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Morphometric Properties and Land Cover Dynamics of River Shemankar Upper Drainage Basin, Plateau State, Nigeria

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ABSTRACT

Climate change and human activities have continued to modify the geomorphic and hydrological properties of the river basin with their far-reaching impacts on water resources, agriculture, and general livelihoods. This study analyzed the morphometric properties and cover dynamics of the River Shemankar Upper Drainage Basin, Plateau State. Results show a 6th-order basin covering 4,249.5 km², with moderate elongation, low drainage density (0.79 km/km²), and high relief of 1,499 m. Agricultural land expanded (51.3%–80.8%), vegetation and rocky outcrops declined, and built-up areas increased (0.5%–3.7%). The regression results show a strong positive relationship ($R^2 = 0.70\text{--}0.81$) between morphometric properties, rocky outcrops, and agricultural land. Vegetation, on the other hand, has weak inverse effects. Both DEMs produced comparable morphometric results; however, SRTM captured more streams and higher hydrological indices. The ANOVA results ($p = 0.285 > 0.05$) show no significant difference, validating both datasets are good for hydrological modeling.

Keywords: Morphometric Analysis, Drainage Basin, Land Cover Dynamics, Hydrological Implications, Remote Sensing, GIS

1. INTRODUCTION

Morphometric analysis is a commonly deployed method for the quantitative analysis of drainage basin properties. It is relevant to the study of the geomorphological and hydrological processes that take place in river basins both through space and time. This method is essential in effective watershed management and also in the creation of effective flood-control mechanisms. Simply put, the morphometric analysis is a systematic method of analyzing the form, shape, and general structure of landforms, with special focus on the river basins.

A myriad of researchers across the world have attempted to define its principles. Indicatively, Horton (1945), who is widely considered one of the pioneering personalities in the same field,

defined it as a quantitative study of the geometry of drainage basins, thus drawing attention to attributes of stream order, stream length, bifurcation ratio, drainage density, and other relevant attributes. Similarly, Langbein (1947) defined it as the exploration of physical properties of river basins, like slope, area, and shape, to gain insight into how they behave hydrologically. It was conceived by Strahler (1952) as the quantitative assessment of watershed geomorphology with the emphasis put on the hierarchy of streams and the connection between the stream order, length, and basin area. According to Fenta *et al.* (2017), the technique implies mathematical assessment of the linear, areal, and relief parameters to clarify the shape of the basin, drainage form, and hydrological behaviour. In addition to this, the morphometric analysis can estimate and predict the infiltration and surface runoff, and other hydrological properties, including soil erosion, sediment movements, groundwater potential, and the tendency to flood.

The measurements and mathematical analysis of such landforms are usually done in the area of a river basin or a catchment. This evaluation implies the calculation of landscape parameters regarding the elevation surfaces and drainage networks in the watershed (Adelalu *et al.*, 2020) and is presented in different formats, including maps, frequencies, graphs, and tables. Linear measurements, such as basin length, basin perimeter, stream order, stream length, stream number, bifurcation ratio, etc., are included in the quantitative measurements; areal measurements, such as drainage density, drainage texture, stream frequency, infiltration number, form factor, length of overland flow, circularity ratio, elongation ratio, constant channel maintenance, etc., are included in the quantitative measurements; and the mathematical analysis includes methods of using formulas to understand the dynamics, complexity, and/or potential of the drainage basin (Alam *et al.*, 2021).

Land cover refers to the physical and biological cover over the surface of the Earth, including vegetation, water, bare soil, and artificial structures (Verburg *et al.*, 2000). Land cover dynamics refer to the temporal changes in the physical and biological cover of the Earth's surface due to natural (e.g., climate variability) and anthropogenic (e.g., urbanization, deforestation) drivers (Lambin *et al.*, 2003).

Empirical studies globally showed that land cover has a direct impact on the hydrological behavior. The study by Negese (2021) discovered that land cover affects erosion, evapotranspiration, infiltration, and runoff in Ethiopia. In the same vein, Naschen *et al.* (2019) observed that land use/cover change and climate change have a very critical impact on the water availability in Tanzanian catchments. Clearing and agricultural growth lower the water storage capacity, lowering groundwater recharge and generating hydrological stress even in the conditions of the future climate. Guzha *et al.* (2018) also reported that vegetated surfaces converted into farmland or urban environments amplify runoff, decrease baseflow, and interfere with natural hydrology in the East African catchments.

Consequently, based on the above, this combined strategy will offer rational knowledge regarding watersheds, making watershed planning and management more reliable (Pophare & Balpande, 2014). This helps in determining areas that have high potential for groundwater recharge and developing land management plans that encourage efficient utilization of water resources.

Geospatial technologies are essential in the measurement of properties of drainage basins and land cover dynamics. Researchers worldwide have utilized GIS and remote sensing to evaluate morphometric properties and changes in land cover. Mutawakil *et al.* (2021) highlighted their effectiveness in hydrological and flood-risk assessments and confirmed that the tools accurately

analyze watershed parameters, enable spatial hydrological analysis, and focus on the area of intervention and development. Furthermore, GIS and RS are able to outline sub-watersheds and determine flood-prone areas depending on topography and drainage features (Withanage *et al.*, 2016).

In Nigeria, some studies revealed the importance of geospatial technologies in morphometric studies. According to Eludoyin & Adewole (2019), Bello & Ajibade (2023), Laka *et al.* (2023), and Kopteer *et al.* (2024), GIS and remote sensing give essential data on the characteristics of the basin, which informs the management and planning of water resources. Based on the above background, it is clear that morphometric and land cover analysis in geospatial technologies gives a holistic insight with respect to geomorphological and hydrological processes and behaviors of river basins over space and time, which plays a key role in the successful management of watersheds and flood control and environmental management strategies. Thus, the study is an attempt to contribute more to the knowledge on the morphometric properties and land cover dynamics in the River Shemankar Upper Drainage Basin, Plateau State, Nigeria.

1.2 Statement of the Research Problem

Despite numerous studies on morphometric analysis and land cover changes, several gaps remain in methodological, conceptual, and data deficiencies. There have been several studies on basin morphometry in different parts of Nigeria; Plateau State, which is characterized by its unique landscape, has not been adequately studied. The literature is sparse, with Laka *et al.* (2023) using multi-criteria GIS and the Analytical Hierarchical Process to map flood risks in the Delimi Catchment and Kopteer *et al.* (2024), who evaluated the effects of floods on agriculture on River Dilimi.

The River Shemankar Upper Basin is virtually unstudied in the scientific literature. There is not any known detailed morphometric characterization or spatio-temporal land cover research of the basin. This poses a gap in the baseline geospatial information and regional baseline data, which restricts the abilities of hydrologists, geomorphologists, planners, and environmental managers to learn about the hydrology of the basin, flood susceptibility, erosion, and long-term sustainability in the context of increasing anthropogenic pressure and climate variability.

Most Nigerian and tropical research has used an isolated methodology, focusing on morphometric analysis for specific purposes, such as groundwater potential, flood-prone areas, watershed priority, erosion proneness, or reservoir sedimentation, without properly investigating the effects of land cover change (like deforestation or agricultural development) on hydrological behavior. This disjointed strategy limits understanding of basin development and how land cover changes affect drainage behavior, which this study addresses.

The majority of the studies applies remote sensing and GIS methods without a critical assessment of the sources of data; in particular, which DEM (e.g., ASTER vs. SRTM) gives the best hydrological outcomes when applied to the tropical basins. DEMs are commonly used without evaluating any accuracy or impact on the derived morphometric properties, which can result in inconsistencies and uncertainty. The absence of a comparative DEM evaluation decreases the trust in morphometric findings, which this study addresses..

Given these gaps and issues, it is very desirable that an integrated, basin-specific, and methodologically rigorous study that integrates morphometric analysis with assessment of long-term land cover dynamics in the Upper River Shemankar Basin be conducted. Such a study is needed to have a stable geospatial base and clarify the relationship between landscape change and basin morphometry.

1.3 Aim and Objectives of the Study

This study aims to carry out morphometric properties and land cover dynamics of the River Shemankar Upper Drainage Basin, Plateau State, Nigeria. The specific objectives of the study are to:

- a. determine selected morphometric properties and land cover in River Shemankar Upper Drainage Basin, Plateau State;
- b. analyse the dynamics in the land cover between 2000 and 2024;
- c. assess the relationship between land cover and selected morphometric properties; and
- d. compare the results of the selected morphometric properties derived from digital elevation models of different sensors.

2. STUDY AREA

The River Shemankar Upper Drainage Basin is situated in North-Central Nigeria, primarily spanning from the southern edge of the Jos Plateau to the lowlands of the southern parts of Plateau State, Nigeria (Figure 1b). It is geographically situated between latitudes 8.626°N to 9.262°N of the Equator and longitudes 9.134°E to 9.786°E of the Greenwich Meridian (Figure 1c). The catchment spans within eight Local Government Areas (LGAs) of Plateau State, which include: Mangu, Pankshin, Kanke, Langtang North and South, Mikang, Shendam, and Qua'an Pan, respectively. Also, the river is a major tributary of the Benue River drainage network and plays a role in the hydrology of the area. Further, the river basin is bounded by five principal river basins, which include: to the North, River Gongola Basin; to the East, River Wase Basin; to the South, lower basin of the River Shemankar; to the Northwest, River Farin Ruwa Basin; and to the Southwest, River Dep Basin, respectively.

3. MATERIALS AND METHODS

3.1 Data

The data utilized in this study include the coordinates (x, y) collected through GPS receiver, the Landsat images of 2000 and 2012 (L7 EM+), and 2024 (L9 OLI/TIRS), ASTER DEM 30m, and SRTM DEM 30m, respectively (Table 1). The SRTM DEM and the Landsat images were downloaded from the archives of NASA (<https://search.earthdata.nasa.gov/search>) and USGS (<https://glovis.usgs.gov/>), while the coordinates were obtained from GPS in space. The coordinates (x, y) were used for ground truthing of the land cover identified; the Landsat images were used to analyze the dynamics in the land cover types in the basin over the study period, while the ASTER DEM and SRTM DEMs were used to extract the drainage basin morphometric properties.

3.2 Data Pre-Processing

ASTER, SRTM, and Landsat images were downloaded as GeoTIFF files and pre-processed to minimize the Digital Number (DN) of pixel errors. Sink filling was done on ASTER and SRTM DEMs to eliminate elevation errors. The raw data were converted into meaningful information to classify the data by pre-processing Landsat images using the ENVI software to improve their quality, interpretability, and accuracy. The FLAASH tool recommended by Vis (2009) was used to perform radiometric correction to eliminate the distortions produced by aerosols, haze, and water vapor. Cloud scan line and cloud-shadow masking were also applied to the QA band and the CFMask algorithm to reduce atmospheric effects. This guaranteed only clear-sky pixels were retained, which returned the images to surface reflectance and created valid and physically meaningful data to be used in further morphometric and land cover analysis.

3.3 Data Processing and Analysis

3.3.1 Drainage Basin and Stream Network Extraction

The delineation and extraction of the catchment area and stream networks were done with the aid of Arc Hydro Tools. The ASTER and SRTM DEMs were subjected to the following manipulations: Fill sinks > Flow Direction > Flow Accumulation > Stream Definition > Stream Segmentation > Catchment Grid Delineation > Catchment Polygon Processing > Drainage Line Processing > Adjoint Catchment Processing. Strahler's (1952) approach, which is common in literature, was used to order stream networks. Streams of the first order are created by source channels; the two streams of the same order create the next level. Higher-order streams dominate when the lower-order streams combine with the higher-order streams. Stream derivation was based on a 1,000-cell accumulation threshold, where every cell in the drainage network had 1,000 cells as a minimum to give some uniformity in hydrological representation.

3.3.2 Measurement of Basic Morphometric Properties of the Drainage Basin

Basic properties of the drainage basin, such as stream order (u), stream number (N_u), stream length (L_u), basin area (A), length (L_b), longest flow path (L_{fp}), perimeter (P), and slope (B_s), were obtained using ASTER and SRTM DEMs. Stream number and stream length were obtained by counting the segments and adding the length field in the attribute table to the vectorized drainage network shapefile (stream order). Stream order and counts were calculated using the grid code, and field geometry calculations gave the actual stream lengths based on their order.

3.3.3 Calculation of Derived Morphometric Properties of the Drainage Basin

Derived properties such as bifurcation ratio (R_b), drainage density (D_d), stream frequency (F_s), elongation ratio (R_e), basin relief (R), relief ratio (R_r), circularity ratio (R_c), stream length ratio (R_l) and form factor (R_f), among others were calculated through the following standard formula presented in Table 2.

3.3.4 Land Cover (LC) Classification

The land cover (LC) image classification was conducted in 2000, 2012, and 2024 to study the dynamics of the land cover and its dependence on the morphometric properties. Blue, Green, Red, Thermal, Near Infrared (NIR), and Short Wave Infrared (SWIR) bands (bands 2-7) were imported to ENVI and stacked because these bands give information on vegetation, built-up areas, water bodies, bare surfaces, agricultural land, and rock outcrops. There were six land cover classes. The River Shemankar Upper Catchment shapefile was used to clip the study area. Maximum Likelihood Classification (MLC) was used under supervision, which enabled close training and classification of sampled pixels. An accuracy assessment was conducted to determine the reliability and validity of the classified remote sensing and GIS-derived data, establishing how well the results reflect real-world conditions.

3.3.5 Assessment of Relationships between Land Cover and Selected Morphometric Properties

To assess the relationships between land cover and selected morphometric properties, the Shemankar Upper Drainage Basin was subdivided into ten sub-basins (Figure 2). All sub-basin shapefiles were overlaid with classified land cover and clipped to obtain the extent of each class (Table 3). Morphometric values were calculated in every sub-basin to study the differences and find out the land cover impacts. As the independent variables, land covers were used to predict the dependent morphometric properties, which include vegetation vs. stream number and other properties, built-up areas vs. stream number and others, and so on.

A regression model was utilized to establish the relationships. The regression analysis determine if there are any statistically significant influence of the land covers on the morphometric properties, which of course, influence the geomorphic and hydrological processes of the study basin. The regression model was adopted in this study, expressed as:

$$Y = a + \beta_1 X_1 + B_2 X_2 + B_3 X_3 + e$$

Where;

Y = Selected properties (Dependent Variable)

a = regression constant

β_1 = regression co-efficient

X_1 = Land cover/built-up (Independent Variable)

X_2 = Land cover/vegetation (Independent Variable)

X_3 = Land cover/bare surfaces (Independent Variable)

e = marginal error

3.3.6 Comparison of Results Morphometric Properties Derived from ASTER and SRTM DEMs

To compare the results of the selected morphometric properties derived from DEMs of STRM and ASTER sensors, ANOVA was utilized. ANOVA is a statistical technique used to determine variations and statistically significant differences between means of two or more groups. The ANOVA was used to test the significance difference between the selected morphometric properties values derived from SRTM DEM and those derived from ASTER DEM.

4. RESULTS

4.1 Morphometric Properties and Land Cover Types in River Shemankar Upper Drainage Basin

4.1.1 Linear Morphometric Properties of the Basin

Table 4 and Figure 3 reveal the linear morphometric propertiess of the basin using ASTER DEM. It is a 6th-order catchment containing 1,230 first-orders, 303 second-order, and 1 sixth-order segment. The total stream length measures 3,389.3 km, with the average length of a stream between 1.4 km and 83.7 km. The stream length ratios are 1.2-3.3, and the average stream bifurcation ratio is 3.6, which lies in the normal range of 3.0-5.0 (Strahler, 1952).

4.1.2 Areal Morphometric Properties of Shemankar Upper Drainage Basin

Table 5 reveals areal morphometric properties of the basin, which include a total area of 4,249.5 km², a perimeter of 347.68 km, and a length of 153.6 km. It has a low drainage density (0.79 km/km²), stream frequency (0.38), and infiltration number (0.30). The indices of shape, such as circularity (0.44), elongation (0.24), and form factor (0.18), suggest an elongated basin.

4.1.3 Relief Morphometric Properties of the Basin

Table 6 indicates that the elevation of the basin is between 1,485 m and 105 m, with a total relief of 1,380 m. Relative relief is 396.92 m, the ratio of relief is 2.58, and the dissection index is 0.29, which means that there is moderate vertical dissection and large elevation variation throughout the basin.

4.1.4 Land Cover Types in the River Basin

Table 7 and Figures 6-8 indicate that in 2000, the basin was dominated by agricultural land (51.3%) and rocky outcrops (28.5%). There were small areas of vegetation (13.0%), bare land

(6.5%), built-up (0.5%), and water bodies (0.2%), which implies intensive farming, moderate vegetation cover, and a lot of rock exposure associated with semi-humid highland basins.

4.2 Land Cover Dynamics in the River Basin between 2000 and 2024

Tables 8 shows significant land cover changes between 2000 and 2012. Agricultural land increased by 723.2 km² (17.0%) to 2,903.8 km² (68.3%), while built-up areas rose to 70 km² (1.6%). By 783.6 km² and 236.1 km², rocky outcrops and bare surfaces decreased, respectively. There was a moderate growth of vegetation cover by 255 km² (6.0%), probably through natural regeneration and succession of fallow land. Water bodies were reduced by 5.4 km².

Table 9 shows that there are significant land cover changes between 2012 and 2024. Built-up areas increased from 70.0 km² (1.6%) to 157.3 km² (3.7%), while agricultural land expanded from 2,903.8 km² (68.3%) to 3,432.6 km² (80.8%). Water bodies marginally rose to 3.2 km². In contrast, vegetation declined sharply from 807.7 km² (19.0%) to 205 km² (4.8%). Such changes indicate the heightened anthropogenic processes, especially agriculture and urban sprawl, which have altered the natural scenery of the basin to a tremendous extent.

4.3 Relationship between Land Cover and Selected Morphometric Properties

Table 10 shows that agricultural land and rocky outcrops are strongly and significantly positively related to the number of streams ($R^2 = 0.75$ and 0.70 , $p < 0.05$). On the other hand, built-up areas, vegetation, water bodies, and bare surfaces are weakly and not significantly related. Agricultural land and rocky outcrops also have a strong positive relationship in terms of drainage density ($R^2 = 0.78$ and 0.72 , $p < 0.05$), and vegetation has a moderate negative relationship ($R^2 = 0.46$). Built-up water bodies and bare surfaces show weak to moderate positive yet insignificant effects. Likewise, agricultural land and rocky outcrops have a strong influence on drainage texture ($R^2 = 0.73$ and 0.68 , $p < 0.05$), and the rest of the land cover types possess weak and insignificant relationships.

Table 11 shows that there are strong positive relationships between stream length and agricultural land and rocky outcrops ($R^2 = 0.81$ and 0.74 , $p < 0.05$). There are moderate positive effects with built-up areas and bare surfaces, and a weak negative relationship with vegetation ($R^2 = 0.29$). In the case of infiltration, agricultural land and rocky outcrops show negative relationships, while vegetation has a moderate effect ($R^2 = 0.57$) and improves soil permeability and groundwater recharge rates. There are also strong positive relationships between stream frequency and agricultural land and rocky surfaces ($R^2 = 0.78$ and 0.72).

4.4 Comparison of Results of Selected Properties Derived from ASTER and SRTM DEMs

The findings of the selected morphometric properties based on the ASTER and the SRTM sensors were compared. The results are presented in Table 12.

The findings showed that the stream order (6th-order) was identical in both DEMs. SRTM, however, had more stream numbers (2,680) than ASTER (1,600), but ASTER had slightly more

total stream length (3,389.3 km) than SRTM (3,254.0 km). Morphometric properties, including bifurcation ratio (3.60 vs. 4.30), drainage density (0.79 vs. 0.77 km/km²), and stream frequency (0.38 vs. 0.63), have slight differences between the datasets (Table 11). SRTM was also more sensitive to drainage intensity and the number of infiltrations. Other parameters were the same, and the elevation values were close, though SRTM tended to exaggerate the extremes more than ASTER (Figure 9).

Hypothesis:

One-way ANOVA was adopted to test at $\alpha = 0.05$ level of significance whether the mean values of the variables differ significantly between the two datasets.

Table 13 revealed no statistical significant variation (p -value 0.285, > 0.05) between the morphometric properties of the ASTER and SRTM DEMs at the 95% confidence level. That is, ASTER and SRTM sensors generated similar morphometric data, only with slight differences because of sensor features (optical vs. radar).

5. DISCUSSION

The drainage pattern in the basin is dendritic, implying a relatively homogeneous lithology and low structural control over hydrological processes, as observed in earlier works of Ajibade *et al.* (2010), Mahala (2019), Eludoyin & Adewole (2019), and Mutawakil *et al.* (2021). It consists of 1,230 first-order streams, 303 second-order streams, and one sixth-order channel, as is expected by the law of stream numbers postulated by Horton, which predicts that the frequency of streams decreases geometrically with their order. Variation in the rock structure is responsible for the variation in stream order in the basin, consistent with what Adediji (2005), Adewole & Eludoyin (2019), and Fenta *et al.* (2017) reported. The high number of first-order streams reflects a youthful, highly dissected terrain, particularly across the Jos Plateau, characterized by steep slopes, shallow soils, and structurally influenced drainage. These environments encourage high surface runoff and low infiltration, predisposing them to flash floods during heavy rainfall. The ratio of stream lengths is 1.2 to 3.3, which means that there is moderate variability across successive stream orders, and lithological and slope controls are not uniform. This implies that stream development is influenced more by relief and structural conditions than by uniform geological resistance, as argued by Resmi *et al.* (2019), Caleb *et al.* (2021), and Pande & Moharir (2017) in their studies. Furthermore, the bifurcation ratio is 3.6, which implies that there is very little disturbance in the structure; hence, basin hydrology is mainly controlled by natural topography and underlying geology with minimal structural input.

The areal properties of the basin indicate that it covers an area of 4,249.5 km², which is a large basin (>2500 km²), as postulated by Singh (1994). These basins are generally well-endowed in terms of drainage and water storage capabilities, especially in the lower sections, and therefore can be used in the multipurpose development of water resources like irrigation, hydropower, and household water supply. The drainage density (0.79 km/km²) is low, the relief is low, and the infiltration rate is high, which is in line with the results of Ajibade *et al.* (2010) and Mahala (2019). Likewise, the frequency of streams (0.38) indicates that there are fewer channels per unit area, indicating low runoff potential and low slope, according to Caleb *et al.* (2021). The high infiltration and low flood potential are further confirmed by the infiltration number (0.30) and the drainage intensity (0.48), which is consistent with what Adelalu *et al.* (2020) observed in the Taraba River Basin. R_c (0.44), R_e (0.24), and R_f (0.18) indicate that the basin is elongated, which

indicates delayed runoff and reduced peak discharge. Strahler (1964) also argues that these long basins with values below 0.5 are less susceptible to floods.

In the general perspective, the linear and areal properties of the Shemankar Upper Drainage Basin revealed a moderately dissected, structurally undisturbed, and hydrologically balanced drainage basin that had a well-developed stream hierarchy, moderate runoff, potential water availability, low flood potential, and active fluvial processes, especially in the northern areas.

The relief properties of the basin show a peak height of 1,485 m and a minimum of 105 m above sea level, resulting in an overall relief of 1,380 m. This high elevation variation indicates a high gradient between uplands and low floodplains, encouraging excessive erosion in the highland regions owing to strong gravitational forces. Strahler (1952) and Mahala (2019) assert that basins that have relief more than 1,000 m are characterized by high runoff velocity, sediment transportation, and active erosion. The relief ratio of 2.58 indicates steep terrain, steep valley sides, and swift stream incision, particularly in the northern part, which is consistent with the results given by Bunmi *et al.* (2017). The dissection index of 0.29 indicates moderate landscape dissection, with active denudation in upper regions and geomorphic maturity downstream, as noted by Salau & Ifabiyi (2019) and Adelalu *et al.* (2020), who found comparable values in the mid-maturity tropical basins and attributed them to balanced erosional forces and deposition. The slope ranges between 0 and 68.7%, with steep upper areas where runoff is promoted and low plains that are not steep, where infiltration is enhanced.

The land cover dynamics of the basin between 2000 and 2024 reveal anthropogenic transformation in its land cover. Agricultural land expanded rapidly from 723.2 km² (17.0%) in 2000 to 2,903.8 km² (68.3%) in 2012, largely at the expense of rock outcrops (−783.6 km²) and bare surfaces (−236.1 km²). The vegetation cover also grew slightly (255 km² or 6.0%), probably as a result of natural regeneration and fallow land succession, whereas built-up areas increased to 70 km² (1.6%). The water bodies reduced slightly by 5.4 km², which could be attributed to sedimentation, water abstraction for agriculture, or climate change. These changes are in line with what Ashaolu *et al.* (2019) found in the Osun Drainage Basin between 1986 and 2016. Between 2012 and 2024, built-up areas further increased to 157.3 km² (3.7%), while vegetation declined sharply to 205 km² (4.8%). Agricultural land expanded to 3,432.6 km² (80.8%). Such growth implies more intensive human activity, which is in agreement with Adediji & Jeje (2004) in the Opa Basin, Southwestern Nigeria, who attribute land conversion to greater runoff and degradation.

The relationships between morphometric properties and land cover show that agricultural land and rocky outcrops ($R^2 = 0.75$ & 0.70 , $p < 0.05$) strongly positively influence the number of streams. This indicates that agricultural activities and bare rock surfaces promote channel formation and bifurcation, likely due to reduced vegetation cover, soil disturbance, and surface runoff. These conditions support the formation of rills and gullies, especially on steep terrains. Therefore, human activities and geological factors together increase drainage density. In contrast, built-up areas, vegetation, water bodies, and bare surfaces have weaker and statistically insignificant relationships ($R^2 = 0.30 - 0.41$, $p > 0.05$), implying that they do not have a substantial impact on the formation of new channels.

The findings show that drainage density is positively correlated with agricultural land and rocky outcrops ($R^2 = 0.78$ & 0.72 , $p < 0.05$). Tilling, bush burning, and clearing of land make soils susceptible to erosion, hence augmenting runoffs and intensifying the development of channels. Likewise, the rocky surfaces that are impermeable also collect surface runoff and increase the density of drainage. Vegetation, conversely, exhibits a moderate negative correlation ($R^2 = 0.46$,

$p < 0.05$), indicating that well-vegetated areas promote infiltration, soil stabilization, and diminished runoff, thus inhibiting channel formation. Weak to moderate positive yet insignificant relations are found between built-up areas, water bodies, and bare surfaces ($R^2 = 0.30 - 0.43$, $p > 0.05$), which means that they had little hydrological control in the basin compared with agricultural land and rocky surfaces.

A high level of runoff and the creation of many micro-channels in agricultural land and rocky outcrops ($R^2 = 0.73$ & 0.68 , $p < 0.05$) have a positive effect on the drainage texture. This means that a fine drainage texture is more likely to be found in these areas. The agricultural activities encourage splash erosion and surface run-offs, which increase channel formation. Conversely, there are weak to moderate but insignificant relationships between vegetation, water bodies, and bare surfaces ($R^2 = 0.28-0.40$, $p > 0.05$), indicating little impact. The negative relationship with vegetation emphasizes its effect on decreasing erosion, runoff, and stream initiation and enhancing coarser drainage textures.

Agricultural land and rocky outcrops have a positive relationship with stream length ($R^2 = 0.81$ & 0.74) because longer streams are found in cultivated and exposed rocky areas, since runoff and infiltration are lower. The positive effects of built-up areas and bare surfaces are moderate ($R^2 = 0.43-0.47$). Conversely, vegetation exhibits a weak negative correlation ($R^2 = 0.29$), which implies that vegetated terrain makes the surface more stable and less erosive and hinders the formation of channels that lead to shorter stream lengths.

Infiltration is negatively correlated with agricultural land and rocky outcrops ($R^2 = 0.69$ and 0.32), which implies that soil disruption and hardened surfaces decrease the absorption of water. Conversely, vegetation has a moderate positive impact ($R^2 = 0.57$), which increases the permeability of soil and groundwater recharge. Further, the stream frequency demonstrates strong positive correlations with the agricultural land and rocky surfaces ($R^2 = 0.78$ & 0.72), which validates the fact that it enhances the runoff and drainage development.

Comparison of morphometric properties of ASTER and SRTM DEMs reveals no statistically significant differences in hydrological representation. Nikolakopoulos et al. (2006) and Adewole & Eludoyin (2019) say that the SRTM DEM has fewer small tributaries than the ASTER DEM. This is probably because the SRTM DEM uses a radar-based elevation system. ASTER had a slightly larger total stream length (3,389.3 km) than SRTM (3,254.0 km), indicating that ASTER may have overestimated the terrain noise. Nevertheless, SRTM registered higher stream frequency, drainage intensity (0.82), and infiltration number (0.49), which means that it is more sensitive to terrain dissection and hydrological processes. Drainage texture, circularity ratio, elongation ratio, relief ratio, and ruggedness number parameters were similar in both datasets, indicating that basin geometry is not highly dependent on the DEM source. Elevations were also comparable, albeit with slight overstatement of extremes by SRTM, implying slightly better information in both terrain representation and hydrology modeling. Conclusively, although both ASTER and SRTM DEMs yielded similar results in their morphometric property output, the SRTM DEM was found to be more reliable and hydrologically consistent in morphometric analysis than the ASTER.

6. Conclusion

The study revealed that the Shemankar Upper Drainage Basin is a well-developed fluvial process, hydrologically well-balanced, and a structurally stable drainage basin with a moderately dissected stream hierarchy. The morphometric properties suggest that it has a mature basin with high infiltration, low runoff, and moderate flood potential, which is evidence of a stable geomorphic and hydrological environment. The basin has, over time, however, undergone

considerable land cover changes due to agricultural expansion, deforestation, and urban growth. The results indicate that human activities have become significant in defining the environmental dynamics of the basin. The correlation between the land cover and the morphometric parameters also highlights the effect of anthropogenic-driven factors on the development of the drainage. Overall, sustainable land management and conservation efforts should be undertaken to preserve the ecological stability and hydrological integrity of the Shemankar Basin.

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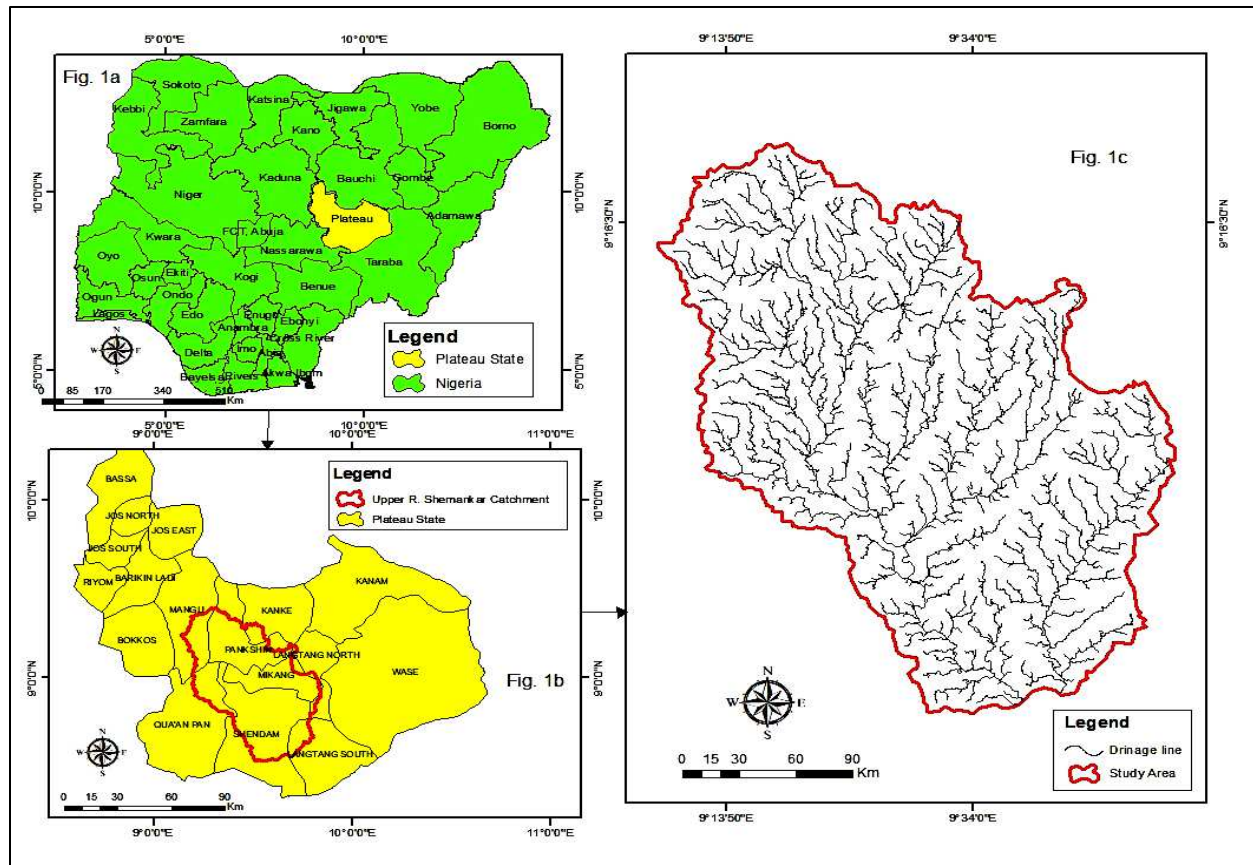


Fig. 1: Location and Position of River Shemankar Upper Basin

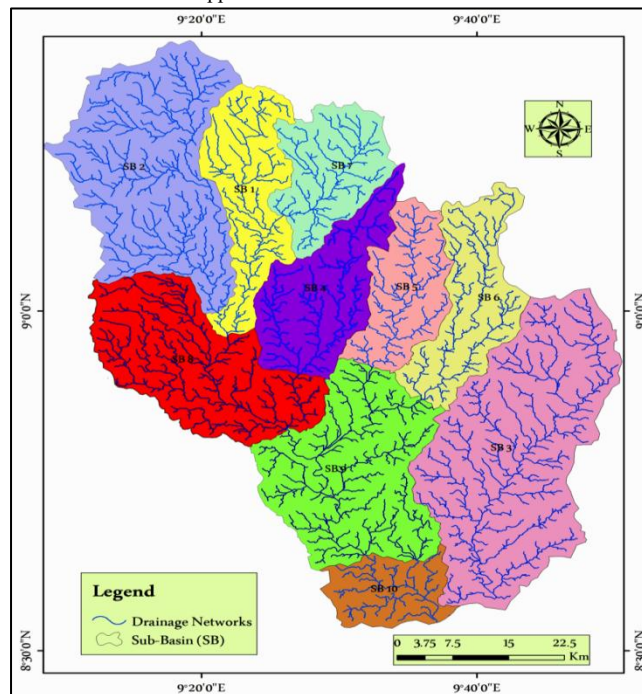


Fig. 2: Sub-basins of Shemankar Upper Basin

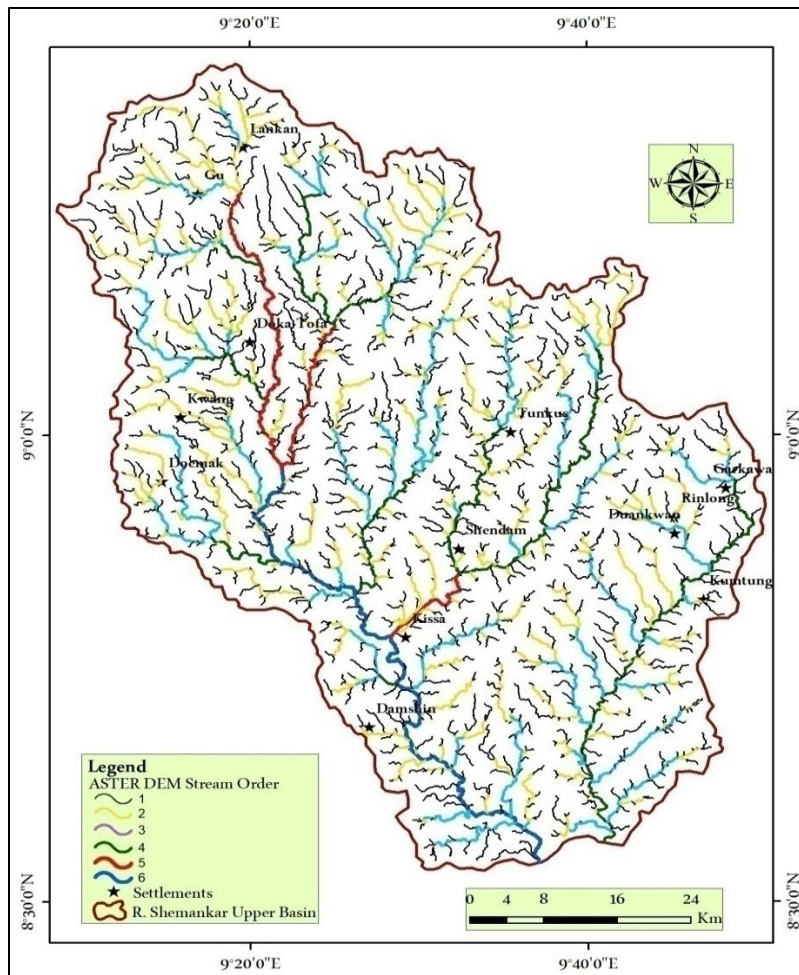


Fig. 3: Drainage Networks and Stream Order of the River Basin

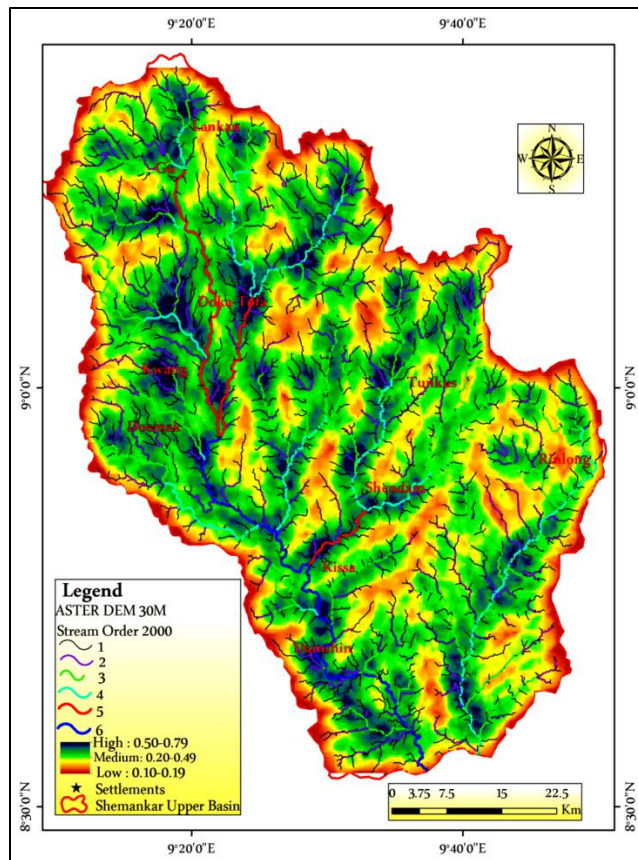


Fig. 4: Spatial view of the Basin's D_d

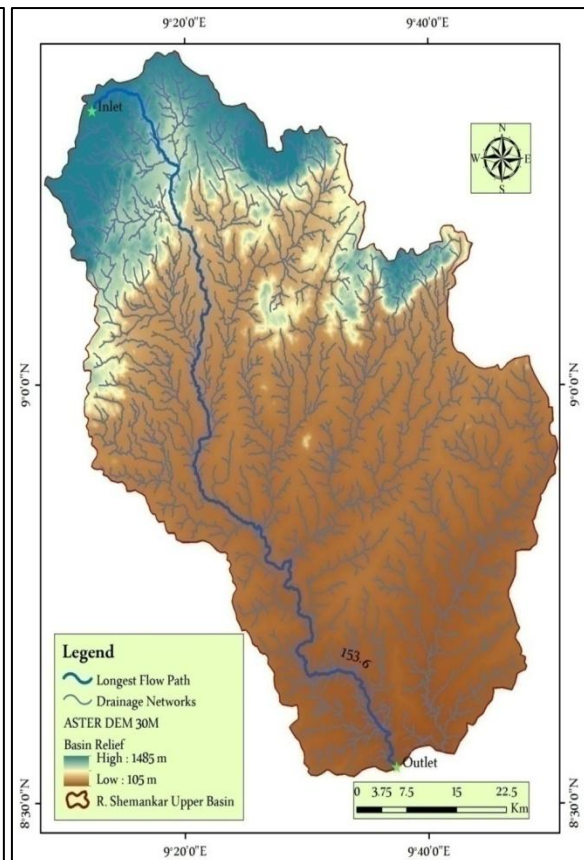


Fig. 5: Spatial view of the Basin's Perimeter & Relief

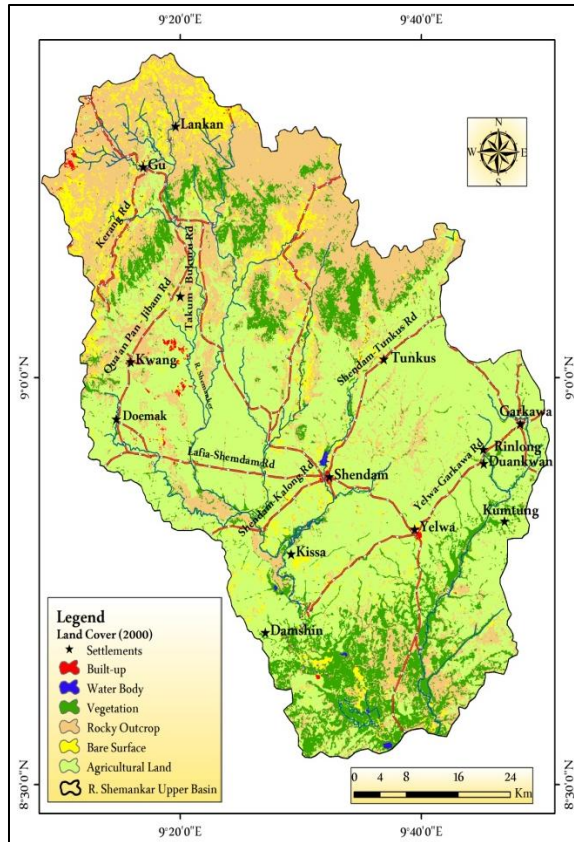


Fig. 6: Land Cover Types in the River Basin (2000)

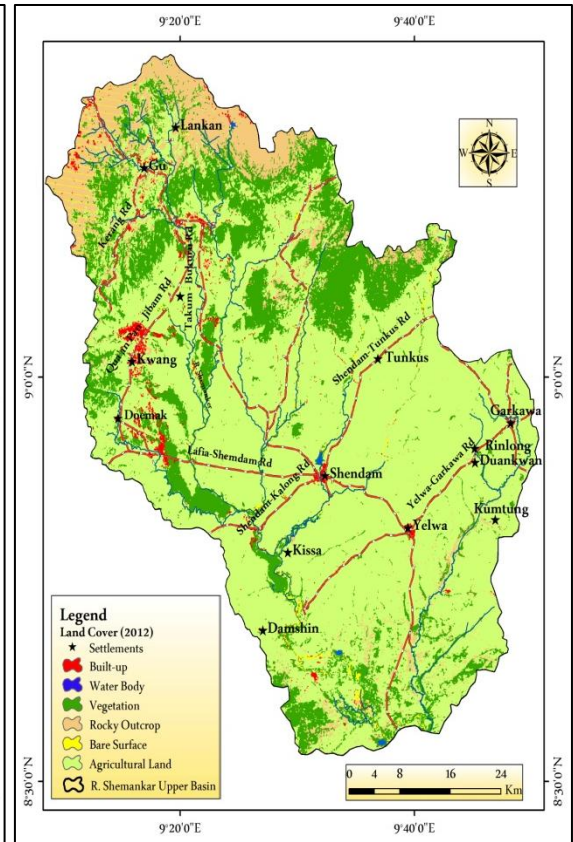


Fig. 7: Land Cover Types in the River Basin (2012)

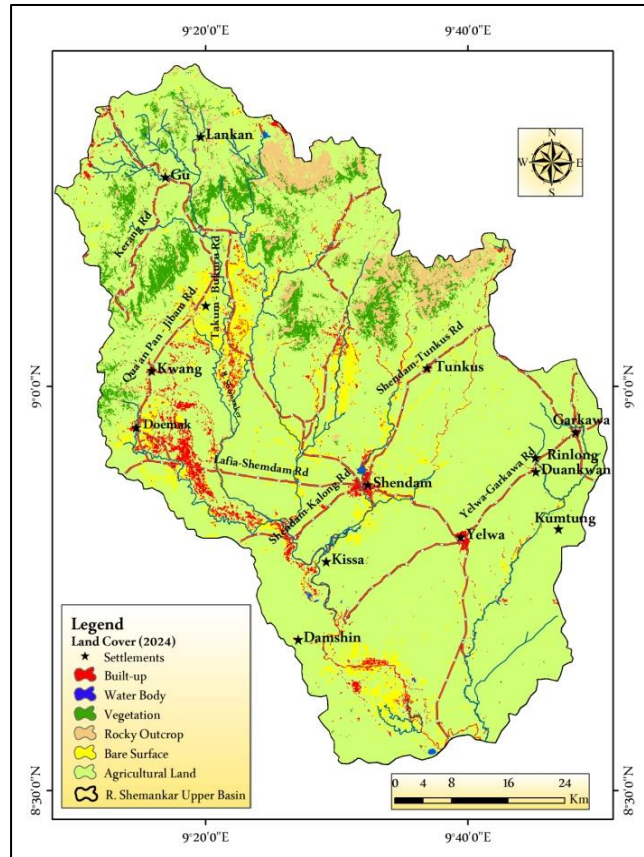


Fig. 8: Land Cover Types in the River Basin (2024)

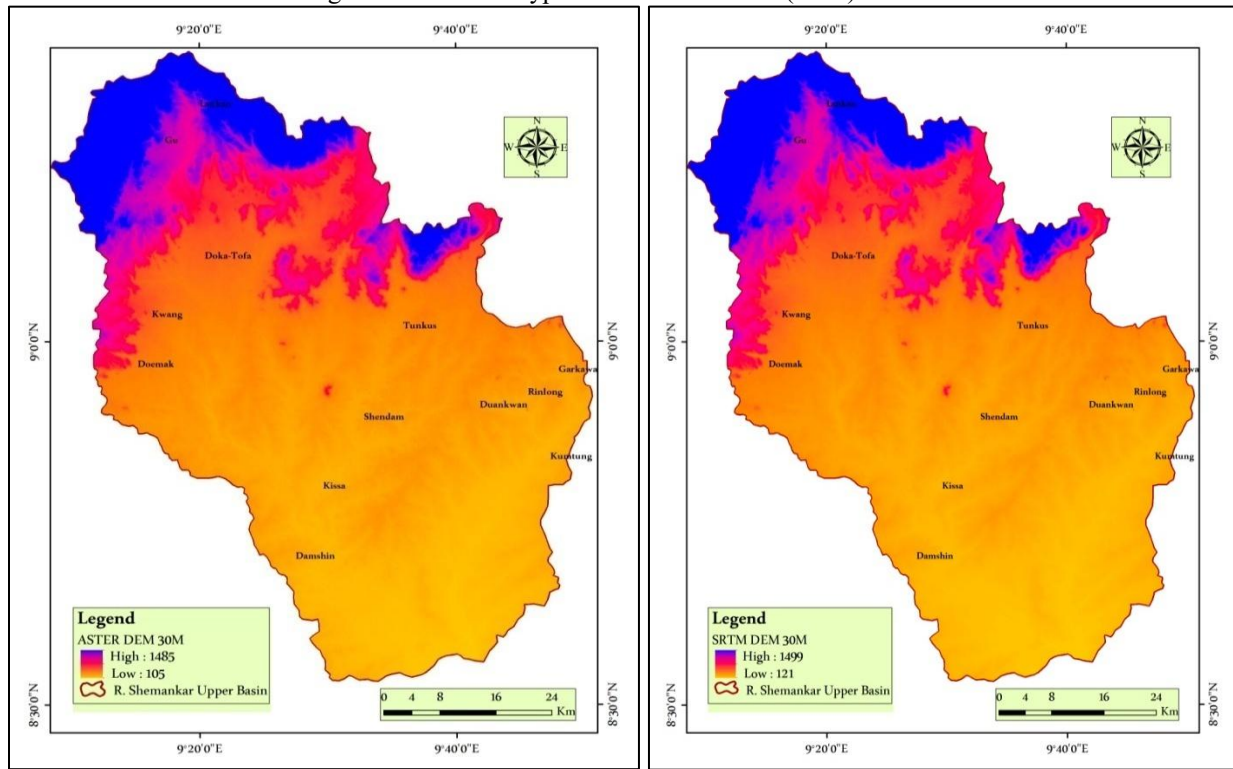


Fig. 9: Basin Relief, ASTER vs. SRTM DEMs

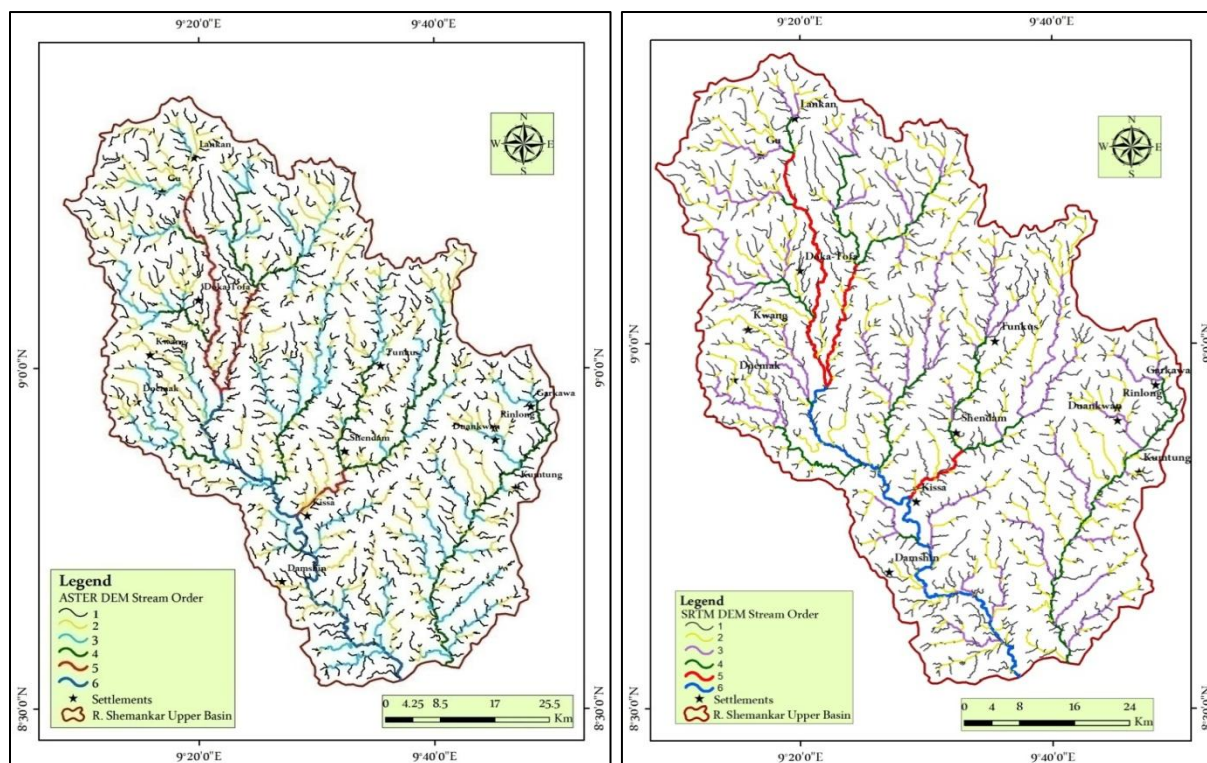


Fig. 10: Drainage Network and Pattern, ASTER vs. SRTM DEMs

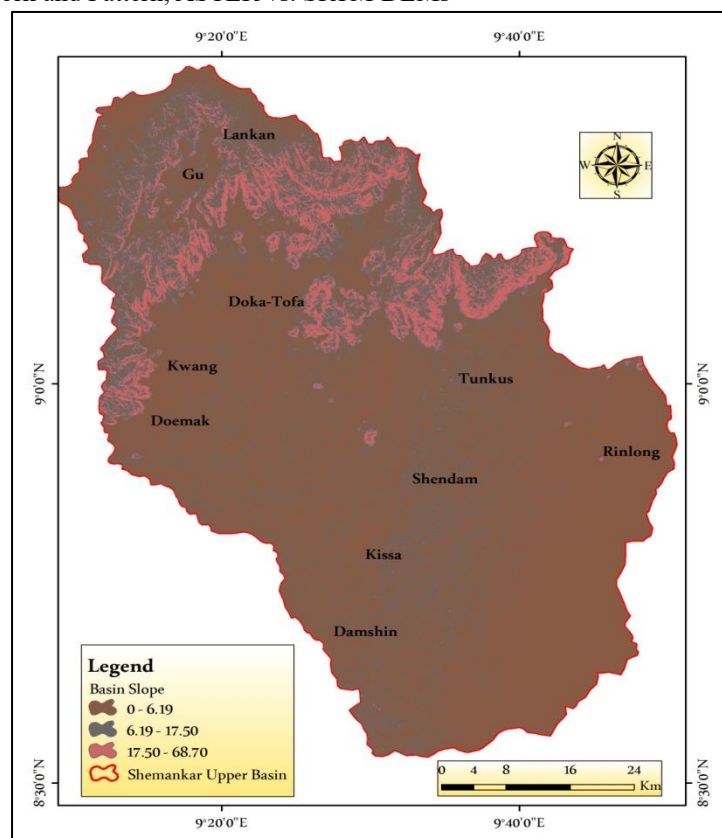


Fig. 11: Basin Slope

List of Tables

Table 1: Types and sources of data

Data	Year	Resolution	Path/Row
Landsat 7 ETM+	2000 & 2012	30 M	188/54
Landsat 9 OLI/TIRS	2024	30 M	188/54
ASTER DEM	2014	30 M	ASTGTMV003_N08E010 n008_e009_1arc.tif
SRTM DEM	2014	30 M	

Table 2: Morphometric Properties and their Formulae and References

Linear Properties		Formulae	References
1	Stream order (U)	GIS Analysis	Strahler (1964)
2	Stream number (N_u)	GIS Analysis	Horton (1945)
3	Stream length (L_u)	GIS Analysis	Horton (1945)
4	Mean stream length (L_{um})	$L_{um} = L_u / N_u$	Strahler (1964)
5	Stream length ratio (R_l)	$R_l = L_u / L_u - 1$	Horton (1945)
6	Bifurcation ratio (R_b)	$R_b = N_u / N_u + 1$	Schuum (1956)
7	Mean bifurcation ration (R_{bm})	$R_{bm} = (R_{b1} + R_{b2} + \dots + R_{bn}) / n$	Schuum (1956)
Areal Properties			
8	Drainage density (D_d)	$D_d = L_u / A$	Horton (1945)
9	Stream frequency (F_s)	$F_s = N_u / A$	Horton (1945)
10	Drainage texture (D_t)	$D_t = N_u / P$	Smith (1950)
11	Circularity ratio (R_c)	$R_c = 4\pi * A / P^2$	Miller (1953)
12	Elongation ratio (R_e)	$R_e = 2 \sqrt{(A/\pi)} / L_b$	Schumm (1956)
13	Form factor ratio (R_f)	$R_f = A / L_b^2$	Horton (1932)
14	Infiltration number (I_f)	$I_f = D_d * F_s$	Faniran (1968)
15	Length of overland flow (L_g)	$L_g = 1/2 * D_d$	Horton (1945)
16	Constant channel of maintenance (CCM)	$C = 1 / D_d$	Schumm (1956)
Relief Properties			
17	Basin relief (R)	$R = H - h$	Schumm (1956)
18	Relief ratio (R_r)	$R_r = H' / L_b$	Schumm (1956)
19	Relative relief (R_{hp})	$R_{hp} = H / P$	Melton (1957)
20	Ruggedness number (R_n)	$R_n = D_d * H / 1000$	Schumm (1956)
21	Dissection index (D_i)	$D_i = H' / R$	Schumm (1956)
22	Basin slope (B_s)	-	GIS Analysis

Table 3: Land Cover Extent and Selected Morphometric Properties of Sub-Basins

Sub-Basin	BU	AL	V	W	BS	RK	N_u	L_u	Area	D_d	F_s	D_t	I_f
SB1	8.4	140	101	0.5	1.6	62.5	112	263.2	312.2	.84	.36	.95	.30
SB2	21.6	279.6	164.6	0.1	11.8	206.8	224	557.7	687.9	.81	.33	1.63	.27
SB3	3.7	765.8	64.3	0.0	1.0	38.7	305	636.5	880.6	.72	.35	1.99	.25
SB4	2.4	237.9	68.5	0.6	4.1	11.2	125	262.6	322.8	.81	.39	1.23	.32
SB5	1.3	173.4	66.5	0.0	1.2	3.9	103	199.7	245.1	.81	.42	1.22	.34
SB6	0.8	256.6	39.7	0.0	1.6	14.1	130	245.6	306.8	.80	.42	1.19	.34
SB7	1.6	107.5	99.9	0.1	1.2	54.5	98	203.9	259.8	.79	.38	1.18	.30
SB8	20.6	378.7	96.9	0.5	3.7	5.9	195	431.4	508.0	.85	.38	1.72	.32
SB9	8.1	481.1	47.8	1.9	8.2	12.5	251	460.5	562.6	.82	.45	2.08	.37
SB10	8.4	140	101	0.5	1.6	62.5	56	128.1	163.7	.78	.34	.86	.27
Total	70.0	2903.8	807.7	4.4	36.9	426.6	1600	3389.3	4249.5				

Table 4: Results of Selected Linear Morphometric Properties of the River Basin

Stream Order (U)	Stream Number (N_u)	Stream Length (L_u)	Mean Stream Length (L_{um}) L_u/N_u	Stream Length Ratio (R_l) L_{um}/L_{um-1}	Bifurcation Ratio (R_b) N_u/N_{u+1}
1 st	1230	1703.9	1.4	—	4.1
2 nd	303	819.2	2.7	1.9	5.7
3 rd	53	478.2	9.0	3.3	5.3
4 th	10	223.0	22.3	2.5	3.3
5 th	3	81.3	27.1	1.2	3.0
6 th	1	83.7	83.7	3.1	—
$\sum N_u = 1600$		$\sum L_u = 3389.3$ km		Av. (R_{bm})=3.6	

Table 5: Results of Selected Areal Morphometric Properties of the River Basin

S/N	Properties	Unit	Results
1	Basin Area (A)	Km ²	4249.5
2	Basin Perimeter (P)	Km	347.68
3	Basin Length (L_b)	Km	153.6
4	Drainage Density (D_d)	Km/km ²	0.79
5	Stream Frequency (F_s)	Km ²	0.38
6	Drainage Intensity (I_d)	Km	0.48
7	Drainage Texture (D_t)	Km/km ²	4.60
8	Circularity Ratio (R_c)	–	0.44
9	Elongation ratio (R_e)	–	0.24
10	Form Factor Ratio (R_f)	–	0.18
11	Infiltration Number (I_f)	–	0.30
12	Length of Overland Flow (L_g)	Km	0.40

Table 6: Results of Selected Relief Morphometric Properties of the River Basin

S/N	Properties	Unit	Results
1	Highest (absolute) elevation (H)	m asl.	1485
2	Lowest elevation (h)	m asl.	105
3	Basin Relief (R)	m asl.	1380
4	Relative relief (R_{hp})	–	396.92
5	Relief ratio (R_r)	–	2.58
6	Ruggedness number (R_n)	–	0.31
7	Dissection index (D_i)	–	0.29

Table 7: Land Cover Types in the River Basin

Land Cover	2000	
	km ²	%
Built-up	23.1	0.5
Water Body	9.8	0.2
Vegetation	552.8	13.0
Rocks	1210.1	28.5
Bare Surface	272.9	6.5
Agricultural Land	2180.8	51.3
Total	4249.5	100.0

Tale 8: Change in Spatial Extent of Area Covered by the Land Cover (2000 – 2012)

Land Cover	2000	2012	Area changed	2000%	2012%	Change %
Built-up	23.1	70.0	46.9	0.5	1.6	1.1
Water Body	9.8	4.4	-5.4	0.2	0.1	-0.1
Vegetation	552.8	807.7	255	13.0	19.0	6.0
Rocks	1210.1	426.6	-783.6	28.5	10.0	-18.5
Bare Surface	273.0	36.9	-236.1	6.5	0.9	-5.6
Agricultural Land	2180.8	2903.8	723.2	51.3	68.3	17.0
Total	4249.5	4249.5	–	100.0	100.0	–

Table 9: Change in Spatial Extent of Area Covered by the Land Cover (2012 – 2024)

Land Cover	2012	2024	Area changed	2012%	2024%	Change %
built-up	70.0	157.3	86.8	1.6	3.7	2.1
Water Body	4.4	7.7	3.3	0.1	0.2	0.1
Vegetation	807.7	205.3	-602.5	19.0	4.8	-14.2
Rocks	426.6	191.7	-234.5	10.0	4.5	-5.5
Bare Surface	36.9	254.8	217.9	0.9	6.0	5.6
Agricultural Land	2903.8	3432.6	528.9	68.3	80.8	12.5
Total	4249.5	4249.5	–	100.0	100.0	–

Table 10: Relationships between Land Cover and Morphometric Properties

Stream Number (N_u) (Dependent)						
Predictor	Coeff (b)	Std Error	t	p-value	Intercept (a)	R²
Built-up	.013	.010	1.30	.230	1499.3	0.38
Agricultural land	.031	.008	3.88	.008	1484.5	0.75
Vegetation	.005	.006	0.83	.410	1499.0	0.30
Water Bodies	.010	.009	1.11	.310	1499.9	0.32
Bare Surfaces	.008	.008	1.00	.345	1499.8	0.41
Rocks	.022	.007	3.14	.015	1497.8	0.70
Drainage Density (D_d) (Dependent)						
Built-up	.007	.004	1.42	.201	0.05	0.36
Agricultural land	.019	.006	3.17	.014	-9.1	0.78
Vegetation	-.013	.005	-2.92	.019	3.0	0.46
Water Bodies	.003	.004	0.50	.640	0.37	0.30
Bare Surfaces	.004	.004	0.78	.475	0.28	0.43
Rocks	.005	.005	3.24	.013	-0.1	0.72
Texture Ratio (D_t) (Dependent)						
Built-up	.008	.006	1.12	.298	0.8	0.34
Agricultural land	.024	.007	3.43	.011	-10.8	0.73
Vegetation	.003	.005	0.52	.620	0.6	0.38
Water Bodies	.005	.006	0.83	.460	1.15	0.28
Bare Surfaces	.006	.006	1.00	.350	1.02	0.40
Rocks	.019	.006	3.08	.016	-0.7	0.68

Table 11: Relationships between Land Cover and Morphometric Properties, 2012

Stream Length (L_u) (Dependent)						
Predictor	Coeff (b)	Std Error	t	p-value	Intercept (a)	R²
Built-up	.011	.009	1.22	.290	599.5	0.43
Agricultural land	.027	.007	3.86	.009	586.5	0.81
Vegetation	-.008	.006	-1.33	.218	601.6	0.29
Water Bodies	.003	.007	0.43	.690	599.9	0.39
Bare Surfaces	.007	.007	1.00	.345	599.8	0.47
Rocks	.021	.006	3.12	.016	597.9	0.74
Infiltration (I_f) (Dependent)						
Built-up	.005	.006	0.91	.410	0.20	0.31
Agricultural land	-.021	.007	-3.08	.016	10.9	0.69
Vegetation	.006	.006	0.93	.402	0.25	0.57
Water Bodies	-.002	.005	-.42	.692	0.47	0.50
Bare Surfaces	.004	.006	0.68	.523	0.33	0.28
Rocks	-.019	.007	-2.84	.021	2.35	0.32
Stream frequency (F_s) (Dependent)						
Built-up	.012	.009	1.33	.224	0.9	0.41
Agricultural land	.028	.008	3.50	.011	12.5	0.78
Vegetation	.005	.006	0.83	.417	0.5	0.44
Water Bodies	.010	.010	1.00	.345	1.4	0.33
Bare Surfaces	.009	.008	1.12	.290	1.23	0.52
Rocks	.023	.007	3.29	.014	0.8	0.72

Table 12: Comparison of Results of Selected Properties Derived from ASTER and SRTM DEMs

S/N	Properties	Unit	ASTER DEM 30M	SRTM DEM 30M
1	Stream Order (U)	–	6	6
2	Stream Number (N_u)	–	1600	2680
3	Stream Length (L_u)	Km	3389.3	3254.0
4	Mean Bifurcation Ratio (R_{bm})	–	3.60	4.30
5	Drainage Density (D_d)	Km ⁻¹ /km ²	0.79	0.77
6	Stream Frequency (F_s)	Km ²	0.38	0.63
7	Drainage Intensity (I_d)	Km	0.48	0.82
8	Drainage Texture (D_t)	Km/km ²	4.60	4.60
9	Circularity Ratio (R_c)	–	0.44	0.44
10	Elongation ratio (R_e)	–	0.24	0.24
11	Infiltration Number (I_f)	–	0.30	0.49
12	Length of Overland Flow (L_g)	Km	0.40	0.39
13	Highest Elevation (H)	m asl.	1485	1499
14	Lowest Elevation (h)	m asl.	105	121
15	Basin Relief (R)	m asl.	1380	1378
16	Relative Relief (R_{hp})	m asl.	396.92	396.34
17	Relief Ratio (R_r)	–	2.58	2.58
18	Ruggedness Number (R_n)	–	0.31	0.31
19	Dissection Index (D_i)	–	0.29	0.29

Table 13: One-way ANOVA of Consistency of ASTER and SRTM DEMs

Source	SS	Df	MS	F Ratio	α	p -value	Decision
Between Groups	0.184	1	0.184	1.216	0.05	0.285	Accept H_0
Within Groups	5.29	36	0.147				
Total	5.474	37					