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HYDROLOGICAL ASSESSMENT OF DARAWA-GERANYA SUB-WATERESHED (DUTSIN-MA) OF ZOBE DAM BASIN, KATSINA STATE

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ABSTRACT
The Darawa–Geranya sub-basin, a tributary of the Zobe Dam basin in Katsina State, has undergone notable LULCC driven by population growth, agricultural expansion, and urbanization, leading to reduced vegetation cover and increased built-up areas. This study seeks to fill the research gap by analyzing the morphometric characteristics and LULCC patterns of the sub-basin using remote sensing and GIS techniques to support effective watershed and reservoir management for environmental sustainability. The data required for this research were Drainage basin morphometric; Satellite image of the study area (1990, 2000, 2010, and 2020); and Shuttle Radar Topographic Mission (SRTM) DEM with a spatial resolution of 30m respectively. The software used for this research were ArcGIS 10.8 and Erdas Imagine 15. The sub-basin covered an estimated area of 126.94km^2, with a texture ratio of 0.95, and ruggedness number of 50.84 respectively, indicating a susceptible topography prone to environmental degradation. Cropland, tree and riparian vegetation and built-up area covered approximately 99.1% of the entire watershed by 2021. The texture ratio of the drainage basin is 0.95, which is an indication of extremely low (Rt). Also, low circularity ratio, elongation ratio and form factor with an elongated basin shape, confirms the immerse runoff activity, which will yield to sediment deposition creating flood plains. Consequently, Darawa-Geranya sub-basin exhibits significant variations in morphometric characteristics such as shape, size, and relief ratio. The need to incorporate morphometric data into future dam design and expansion plans for optimized water resource management and further research were among the recommendations.

Keywords: Dutsin-Ma, Watershed, Hydrological, Zobe dam, Darawa-Geranya

1. INTRODUCTION

Land use and land cover changes (LULCC) have become a global environmental concern due to their rapid intensification, particularly from urban expansion and agricultural transformation (Townsend, 1992; Lambin et al., 2001). These changes significantly affect the Earth's surface processes, influencing the energy balance, hydrological, and biogeochemical cycles (Turner, Meyer, & Skole, 1994; Abubakar, Musa, & Sule, 2002; Ocheri, et al., 2025). A watershed, first conceptualized in Nigeria by NEWMAP (2018), represents a geo-hydrological unit draining into a common outlet (Chorley, 1969; Strahler, 1964). It plays a vital role in managing water and land resources within a drainage system (Singh & Singh, 1997).

The Darawa-Geranya sub-basin, located within the Zobe Dam basin of Katsina State, Nigeria, has undergone extensive LULCC over the years (Adams, Bello, & Aliyu, 2018). Remote sensing analyses between 2000 and 2015 revealed significant vegetation loss, replaced by agricultural and urban land uses, largely due to population growth and intensified irrigation (Adefisan, Omotosho, & Ajayi, 2015; Ibrahim & Abdullahi, 2021). Such alterations have implications for water availability, soil fertility, and ecosystem stability (Arowolo & Deng, 2018; Jidauna, Joseph, Ndabula, & Oyatayo, 2018).

The Dutsinma Dam within this sub-basin provides irrigation, potable water, and hydropower, making morphometric analysis essential to evaluate its hydrological efficiency (Horton, 1945; Miller, Guertin, & Goodrich, 2014). Morphometric characteristics, when integrated with LULCC data using GIS and remote sensing, enhance understanding of watershed responses to environmental and anthropogenic stress (Patton & Baker, 1976; Rai, Zhang, Paudel, Acharya, & Basnet, 2018). However, limited studies have focused specifically on the Darawa-Geranya sub-basin, highlighting the need for comprehensive morphometric and LULCC analyses to support sustainable water resource management and environmental planning (Ajibade, Adebayo, & Fagbohun, 2019; Eze, Ocheje, & Ogbonna, 2022).
The Dutsinma Dam, constructed across the Darawa River (a tributary of the Zobe Dam basin), is an essential resource providing water for irrigation, domestic supply, and potential hydropower. Understanding its morphometric characteristics—such as shape, drainage pattern, and catchment dynamics—is key to assessing its hydrological performance. While global studies have examined morphometry and LULCC of various basins, limited research exists for the Darawa-Geranya sub-basin. The study seeks to fill the gap by analyzing the morphometric characteristics and LULCC of the Darawa-Geranya sub-basin using GIS and remote sensing.

2. STUDY AREA AND METHOD

2.1. Study area

The study area, covering about 1,674 km², lies between latitudes 12°09′9″N–12°04′6″N and longitudes 7°06′1″E–7°05′0″E. It is bordered by Kurfi and Charanchi in the north, Danmusa and Matazu in the south, Kankia in the east, and Safana in the west (Figure 1). The region experiences a tropical continental climate with high mean annual temperatures above 27°C and annual rainfall of 600–700 mm. It has four seasons: a cool dry (harmattan) season (December–February), a hot dry season (March–May), a wet season (June–September), and a post-rainy transition (October–November). Temperatures range from 21–28°C in winter to 32–38°C in summer, influenced by the north-east (dry) and south-west (rain-bearing) trade winds.

The soil is mainly ferruginous tropical soil, with sandy loam and drift deposits of medium fertility supporting crops such as millet, groundnut, sorghum, and sesame. Along water channels, loamy soils support maize, tomatoes, pepper, and onions. Vegetation is Sudan–Sahelian, dominated by grasses and scattered drought-resistant trees, though degraded due to human activity and declining rainfall. The population was 169,671 in 2006 and projected at 258,221 in 2020, mainly Hausa Muslims with minority tribes. Economic activities include crop farming, trading, civil service, and transport-driven commerce (Abdul-Aziz, 2015; Hamza, 2015; NPC, 2006).

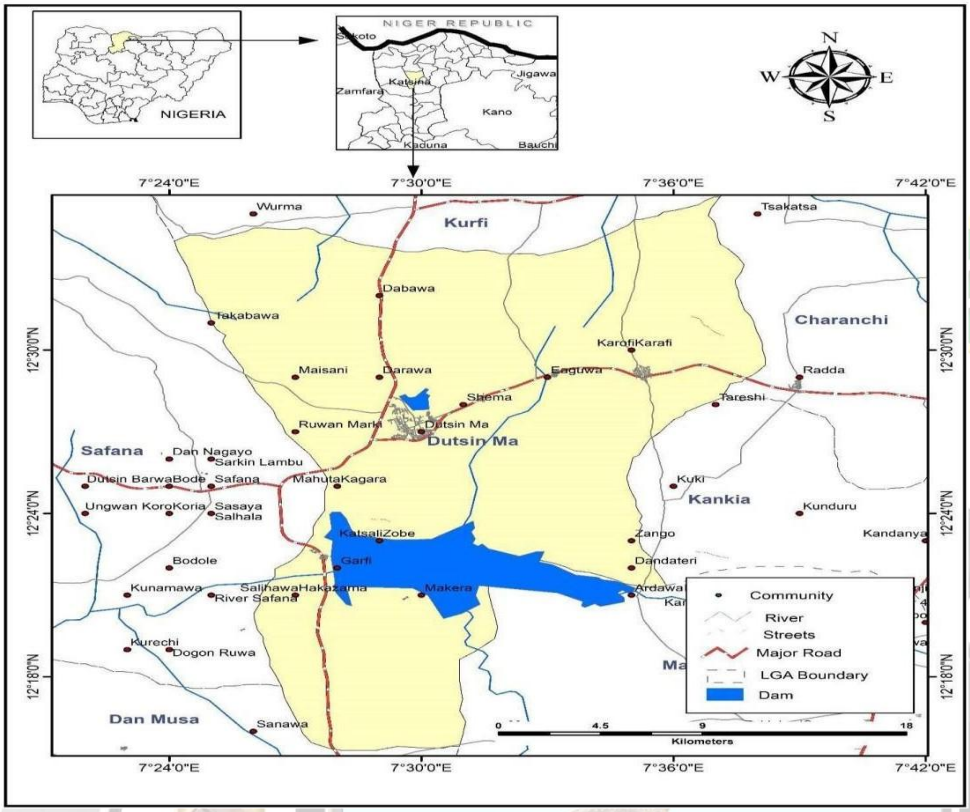

Figure 1: Study Area

Source: Adapted from Google Earth Imagery, 2023

2.2 Methods

The research utilized various datasets and geospatial techniques to analyze drainage basin morphometry and land use/land cover change (LULCC) within the study area. Key data sources include drainage basin morphometric data, topographic and hydrographic maps, and satellite imagery spanning from 1980 to 2020 (USGS, 2023). The Digital Elevation Model (DEM) used was derived from the Shuttle Radar Topographic Mission (SRTM) Version 6.2 with a 30 m spatial resolution to support morphometric analysis (NASA, 2020). Landsat images from 1990, 2000, 2009, and 2020 were employed to assess LULCC patterns and detect environmental transformations across three decades (Table 1).

Table 1: Details of Selected Imageries

Satellite Sensor	Row/Path	Date of Acquisition	Source
Landsat 4 (TM)	51/189	1990-Februry-12	USGS
Landsat 7 (ETM)	51/189	06/12/2000	USGS
Landsat 7(ETM)	51/189	2009 May 07	USGS
Landsat 7(ETM)	51/189	2020 January 08	USGS
Landsat 8	52/188	2023 May, 22	USGS

Image interpretation and classification were facilitated using ArcGIS 10.8 and ERDAS Imagine 15, while Google Earth Pro aided in verifying land cover features.

Supervised classification categorized land use into five classes—built-up/urban, tree and riparian cover, water bodies, bare surfaces, and cropland. Results showed that cropland increased from 61% in 1990 to 85.06% in 2021, whereas tree and riparian vegetation declined from 34% to 3.63%, indicating significant agricultural expansion at the expense of vegetative cover (Townsend, 1992). The analysis applied thematic post-classification comparison to measure the magnitude and direction of land use changes.

Morphometric parameters derived from the DEM followed Horton (1945), Strahler (1964), and Schumm (1956), including stream order, drainage density, bifurcation ratio, elongation ratio, form factor, and ruggedness number. These parameters describe hydrological behavior, terrain relief, and drainage efficiency. For instance, the bifurcation ratio (Rb) revealed stream branching patterns, while drainage density ($Dd = Lu/A$) reflected runoff potential and infiltration capacity (Horton, 1945). High ruggedness numbers indicated steep terrain and higher erosion susceptibility (Strahler, 1968). Overall, the integration of GIS and Remote Sensing provided robust insights into geomorphological characteristics and spatio-temporal LULC dynamics essential for sustainable watershed management.

3. RESULTS AND DISCUSSION

3.1 Delineation the Main Basin and its Sub-Basins

The Zobe basin, on the River Karadua covers an area of 657.10 km^2. It has seven (7) sub basin, and Darawa-Geranya sub-basin is one of them. The Dutsin-ma Dam is located on a tributary of this sub basin. The sub basin has an area of 127.14 km^2 and the deliniation is shown in figure 2 below.

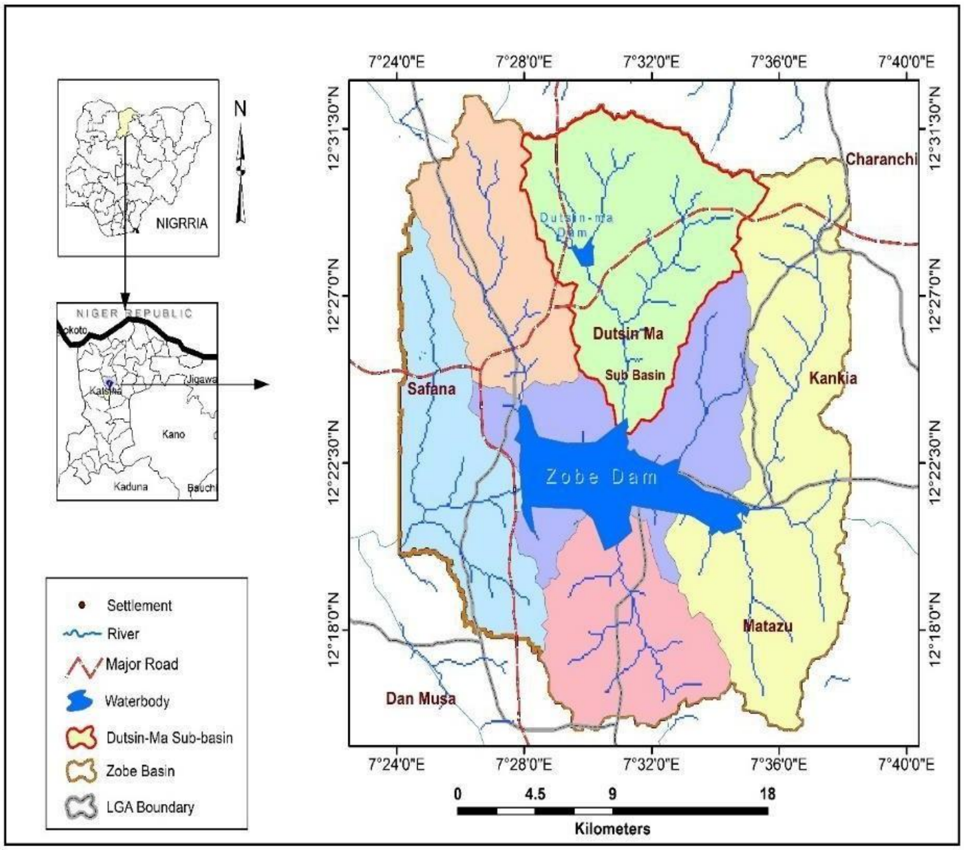

Figure 2: Map showing the study area

3.2 Characteristics of Darawa-Geranya Sub-Basin

Morphometric Analysis was carried out on a Digital Elevation Model of the study area to generate the characteristics of the Drainage basin. The result of the morphometric analysis of the sub-basin is presented in Table 2.

Table 2: Morphometric Analysis of the Sub-Basin

MORPHOMETRIC PARAMETER	FORMULA	RESULT
Stream order (U)	Hierarchical order	3
Stream Length (Lu)	Length of the stream	52.72km
Mean Stream Length (Lsm)	Lsm= Lu/LN	2.93 km
Stream Length Ratio (RL)	RL= Lu / Lu-1	26.88
Mean Bifurcation Ratio (Rb)	Rb = Nu / Nu+1	1.89
Drainage density (Dd)	Dd=L/A	0.41 km^2
Drainage intensity (Di)	Di = Fs/ Dd	0.41
Stream Frequency (Fs)	$F_S = N_u / A$	0.81
Elongation ratio (Re)	Re=√(Au/π)/ Lb	0.17
Circulatory ratio (Rc)	Rc=4πA/P²	0.52
Elongation ratio (Re)	Re=√(Au/π)	0.23
Compactness Coefficient	P/2√A π	1.36
Basin Area (A) km^2	GIS Software Analysis	127.14 km^2
Perimeter (P) km	GIS Software Analysis	54.41km
Total Basin Relief m	R= H-h	124m
Texture ratio (Rt)	Rt= Nu / P	0.96
Length of Overland Flow (Lof) km	Lof= 1/2Dd	1.22km
Constant Channel Maintenance (C)	C = 1/ Dd	2.44
Infiltration Frequency (In)	In = Dd x Fs	0.07
Ruggedness Index (R_n) = Dd x R	(R_n) = Dd x R	50.84
Relief Ratio (Rh)	Rh = Bh / Lb	33.26

Source: Field work, 2023

3.2.1 Lineal Characteristics

Morphometric parameters under linear characteristics were computed using standard methods and formulae as observed in literature. (Horton 1932, 1945; Smith 1954; Strahler, 1964).

3.2.1.1 Stream Ordering and Stream Number

The drainage map along with basin boundaries were extracted as line and polygon coverage. The basin has 52 streams with twenty-three 1st order, sixteen 2nd order and thirteen 3rd order streams. This result is presented in figure 3 and 4, as well as in and Table 3.

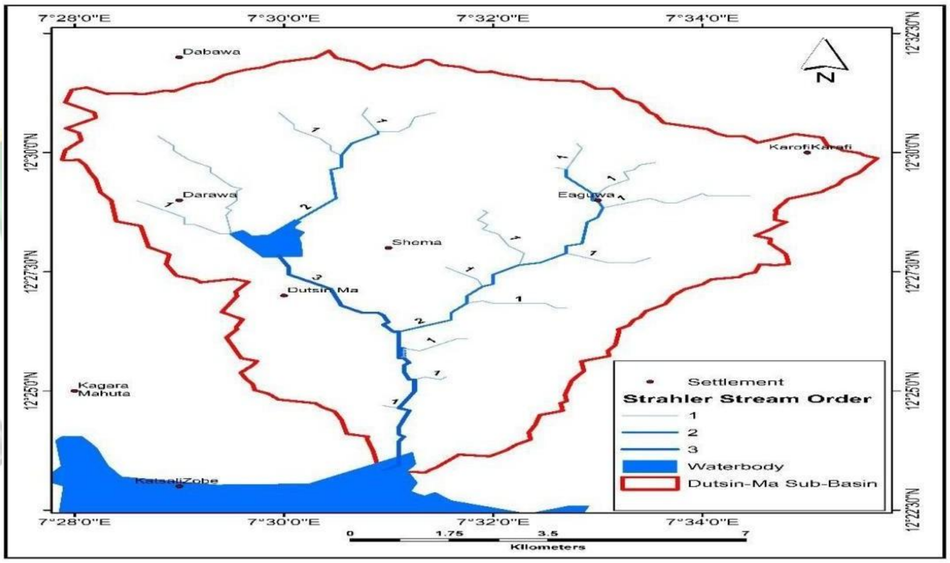

Figure 3. River Ordering

Table 3: Stream Ordering

Stream Ordering	**I**	**II**	**III**	**TOTAL**
Number of Streams (Nu)	23	16	13	52
Stream Length (Lu) Km	26.99	15.32	10.41	52.72
Mean stream Length (Lsm) Km	1.17	0.96	0.80	4.17

3.2.1.2 Stream Length

The stream length of the watershed is 11km. The Stream length is the distance measured from a stream source to a given point or outlet of the river, an increase in stream length ratio from lower order to higher order indicates a mature geomorphic stage.

3.2.1.2 Bifurcation Ratio (Rb)

The bifurcation ratio is an indicative parameter of the shape of the basin. Bifurcation ratio values range from 2 to 5 in a well-developed drainage network. The bifurcation ratio value of the study area is 1.89 which is below the two-value range. The bifurcation ratio indicates that the basin has slightly steep slope drainage basins.

3.2.1.3 Stream Length Ratio (L_{ur})

The stream length ratio of the three (3) order is shown Table 4 (2.93). This ratio depicts a significant reduction across the increasing orders within the drainage basin. Table of The Bifurcation and Stream Length Ratio of the Study Area.

Table 4: Stream Length and Bifurcation Ratio

Stream Length ratio	1st	2nd	3rd	Mean Stream Length ratio
	1.17	0.96	0.80	2.93
Bifurcation Ratio		**1st/2nd**	**2nd/3rd**	**Mean Bifurcation ratio**
		2.55	1.23	1.89

3.2.1.4 Length of Overland Flow (Lof) Km

The *Lof* value is 1.22. The high value in the watersheds indicates a gentle slope and overall long flow path area conforming to the elongated nature of the watershed. This is characteristic of a plane. The result for mean stream length, Average width and Maximum Basin length are presented in Table 5.

Table 5: Other Lineal Characteristics

Mean stream length	Average width of catchment	Maximum Basin length
1.014km^2	3.45km	16.km

3.2.2 Drainage Characteristics

3.2.2.1 Drainage density (Dd)

The drainage density of the Sub-Basin is 0.41. High drainage density is favored in regions of weak or impermeable subsurface materials, and less vegetation cover.

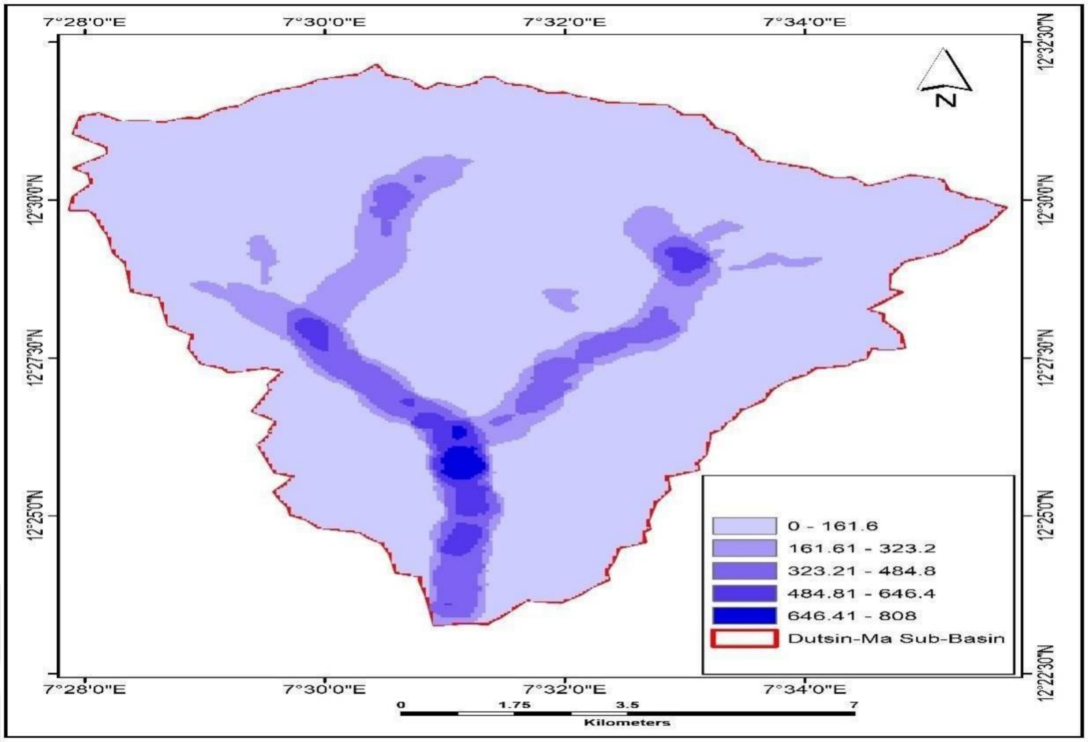

Figure 4: River Ordering

3.2.2.2 Stream Frequency (Fs) and Stream Density

The Stream Frequency It shows a positive relation with drainage density. The stream frequency of the study area is 0.8. The stream density is Total length of streams divided by basin area which result is 0.97.

3.2.2.2 Infiltration Frequency (In)

The lower the infiltration and the higher the run-off, and the lower the infiltration number, the higher the infiltration potential. The infiltration frequency of the area is 0.07. This implies a low infiltration potential in the sub basin which agrees with the work of Jidauna, Kwando, & Ndabula, (2023) that it reflects in the dwindling groundwater potentials, yield and availability within and around the basin.

3.2.3 Shape Characteristics

The shape of the basin is often influenced by the elevation, as well as the relief of the basin as reflected in Figure 5.

3.2.3.1 Form Factor

The form factor predicts the intensity of a basin of a defined range, the form factor of the drainage basin is 1.21. The range value for the form factor <0.78 (elongated) and >0.78 (circular). Hence, the study area shows circular, which means high peak flows for a shorter duration, which is line with Jidauna et al. (2016) description of the flow regime river systems in the study area.

3.2.3.2 Elongation Ratio

This ratio of 0.52 defines the drainage basin as region characterized with very low relief. Similarly, Dar et al. (2013), categorized values into four groups: circular (>0.9), oval (0.9-0.8), less elongated (0.8-0.7), and elongated (<0.7). Hence the drainage basin is elongated applicable to climates and geological process.

3.2.3.3 Compactness Co-efficient

The compactness coefficient of the drainage basin is 1.36, which implies a very low lithographic build up. The Compactness Co-efficient is independent of the size of the watershed and dependent only on slope, similarly terrain shows a very gradually slope as shown in figure of the contour map.

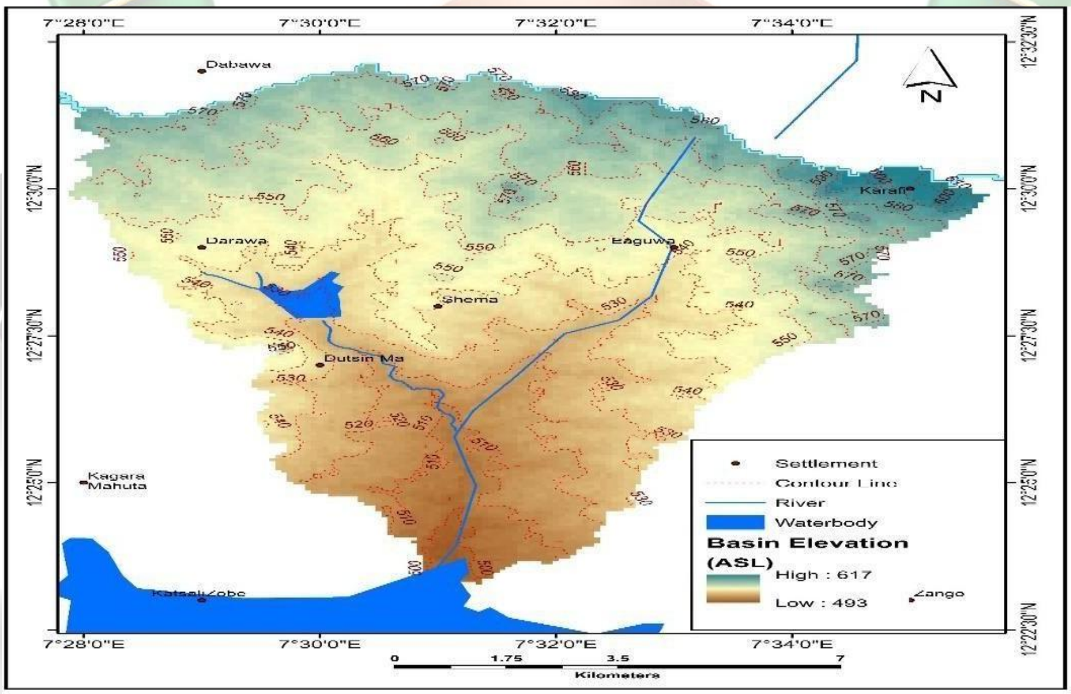

Figure 5: Elevation

3.2.3.4 Circularity Ratio

The drainage basin has a circularity ratio of 0.52, representing a linear description of the aerial shape of a basin. This ratio holds significant meaning as it reflects the developmental stage of a basin's dendritic pattern of tributary basins.

3.2.4 Slope Characteristics

The slope characteristics of the study area is presented in Figure 6.

3.2.4.1 Texture Ratio (Rt)

Slope, soil type, climate, vegetation, and infiltration capacity will affect the texture ratio of the watershed. The texture ratio of 0.95, describes the potential of the drainage basin to be overly saturated by water.

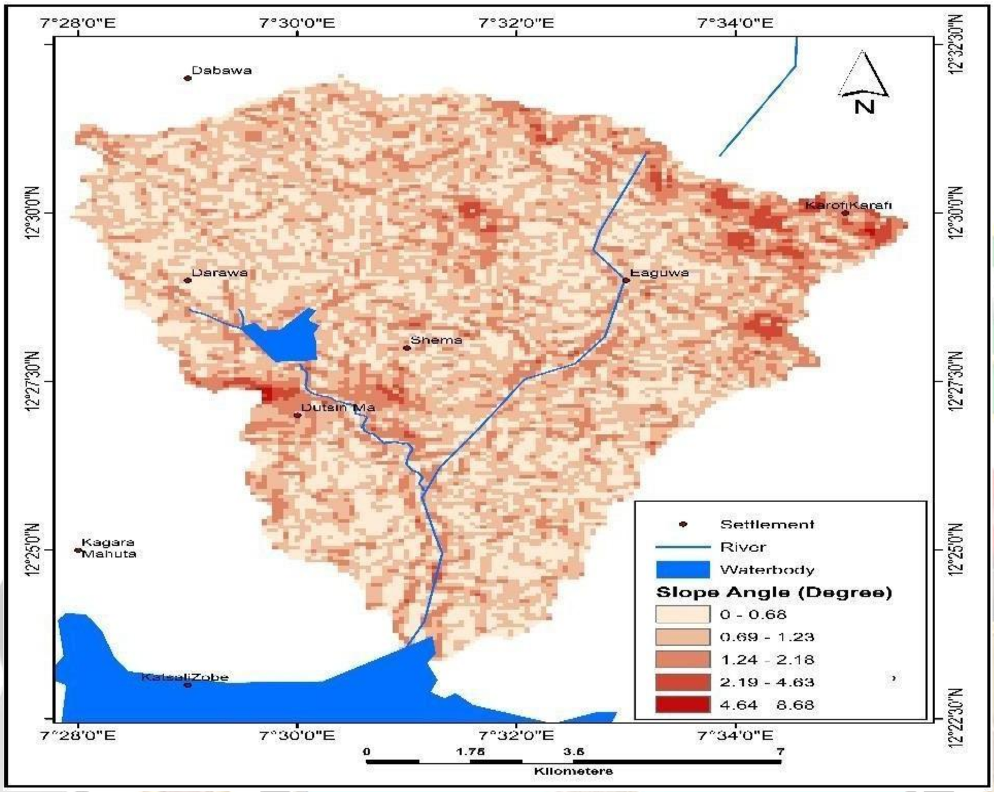

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Figure 6: Slope

3.2.4.2 Constant Channel Maintenance (C)

The constant channel maintenance value of the area is 2.44. Less vegetative and plain terrain depicts a low constant of channel maintenance. This indicates that the area is susceptible to flood.

3.2.4.3 Texture ratio (Rt)

The texture ratio of the drainage basin is 0.95, which is an indication of extremely low (Rt) This implies that the land surface in the watershed is characterized by features that enhance the infiltration of water into the soil which result to high soil moist condition of the study area.

3.2.4.4 Ruggedness Number

The ruggedness number as derived from the mathematical expression is given as 50.84. This indicates a susceptible topography prone to environmental degradation. Implying a very low rugged terrain in the drainage basin.

3.2.5 Elevation Characteristics

The results on the elevation characteristics of the sub-basin is presented in Figure 7.

3.2.5.1 Relief

The area is a gentle undulating slope with lowest point 493 meters, with peak highland hill at 617 meters. Majority of the basin is on a flat land with gentle slope.

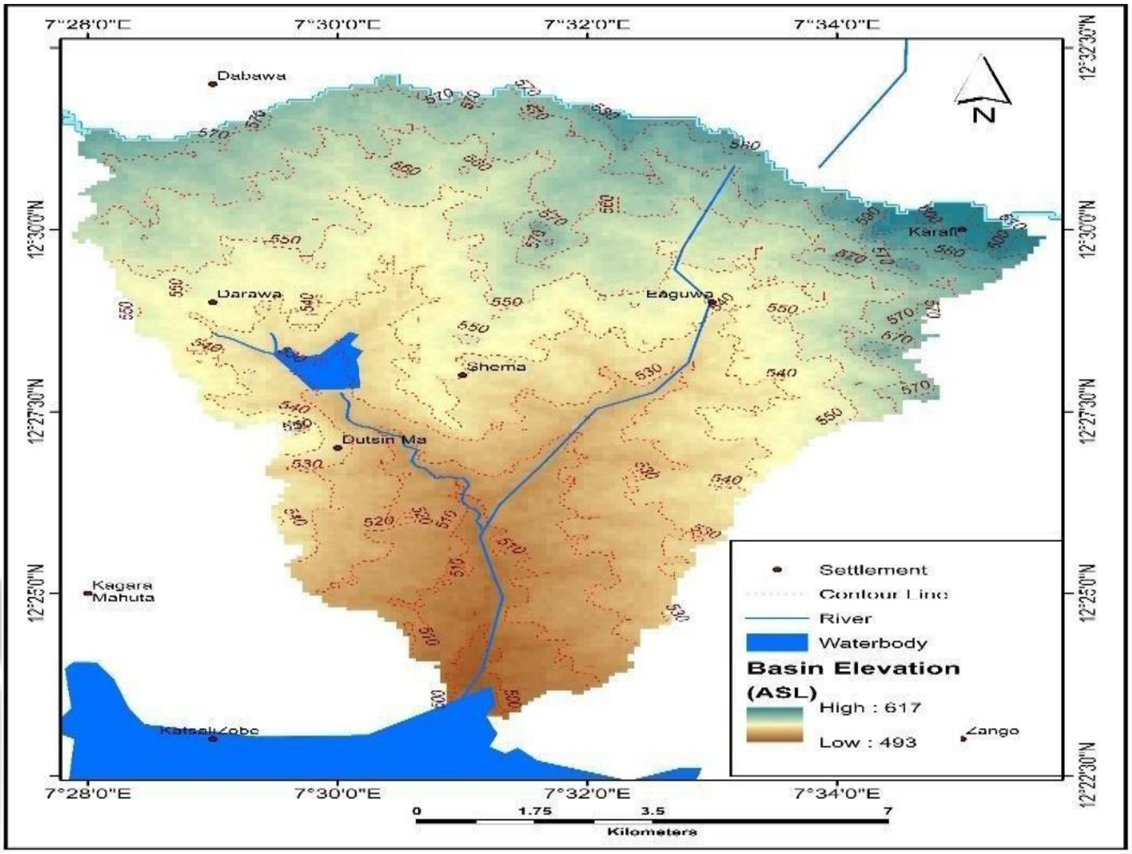

Figure 7: Slope

3.2.5.2 Maximum Relief

The difference in the elevation between the highest point of the study area and the lowest point on the valley floor is known as the total relief of the river basin. The maximum relief is 124 meters.

3.2.5.3 Relief Ratio (RR)

This is the product of relief divided by horizontal distance between highest and lowest point. This gives a relief ratio of 7.79.

3.2.6 Areal Characteristic

3.2.6.1 Catchment Area Mean Catchment Area

The basin area is 127.14 km square while the mean catchment area is total catchment area divided by segment which result in 63.57. Table 4.4 presents the morphometric characteristics result of the Subbasin

3.3 LANDUSE LAND COVER

The mapping out of different land use types sub basin was carried out for 1990, 1999, 2009 and 2021 was carried out by classifying the satellite imageries into various land cover types as discussed in these sections types as stated. In 1990, waterbody covered is 0.31%, Tree and riparian vegetation covered 34.5% of the study are while cropland has the highest land cover of 61.25%. The smallest land cover by area, as seen in table 6 and figure 8 below is bare surface with 0.2%.

Table 6: Land Cover and Area Coverage

Land use	1990 Period (Km2)	%	1999 Period (Km2)	%	2001 Period (Km2)	%	2021 Period (Km2)	%
Bare areas	0.26	0.2	0.34	0.27	0.23	0.18	0.04	0.03
buildup areas	3.93	3.1	5.83	4.59	8.57	6.75	13.4	10.55
Cropland	77.75	61.25	90.18	71.04	94.15	74.17	107.98	85.06
Waterbody	0.4	0.31	0.53	0.42	0.2	0.16	0.3	0.24
Rock cover	0.77	0.61	1	0.79	2.65	2.08	0.62	0.49
Trees & Riparian Cover	43.83	34.53	29.07	22.9	21.14	16.65	4.6	3.63
Total	**126.94**	**100**	**126.94**	**100**	**126.94**	**100**	**126.93**	**100**

This analysed imagery of 1999 shows a water cover of 0.42%, Tree and Riparian vegetation cover of 22.9% and a built-up cover of 5.83%. This period 2009 shows a water cover of 0.16%, Tree and Riparian vegetation cover of 16.65% and a built-up cover of 8.57%. The period of 2021 is characterized by a landcover of water at 0.24%, Built-up area at 10.55%, and cropland at 85.06% agrees with findings of Jidauna et al. (2018).

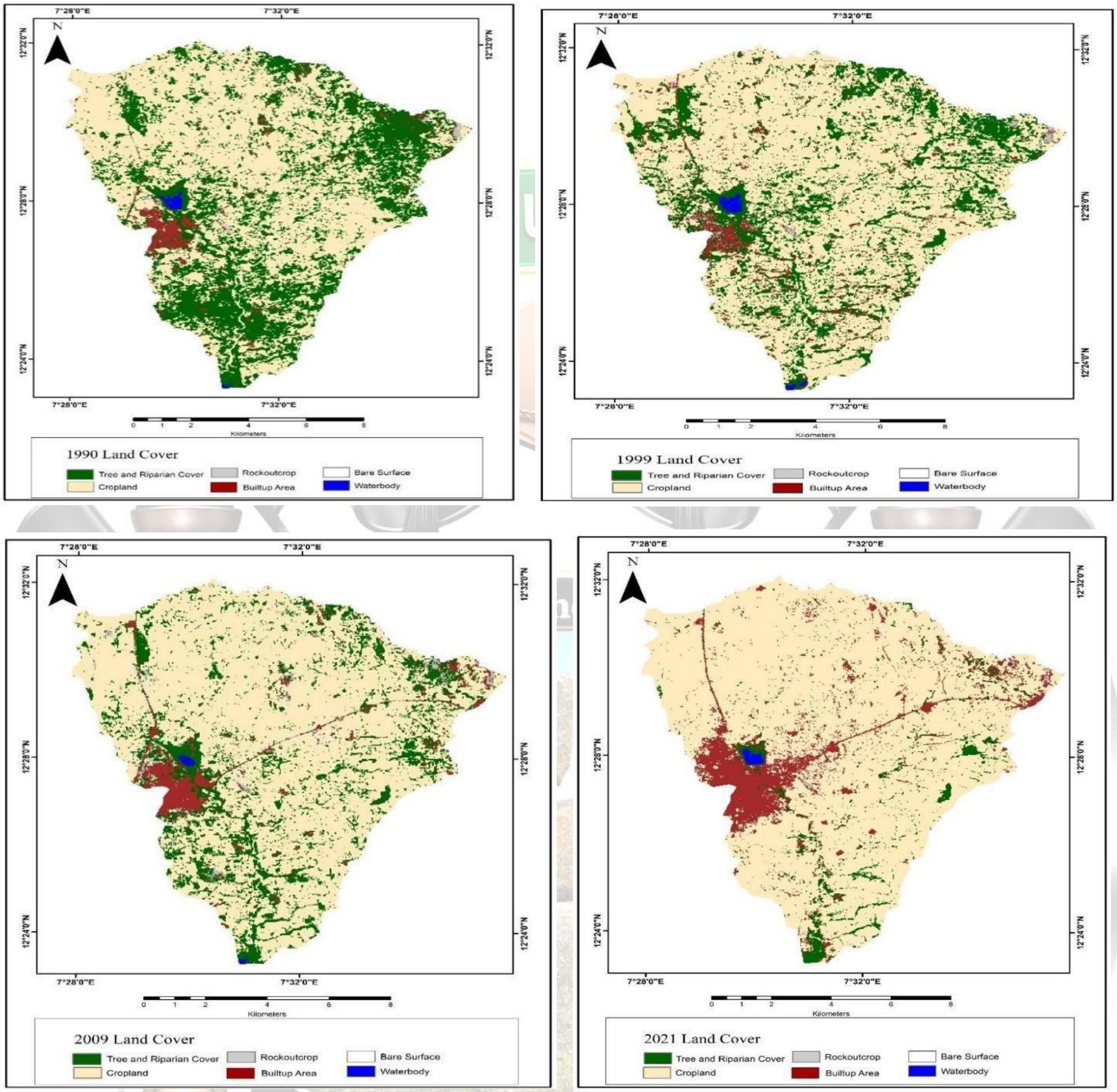

Figure 8: Landcover

3.4 LAND COVER CHANGE

The results of the land cover analysis are presented in Table 7 which summarized the pattern of changes observed across the different periods.

Table 7: Land cover changes across the different periods

Land Use	1990-1999			1999-2009			2009-2021		
	Area (Km^2)	Rate	Status	Area (Km^2)	Rate	Status	Area (Km^2)	Rate	Status
Bare areas	0.079	0.008	gain	-0.1109	-0.011	Loss	-0.1867	-0.0186	Loss
Buildup areas	1.8978	0.21	gain	2.7378	0.273	Loss	4.832	0.4832	Gain
Cropland	12.4274	1.38	gain	3.9796	0.398	Gain	13.8206	1.38206	Gain
Waterbody	0.1358	0.015	gain	-0.3275	-0.0327	Loss	0.0959	0.00959	Gain
Roc k cover	0.2311	0.025	gain	1.6459	0.165	Gain	-2.0291	-0.20291	Loss
Trees and riparian cover	-14.768	-1.64	loss	-7.9251	-0.792	Loss	-16.538	-1.65379	Loss

The highest land cover change between the periods of 1990 to 1999 was tree and riparian vegetation that lost 14.77 km^2 area between this period, this result in 12.42 km^2 gain in cropland and 1.89 km^2 gain in built-up area. This is evidently an indicator of increase farming activity and building development in the area between the periods. However, in 1999 to 20009 tree and riparian cover further lost 7.93 km^2 area while built-up gained 2.73km^2 showing an intensified urbanization and agricultural activity with cropland gaining 3.97 area. Water body lost 0.3km^2 area and other cover area losses are visible. The trend posses a great risk on water resources in the study area which agrees with the work of Jidauna, Dabi, & Oche, (2020).
The period of 2009 to 2021 showed that water body slightly gained 0.096km square this s followed by a loss 016.5km^2 of vegetation and a gain of 4.8km^2 of builtt-up area. This trend reflects the expected urban expansion and loss of other land cover due to demands from anthropological activity such as farming and other socio-economic activity. This has implications on sustainable water quality and utilization as presented byJidauna, Barde, Ndabula, Oche, & Dabi, (2017).

4. CONCLUSION

The morphometric analysis of the Darawa–Geranya sub-basin reveals a significant conversion of natural land cover into urban, agricultural, and other anthropogenic uses. This transformation poses serious implications for water quality, biodiversity, soil stability, and the overall ecological balance of the basin.

5. RECOMMENDATIONS

The study recommends urgent action toward proactive environmental management in the Darawa–Geranya watershed. Sustainable land use planning, afforestation, and watershed conservation should be prioritized to prevent further environmental degradation. Strengthening public awareness and enforcing land use regulations will help control harmful human activities. Additionally, promoting eco-friendly and climate-smart agricultural practices can reduce pressure on natural resources and enhance the ecosystem’s resilience. These combined measures are vital to sustaining the watershed’s ecological balance and ensuring long-term environmental stability in the face of human and climatic challenges.

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