial techniques previously unapplied to drainage basin studies in this area. ArcGIS 10.7 software was used alongside ALOS-PALSAR Digital Elevation Model (DEM) data acquired from the Alaska Satellite Facility to analyse the linear, areal, and relief morphometric parameters of the watershed. Key parameters evaluated included stream order, stream length, bifurcation ratio, drainage density, stream frequency, elongation ratio, circularity ratio, form factor, and relief ratio.

Results reveal that River Ogbese is a fifth-order drainage basin comprising 1,179 drainage networks: 598 first-order, 297 second-order, 143 third-order, 106 fourth-order, and 35 fifth-order streams. The average drainage density is 4.25 km/km^2, and the mean bifurcation ratio is 2.12. The basin exhibits sub-dendritic and dendritic drainage patterns, indicating textural homogeneity and minimal structural control over surface flow. These findings provide valuable insights into the relationships between drainage networks and landscape characteristics, supporting informed decision-making in watershed management, land use planning, environmental conservation and public health safety. The study serves as a useful reference for hydrologists, researchers, and water resource planners. Future studies are recommended to incorporate high-resolution remotely sensed and ground-control data to further advance natural resource management in the basin.

Keywords: *Environment, Morphometric analysis, Drainage basin, Public health, and Geospatial technologies.*

I. Introduction

Watershed protection has drawn attention to the safety of natural resources such as soil and water. The nature of these resources has a great impact on public health. Environmental scientists are expected to assess them critically for the prevention and mitigation of disasters. A protracted period of development has resulted in the discipline of river morphometry being interconnected and unified. The five unique phases that are used to contextualize this progression are antecedents, formulation, intensification, evaluation, and exploration of new directions. Morphometric characteristics have been helpful for analysing watersheds as it shows the relationship among many features of a catchment, like stream order, stream length, drainage density [1].

Morphometric analysis is the quantitative measurement and mathematical characterisation of landform geometry [2]. Drainage morphometric analysis provides a quantitative framework for understanding the geological, topographical, and structural characteristics of a drainage basin, as well as the interrelationships among these factors [3]. It is also useful for prioritising sub-watersheds for conservation and management interventions through the integrated assessment of linear, areal, and relief morphometric parameters [4]. The configuration and development of drainage network patterns are strongly influenced by bedrock lithology, geological structures, and tectonic controls, which can be systematically evaluated through quantitative morphometric analysis [5, 6]. Consequently, drainage morphometry and the characterisation of drainage network patterns constitute important tools for informed watershed management, environmental planning, and the sustainable utilisation of natural resources.

It plays a central role in elucidating the geohydrological behavior of a drainage basin by relating terrain attributes to flow dynamics. The approach allows the estimation of infiltration and surface runoff, as well as related hydrological processes within a watershed, such as soil erosion and sediment

transport, all of which bear directly on natural resource conservation [7]. Conventional in-situ methods are capital- and labor-intensive and time-consuming [8]. Consequently, remote sensing and Geographic Information System (GIS) techniques have emerged as efficient and cost-effective tools for drainage basin analysis and for the assessment and management of surface and groundwater resources [9]. A drainage basin is an area of land in which precipitation excess (surface runoff) is collected and routed to a common outlet. It is a fundamental hydrological unit of a catchment, as the movement of water within it is governed by its physiographic characteristics [10].

Networks of drainage basins show both temporal and geographical fluctuations. The hydrological behaviour of a drainage basin provides critical information for the design of soil and water conservation measures, flood management, identification of erosion-prone areas, and the planning of water-harvesting and groundwater-recharge structures. Therefore, both on-site and off-site environmental conditions within a watershed should be considered in basin management [11]. As water moves through a drainage basin, it erodes, transports, deposits, and redistributes sediments, nutrients, and pollutants, thereby influencing watershed biogeochemical processes and water quality [12; 13]. These processes affect the basin's on-site and off-site ecology; as a result, studying drainage basin processes may help us understand how water moves through the hydrologic cycle to support long-term growth, prevent soil erosion, and conserve water.

Watershed studies are essential because of their implications for environmental quality and public health. Remote sensing (RS) and Geographic Information System (GIS) techniques have simplified the investigation of watershed characteristics. Morphometric analysis, when conducted systematically, is a robust approach to characterising watershed form and behaviour, since RS and GIS provide powerful tools for analysing the hydrological processes of a river basin [14: 15; 16]. This study applies geospatial techniques to the morphometric analysis of the River Ogbese basin, with relevance to environmental risk assessment, disaster prevention, and environmental health and safety.

Materials and Methods

Study Area

The study was conducted in the Ogbese watershed, which drains through Ayede-Ogbese, Agbe-Oyirin, and Asolo to Ologboyo village, a short distance from Akure, Ondo State. The River Ogbese is a major tributary of the River Ose in south-western Nigeria. The watershed lies between latitudes 6°43′00″N and 7°45′00″N and longitudes 5°45′00″E and 6°34′00″E (Figure 1), and covers a total area of 64.156 km^2. The river rises from Apata Hill in Awo-Ekiti, Ekiti State [17; 18], and flows for about 22 km before joining the River Ose. The Ose is approximately 300 km long and discharges into the Atlantic Ocean through a network of creeks and lagoons [17; 18].

The area lies within the tropical rainforest zone and experiences distinct wet and dry seasons. South-westerly wind currents bring a relatively cooler rainy season from April to October, with mean annual rainfall of about 1600-2100 mm, although a short dry spell may occur in August [17; 19]. North-easterly wind currents bring a hot dry season from November to March. Rainfall peaks between August and October, coinciding with peak discharge, water stage, and runoff in the river [20]. The Harmattan, characterised by hazy conditions, typically occurs between December and January [21].

Mean daily maximum temperatures range from 30 to 35 °C, while mean daily minimum temperatures range from 21 to 26 °C [20; 19].

The terrain is gently undulating and situated within the Ogbese River valley. Elevations range from about 320.04 m (1050 ft) in the lowest portion to about 365.76 m (1200 ft) [22]. The area is underlain by crystalline rocks of the Nigerian Basement Complex, principally the undifferentiated Precambrian gneisses and migmatites [21]. These belong to the migmatite-gneiss-quartzite group and schist belt, are Precambrian in age, and fall within the zone of Pan-African reactivation [23]. Exposed rock types include quartzite, schist, granite gneiss and migmatite gneiss, with granite gneiss occurring in the low-lying areas of Ogbese and Eporo [24]. Except for a small area of less than 0.04 ha in the extreme north-west where the bedrock outcrops, the basement is mantled by superficial deposits of gravel, lateritic concretions, sand, silt and clay [25].

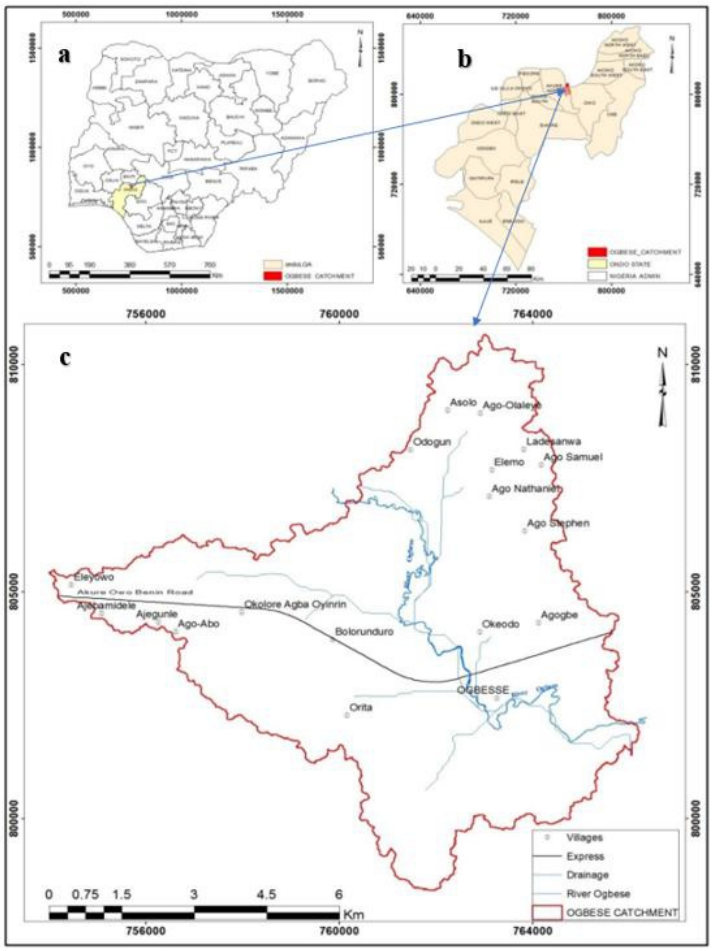


Figure 1: Study Area: (a) Nigeria, (b) Ondo State and (c) Ogbese

Data Acquisition and Analytical Technique

Morphometric Characteristics of Ogbese Watershed

Data Sources and Methods

Geographic Information System (GIS) and remote sensing (RS) techniques were integrated with mathematical analysis to characterise the morphometry of the Ogbese watershed. The Advanced Land Observing Satellite Phased Array type L-band Synthetic Aperture Radar Digital Elevation Model (ALOS PALSAR DEM), obtained from the Alaska Satellite Facility, was used to delineate the watershed and derive its drainage pattern and stream network. ALOS PALSAR is an all-weather microwave sensor, and its DEM has a spatial resolution of 12.5 m.

This resolution is fine enough to resolve shallow and narrow channels that coarser datasets cannot detect, as is the case in the study area (Johanna and Jianping, 2018). The dataset is also freely available and has been reported to be of high vertical accuracy, which makes it suitable for application over large areas [26]. Watershed and stream network delineation were performed automatically in ArcGIS (version 10.7), and morphometric parameters were computed using the HEC-GeoHMS extension and ArcGIS. The procedures used to delineate the watershed and generate the stream network are described in the following subsection:

Hydrologic Parameters Extraction

To extract hydrological parameters of the study area, ArcMap and HEC-GeoHMS (Geospatial Hydrologic Modelling System) tools were used. This software allows visualizing spatial information and extracting the basin characteristics using the ALOS PALSAR DEM dataset; it also provides a finer spatial resolution that can detect much shallower drainage networks. Furthermore, the dataset is freely available and is error-free, making it useful for large geographic areas [27].

Prior to the processing of the DEM, a terrain pre-processing (DEM) operation was performed. This operation is called DEM Reconditioning in ArcHydro; minor streams are excluded through this process, after which the thalwegs were shown. The InfoTerra imagery was used along with the DEM (ALOS PALSAR) to identify the drainage network in the basin and to delineate the watershed boundary. Thereafter, it was validated with the topographical map sheet (Akure Sheet 264NE Scale1:50,000). The methodological flowchart used to conduct this study is shown in Figure 2.

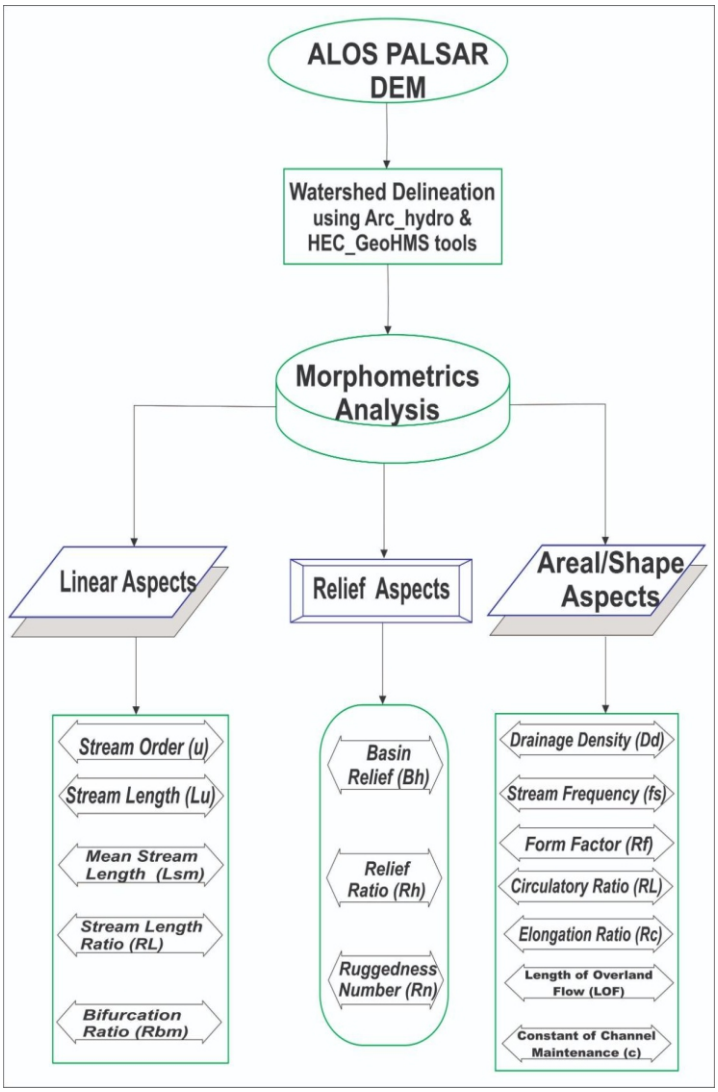


Figure 2: Flowchart of Calculus of Morphometric Parameter

Land-use Land Cover (LULC) Analysis of 2002-2022

To assess the land use change over time in the study area, the LULC classification of 2002 and 2022 was carried out by analysing the Enhanced Thematic Mapping (ETM+) and Operational Land Imager (OLI), satellite imagery respectively with the aid of ArcGIS.

The Morphometric Characterisation Parameters

Fluvial morphological analyses are instrumental in characterizing river system dynamics. Evaluating processes such as channel aggradation and degradation, planform adjustments, bank erosion, and flood inundation provides a robust empirical foundation for developing targeted mitigation strategies against fluvial hazards [28]. Furthermore, the selection of specific morphometric parameters is predicated on their direct functional relationships with runoff volume, peak discharge, and sediment delivery. In alignment with established hydrological literature, elevated values of these parameters correspond to an intensified runoff response and sediment yield (29; 30; 31; 32; 33; 2; 3).

Linear Aspect

Linear morphometric analysis of the watershed encompassed the quantification of basin length, stream order (U), stream length (L~u~), mean stream length (L~sm~), stream length ratio (R~L~), and bifurcation ratio (R~bm~). Each parameter was derived using the established mathematical formulations and reference standards outlined in Table 1.

Table 1: Algorithms of the Linear Aspect Parameters

Morphometric Parameter	Methods	Reference
Stream order (U)	Hierarchical order	Strahler 1964; Reddy *et al*, 2004
Stream Length (Lu)	Length of stream	Horton 1945; Ajibade *et al*, 2010
Mean stream Length (Lsm)	LSM = Lu/Nu, where Lu = stream length, Nu = Total number of stream segments	Horton 1945; Singh *et al*, 2018
Stream Length ratio (R)	RI = Lu/Lu-1, where Lu = Total stream length, Lu-1 = Length of next lower order	Horton 1945; Singh *et al*, 2018
Bifurcation Ratio (Rb)	Rb = Nu/Nu+1, where Nu = Total number of stream segments, Nu+1 = number of stream segments of next higher order	Schumm, 1956; Reddy *et al*, 2004

Aerial Aspect

Areal morphometric analysis involved the quantification of basin area, drainage density (D_d), stream frequency (F_s), form factor (R^f), circularity ratio (R_l), elongation ratio (R_c), length of overland flow (l_o), and the constant of channel maintenance (C). All parameters were computed using the mathematical algorithms and reference standards outlined in Table 2.

Table 2: Algorithms of the Areal Aspect Parameters

Morphometric Parameter	Methods	Reference
Drainage Density (Dd)	Dd = L/A, where L = Total length of streams; A = Area of Watershed	Horton, 1945; *Shakil et al*., 2018
Stream Frequency (Fs)	Fs = N/A, where N = Total number of streams; A = Area of Watershed	Horton, 1945; *Shakil et al*., 2018
Form Factor (Rf)	$Rf = A/(Lb)^2$, where A = Area of watershed; Lb = Basin Length	Horton, 1945; *Shakil et al*., 2018
Circularity Ratio (Rc)	$Rc = 4\pi A/P^2$, where A = Area of watershed; P = Perimeter of watershed; π = 3.14	Miller, 1953; Horton, 1945; Nissar and Mohammed, 2018
Elongation Ratio (Re)	$Re = 2\sqrt{(A/\pi)}/Lb$, where A = Area of watershed; Lb = Basin Length; π = 3.14	Reference not clearly aligned in the image
Length of Overland Flow (Lof)	Lof = 1/2Dd, where Dd = Drainage density	Horton, 1945; Singh *et al*., 2018
Constant Channel Maintenance (C)	C = 1/Dd, where Dd = Drainage density	Horton, 1945; Obi *et al*., 2004

Relief Aspect

Relief morphometric analysis of the watershed included the quantification of basin relief (B_h), relief ratio (R_h), and ruggedness number (R_n). Each parameter was derived using the computational algorithms and reference standards specified in Table 3.

Table 3: Algorithms of the Relief Parameters

Morphometric Parameter	Methods	Reference
Basin Relief (Bh)	Vertical distance between the lowest and highest points of the watershed	Schumm, 1956; Alfa *et al*., 2018
Relief Ratio (Rh)	Rh = Bh/Lb, where Bh = Basin Relief; Lb = Basin Length	Schumm, 1956; Singh *et al*., 2018
Ruggedness Number (Rn)	Rn = Bh × Dd, where Bh = Basin Relief; Dd = Drainage density	Schumm, 1956; Reddy *et al*., 2004

Linear Aspect

Linear morphometric characteristics of the basin—specifically stream order, stream length, stream length ratio, and bifurcation ratio—were quantified as detailed in the following section:

Results and Discussion

Determination of Hydrological Parameters (Stream Order, Stream Number Analysis, Stream Length (Lu), Basin Area (B *a*), Perimeter (B *p*), and Length (B *l*)

Figure 3 illustrates the channel network and hierarchical classification of the drainage basin based on Strahler's stream ordering system. Following Strahler's framework, where headwater channels devoid of tributaries are designated as first-order, junctions of equal order increment the rank, and junctions of unequal order retain the higher rank, a total of 1,179 stream segments were identified (Table 4). These comprise 598 first-order, 297 second-order, 143 third-order, 106 fourth-order, and 35 fifth-order streams.

Consistent with established hydrological patterns, stream frequency exhibits a pronounced inverse relationship with stream order, progressively decreasing as the order increases [34]. The high abundance of first-order streams reflects significant terrain complexity and bedrock lithological control [33], while also indicating an elevated susceptibility to flash flooding following intense precipitation events [35]. Total stream lengths across the catchments range from 6.44 km to 147.83 km. Classified as a fifth-order drainage basin, the system exhibits standard scaling dynamics wherein higher-order channels correspond to increased discharge capacity and flow velocity. Furthermore, adhering to the criteria defined by Ogunkoya [36] which specifies that channels of fifth-order and above qualify as a true river—the Ogbese watershed is appropriately classified as a river system.

Table 4: The Morphometric Parameters of the Ogbese River Basin

Stream Order (u)	Number of Stream Segments (Nu)	Percentage Composition of Stream Orders (%Nu)	Total Length of Streams (Lu)	Mean Stream Length (km)
1	598	50.72	147.83	0.25
2	297	25.19	67.002	0.23
3	143	12.13	31.28	0.34
4	106	9.00	20.41	0.22
5	35	2.97	6.44	0.18
Total	**1179**	**100**	**272.96**	**1.22**

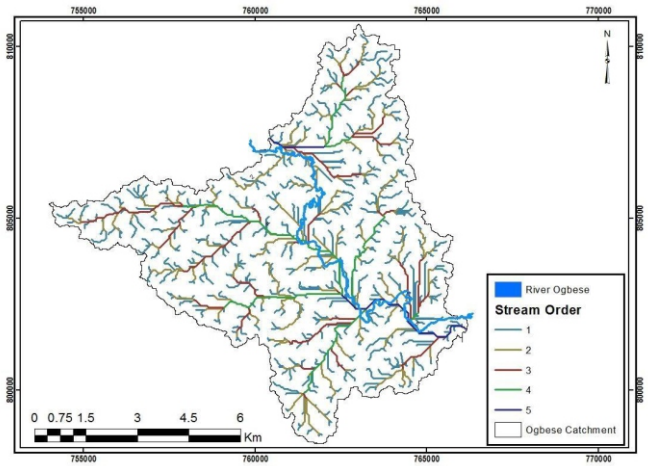


Figure 3: Stream Order Classification of Ogbese Basin (Authors work)

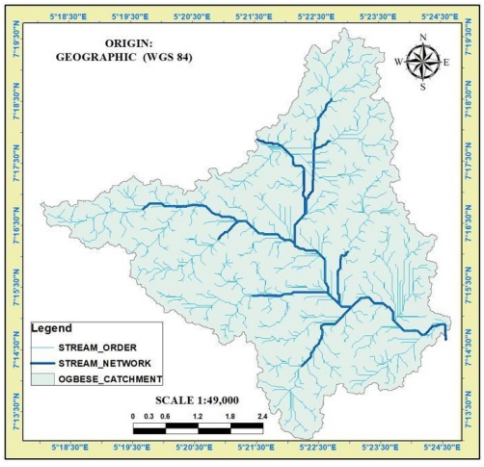


Figure 4: Overlay of the Stream Order and Stream Network of Ogbese Basin

Relief Aspect

In determining the relief aspect of the drainage basin, the basin relief (Bh), relief ratio (Rh), and Ruggedness number (Rn), are required and they systematically discussed in the following section:

Basin Relief (Bh), Ruggedness Number (Rn) and Relief Ratio (Rh)

The catchment mouth is situated at an elevation of 310 m above mean sea level (a.m.s.l.), with a total basin relief of 50 m calculated relative to the mouth (Table 6; Figure 5). These relief characteristics indicate that the Ogbese Catchment is dominated by rapid surface runoff and low infiltration capacity. The ruggedness number (R_n) defined by Strahler [37] as the product of basin relief and drainage density, reflects the combined effects of slope steepness and relief variation. The high R_n value of 212.5 highlights significant structural complexity and an elevated susceptibility to soil erosion within the basin [38]. Additionally, the relief ratio (R_h) quantifies the gradient profile by evaluating the ratio of vertical relief to horizontal basin length.

Topographic parameters were further analyzed using an Advanced Land Observing Satellite (ALOS) Digital Elevation Model (DEM). Because surface runoff converges in lower-lying areas, downstream segments experience increased discharge and heightened vulnerability to heavy precipitation events [39]. The DEM analysis reveals that elevations across the basin range from 324 m to 394 m a.m.s.l. (Figure 5). Notably, the subdued relief and gentle slopes identified in the southeastern sector indicate a flat topography, rendering this specific region particularly prone to fluvial inundation and flooding.

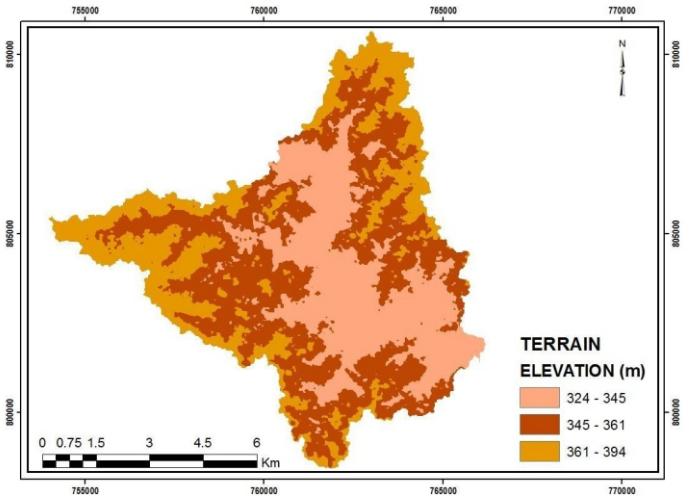


Figure 5: Terrain Elevation

Land Use/Land Cover

Land use/land cover is essential in environmental study as this reveals the changes of different features on the earth's surface that occur over time in an area. Thus, Figure 6-7 and Table 5 show that in 2002 and 2022 the forest was predominant, having 38.16km^2 (70.53%) and 26.29 km^2 (41.00%), respectively. This implies that the forest decreased by 11.86 km^2 (29.53%), while the lowest LULC is built-up, at 1.58 km^2 (2.92) and 2.61 km^2 (4.08) in 2002 and 2019, respectively. This means that the built-up area increased by 1.03 km^2 (1.16%). Between 2002 and 2019, the water bodies increased from 4.73km^2 (8.73%) to 9.301km^2. (14.50%), showing an increase of 4.58 km^2 (5.77%).

This shows that there are significant developments that have occurred from 2002 to 2019, and this could be attributed to the influx of people cultivating the arable land for food production and deforestation of the area in order to get a place of abode.

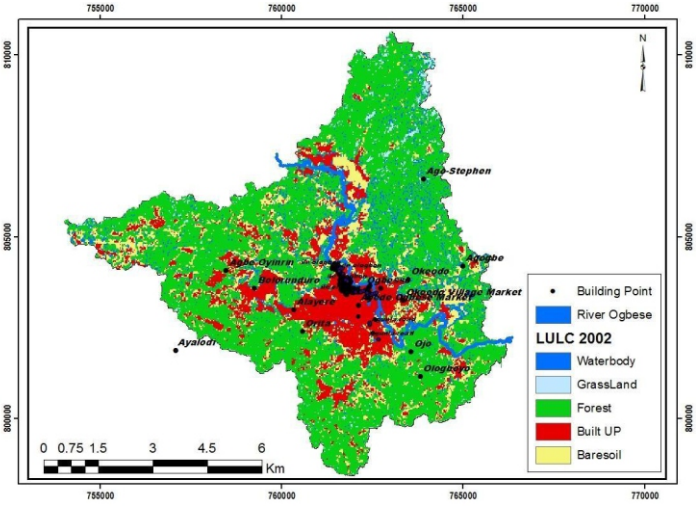


Figure 6: Landuse/Landcover Classification in 2002 (Source: ETM+2002)

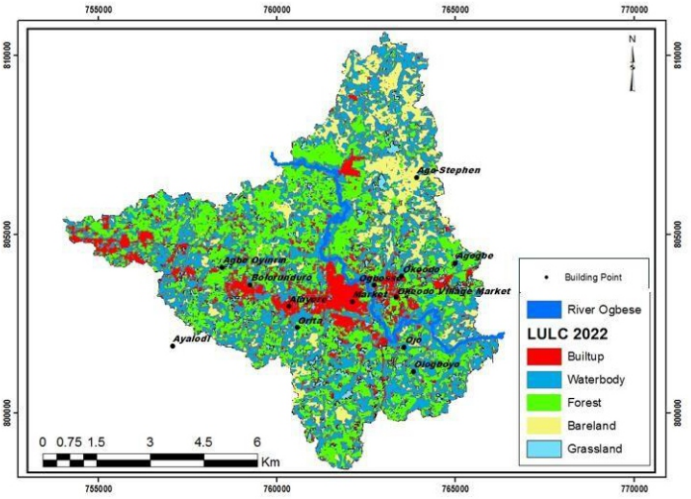


Figure 7: Landuse/Landcover Change in 2022 (Source: OLI, 2008)

Table 5: Landuse/Landcover Changes between 2002 and 2022

Landcover Classes	2002 (km²)	2002 (%)	2022 (km²)	2022 (%)	Change between 2002 and 2022 (km²)	Change between 2002 and 2022 (%)
Built Up	1.58	2.92	2.61	4.08	-1.03	-1.16
Water Bodies	4.73	8.73	9.30	14.50	-4.58	-5.77
Grass Land	1.28	2.36	20.13	31.40	-18.86	-29.04
Forest	38.16	70.53	26.29	41.00	11.86	29.53
Bare Soil	8.36	15.46	5.78	9.02	2.58	6.44
Total	**54.11**	**100**	**64.12**	**100**	—	—

Soil Characteristics

Table 6 shows the soil particle size in the study area, and there are three types of soil that are predominant in the sample collected. These include sand, silt, and clay. The classification of the soil texture classes is shown in Table 6, while Figure 8 reveals the spatial distribution of the soil types in the study area. The finding in Table 6 indicates that Sandy Loam has a basic infiltration rate of 8.8cm/hour and they covered 36.46%, Sandy Clay Loamy covered 37.23% with an infiltration rate of 2.27cm/hour, while the Loamy Sand have infiltration rate of 6.01cm/hour (26.31%) in Ogbese catchment. This suggests that the basin soil have low infiltration and there may be high overland flow in the basin.

Table 6: Soil Type and Percentage Area Covered

Hydrological Soil Group	Soil Type	Area (Hectares)	Area (%)	Rank
Group-A	Sandy Loam	2335.74	36.46	1
Group-B	Sandy Clay Loamy	2385.05	37.23	2
Group-C	Loamy Sand	1685.11	26.31	3
Total	—	**6405.90**	**100.00**	—

(Source: Author's Field Work, 2021)

Aerial Aspects

Areal morphometric parameters quantify the total projected area contributing overland flow across various stream orders. These metrics—comprising drainage density (D_a), infiltration number (I^f), length of overland flow (l_o), circularity ratio (R_c), elongation ratio (R_e), form factor (R^f), and stream frequency (F_s)—are critical for assessing watershed hydrology and groundwater potential [1]. As outlined in Table 7, the Ogbese drainage basin encompasses an area of 64.156 km^2, a perimeter of 69.725 km, and a length of 13.946 km. The compact dimensions of the catchment result in a reduced time of concentration (lag time), limiting opportunities for infiltration and evapotranspiration, thereby accelerating peak runoff and heightening flood vulnerability. This relationship aligns with established findings by Ifabiyi [40] regarding catchment size and flood frequency dynamics in Nigerian watersheds.The drainage density (D_a) of 4.25 km/km^2 reflects a fine drainage texture driven by impermeable subsurface lithology, sparse vegetation, and high relief, which collectively promote rapid surface runoff and high erosion potential. Additionally, the infiltration number of 78.2 indicates a low infiltration capacity, further exacerbating surface runoff generation. The length of overland flow (0.17 m) denotes relatively short flow paths, allowing surface runoff to route quickly to the channel network [41]. Basin shape indices provide further insight into the catchment's geomorphic evolution. A circularity ratio (R_c) of 0.2 indicates that the watershed is in a youthful stage of development. Furthermore, the elongation ratio ($R_e = 0.65$) and form factor ($R^f = 0.33$) characterize an elongated basin configuration. While elongated basins typically attenuate peak discharge over longer durations, the high stream frequency (F_s = 18.4) combined with impermeable subsurface materials generates substantial surface runoff under medium-to-high relief conditions [42].The mean bifurcation ratio ($R_{\beta m}$) of 2.12 points to a rolling or relatively flat terrain developed on homogeneous, softer lithology [43]. While low bifurcation ratios indicate highly efficient drainage networks that rapidly collect and transport water by elevating flood risks in susceptible terrains [44]. The calculated relief ratio of 3.58 m/km indicates that the dominant portion of the basin features gentle slope gradients.

Table 7: Computation of Linear and Areal Parameters

Morphometric Parameter	Symbol/Formula	Calculated Value
Area (km²)	A	64.156 km²
Perimeter (km)	P	69.725 km
Basin Length (km)	Lb = 1.312 × A^0.568	13.946 km
Stream Frequency (Fs)	Fs = Nu/A	18.4
Form Factor (Rf)	Rf = A/Lb²	0.33
Elongation Ratio (Re)	Re = (2/Lb) × (A/π)^0.5	0.65
Circulatory Ratio (Rc)	Rc = 4π × A/P²	0.17
Drainage Density (km/km²)	Dd = Lu/A	4.25
Infiltration Number (If)	Dd × Fs	78.2
Length of Overland Flow	Lg = 1/(Dd × 2)	0.12
Basin Relief (Bh)	H − h	50
Ruggedness Number (Rn)	Rn = Bh × Dd	212.5
Relief Ratio (Rh)	Rh = Bh/Lb	3.58
Constant Channel Maintenance (C)	C = 1/Dd	0.24

Table 8: Computation of the Bifurcation Ratios

1St/ 2nd Order	2nd/ 3nd Order	3rd/ 4th Order	4th/ 5th	Mean Bifurcation Ratio
2.01	2.08	1.35	3.03	2.12

Anthropogenic misuse and infrastructural neglect are primary factors contributing to the environmental health hazards frequently associated with hydraulic structures, including roadside drainage ditches, culverts, dam-site drainage networks, irrigation canals, and wastewater treatment and disposal facilities. While irrigation canals typically benefit from scheduled maintenance regimens administered by agricultural cooperatives or governmental agencies—resulting in favorable hydraulic regimes characterized by higher flow velocities and superior water quality—general drainage networks frequently exhibit contrasting conditions, such as flow stagnation and water quality degradation. These critical operational deficiencies pose substantial public health risks, underscoring the necessity for prioritized monitoring and targeted hazard mitigation strategies.

Conclusion

Environmental issues are critical matters in public health as environmental factors have an immense impact on public health. The morphometric analysis of a drainage basin using ALOS PALSAR Digital Elevation Model (DEM) data provides crucial, high-resolution insights into the hydrological behavior of a watershed, which directly impacts public health through flood risk management, water resource assessment, and environmental sanitation. High-resolution 12.5m ALOS PALSAR DEMs allow for precise, automated extraction of drainage networks, identifying areas susceptible to erosion, flooding, and the formation of stagnant water bodies that serve as breeding sites for vectors. GIS and remote sensing techniques are powerful tools for the assessment of morphometric parameters of basin hydrology as it helps in understanding the basin hydrology to potential prioritisation of sub-watershed, effective soil and water conservation work, natural resource management, and flood risk analysis. This study has clearly revealed the morphometric characteristics Ogbese River Basin in Ayede–Ogbese, Ondo State. Ogbese River is a fifth-order basin, elongated in nature (0.65) with a basin area of 64.156km^2 and a perimeter of 69.725km. This river exhibits a dendritic pattern according to strahlers' scheme of stream ordering.

The high drainage density (4.25km) of the study area proved that the basin is weak and it has impermeable subsurface material, sparse vegetation and high relief. All these characteristics of the basin lead to fine drainage texture, high runoff, and erosion potential of the basin area. A dendritic drainage pattern combined with high drainage density reflects a basin that is physically predisposed to rapid runoff, high flood potential, limited infiltration, elevated erosion, and sediment transport. These geomorphological and hydrological conditions have direct public health impacts, including increased flood hazards, reduced water availability during dry periods, land degradation, infrastructure vulnerability, and water-quality challenges. Effective watershed management, conservation of vegetation, and flood mitigation infrastructure are therefore essential for minimising these public risks.

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