

Morphometric Characterization And Land Use Dynamics In The Hindon River Basin Using Remote Sensing & GIS

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Abstract

This research focuses on evaluating the morphometry of the Hindon River basin by analyzing the linear, areal, and relief aspects, combined with LULC change detection through supervised classification and NDVI techniques. The Hindon River, a tributary that merges with the Yamuna River, originates in the Shakumbhari Devi range of the Shivalik Hills in Uttar Pradesh's Saharanpur district and converges with the Yamuna near Tilwada village in Gautam Buddha Nagar. The basin extends over an area of around 6,940 km², with elevation range in between 190 m and 868 m above mean average sea level. Morphometric evaluation indicates that the shape of Hindon River basin is elongated with low relief, moderate structural influence, and sparse drainage density factors that contribute to reduced surface runoff and lower susceptibility to erosion. LULC assessments highlighted a substantial rise in built-up land and a simultaneous reduction in agricultural and barren areas between 2017 and 2024, suggesting rapid urban development. Meanwhile, NDVI analysis revealed relatively consistent vegetation cover over the years, with only slight variations in greenness.

Keywords: Basin Morphometry, GIS & Remote Sensing, LANDSAT 8-9, SRTM-DEM, LULC, NDVI.

1. INTRODUCTION

Understanding the catchment's physical properties particularly morphometrical assesment and land use land cover (LULC) are essential for hydrological analysis and watershed management (Geetha & Soman, 2019; Shekhar & Matthew, 2024; Sreeshna et al., 2024). River basin morphometry supports soil erosion prone area's identification, areas affected with floods, sediment transport paths, and regions impacted by waterlogging or groundwater accumulation (Khan & ElKashouty, 2023; Muthukumar et al., 2020; Hariprasad et al., 2024). This knowledge informs the planning of structural interventions including spillways, bunds, terraces, drainage systems, and artificial recharge structures (Saha et al., 2022). Morphometric parameters and land use land cover of the basin also influence key hydrological behaviours such as runoff generation, flow velocity, peak discharge, and time of concentration (Sahoo et al., 2024). They are increasingly used to locate hydrological hotspots and support sustainable land and water resource planning (Vig et al., 2024; Sutradhar & Mondal, 2023). Inputs such as stream order, drainage density, slope, and elevation (Khalifa et al., 2023; Alatas et al., 2022) provide a framework for assessing geomorphic and hydrologic processes at the watershed scale (Altaf et al., 2013). While several studies have focused on water quality in the Hindon River such as BOD/COD assessments (Sharma et al., 2014), heavy metal contamination (Mishra et al., 2020), and microbiological pollution (Sharma et al., 2021) limited research has addressed the river basin's morphometry in detail. Earlier morphometric studies in other regions (Nag, 1998; Waiker & Chavadekar, 2014; Chopra et al., 2005; Prabhakar et al., 2019) have shown the value of integrating Remote Sensing and Geographical Information System.

This study expands on that by providing a detailed morphometric evaluation (Areal, Linear & Relief aspects) and a comparative land use land cover (LULC) assessment spanning 7 years (2017 & 2024), offering insights for watershed planning and management. The second objective of the study is to the detection of long-term 30 years spatiotemporal differences (1990 & 2022) in vegetation characteristics of the watershed using Normalized difference vegetation Index (NDVI).

2. MATERIAL & METHODS

2.1 Study Area

The Hindon River is major tributary of the River Yamuna, originates from the Shivalik Hills in Saharanpur district, Uttar Pradesh, and flows 312 km before joining the Yamuna near Tilwada village in Gautam Buddha Nagar district. The basin extent is 28°24'9"N-30°17'18"N and 77°12'30"E-77°55'4"E,

covering parts of six districts in Uttar Pradesh, with minor portions in Uttarakhand and Delhi. The elevation ranges from msl lies between 190 m to 868 m. Annual rainfall averages 702 mm, with most precipitation during the monsoon months (June-September).

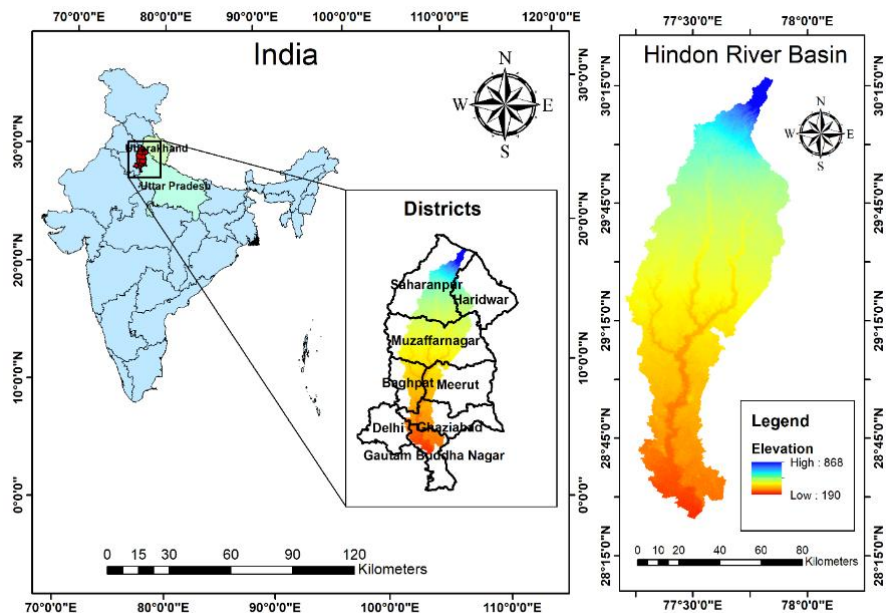


Figure 1. Location map with Digital Elevation Model (DEM) of the Hindon River Basin, illustrating elevation (from mean sea level) variation and boundary.

2.2 Data used

This study includes two components: (1) Assessing the basin morphometry under the areal, linear and relief aspects, (2) Comparison of present land use land cover (2024) with past 7 years LULC (2017) and (3) Long term Land use land cover detection (1990 and 2022) by Normalized Difference Vegetation Index (NDVI). SRTM DEM (~30m) data were used to generate key morphometric maps including Digital Elevation, stream order, slope and aspect.

For LULC analysis, Sentinel-2 (~10 m) datasets were used. Supervised classification was applied to detect land cover changes, and NDVI was calculated using LANDSAT 4-5 and LANDSAT 8-9 datasets for 1990 and 2022 using red and near-infrared bands. All spatial analysis and map preparation were conducted in ArcGIS 10.3. The complete workflow is shown in Figure 2.

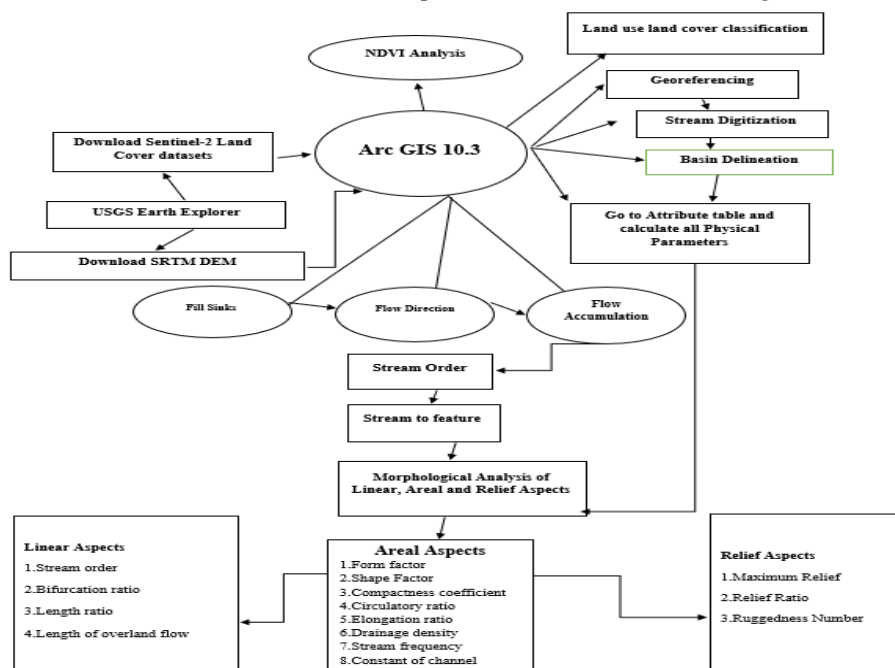


Figure 2. Methodology adopted for study of the Hindon River Basin.

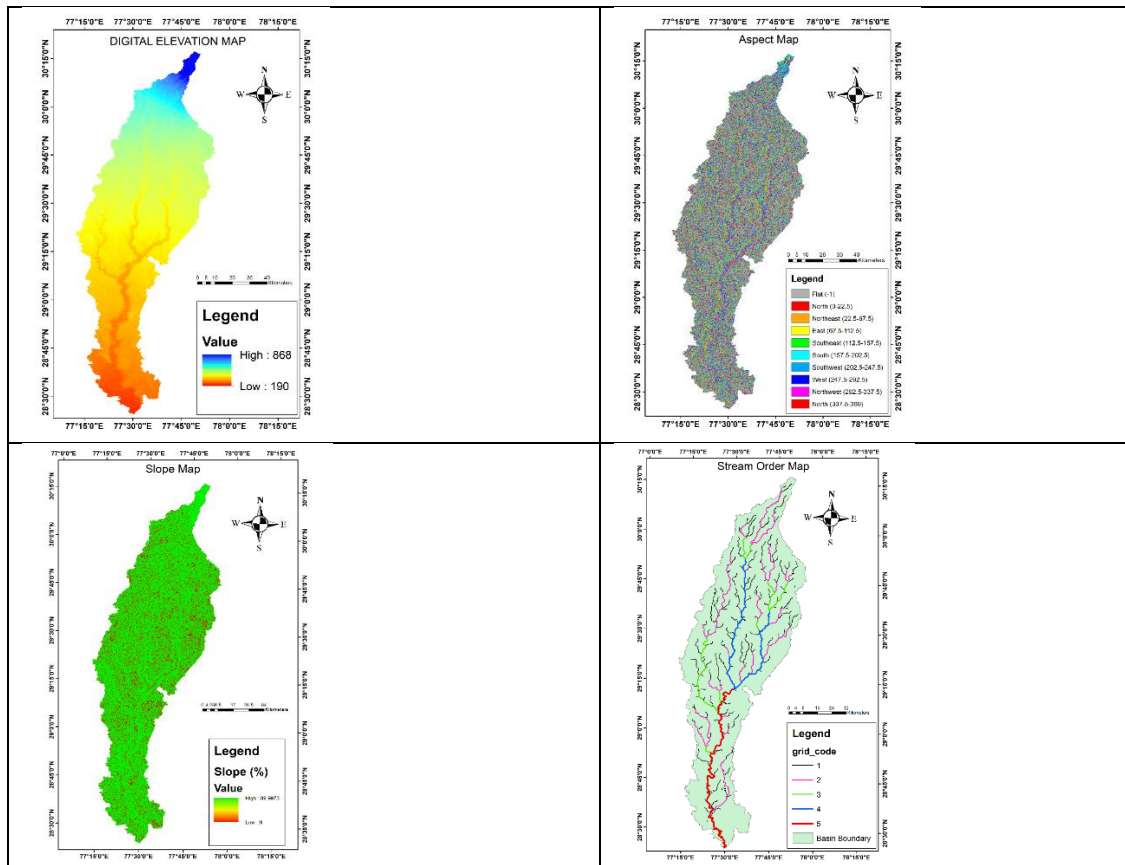


Figure 3. Hindon Basin Digital Elevation, Aspect, Slope and Stream Order Maps.

3. RESULTS & DISCUSSION

3.1 Linear Aspects

Stream ordering, a foundational step in morphometric analysis, categorizes drainage hierarchies and provides insight into the structural complexity of a basin. Using Strahler's method (1952), based on the original concept by Horton (1945), the Hindon River basin was found to have a maximum stream order of 5th, derived from Shuttle Radar Topography Mission (SRTM) digital elevation (~30 m) data. The stream number (N_u) analysis revealed a total of 758 stream segments, with a steep decline in frequency across increasing orders 658, 1st order, 84, 2nd order, 13, 3rd order and 2, 4th order stream indicating a predominantly dendritic drainage pattern typical of uniform lithological and topographic conditions (Rai et al., 2019). The total stream length (L_u) across the basin were computed 2047 km in which 1124 km in 1st order, 471 km in 2nd order, 156 km in 3rd order, 155 km in 4th order and total 141 km in 5th order were found. This general increase in stream length with order, although with minor irregularities, reflects typical natural drainage development influenced by terrain and surface runoff dynamics. The observed stream characteristics collectively highlight the structural maturity and hydrological behavior of the Hindon River system.

Table 1. Linear aspects Morphometry results of Hindon River Basin

Stream Order	Stream number (N_u)	Total no. of Streams	Stream length (L_u)	Total Stream length (km)	Stream Length ratio (R_l)	Bifurcation ratio (R_b)	Mean Bifurcation ratio (R_{bm})	Length of overland flow
I	658	-	1124	-	-	7.83333333	-	-
II	84	-	471	-	0.909677419	6.46153846	-	-
III	13	758	156	2047	0.993589744	6.5	5.698717949	1.553004397

IV	2	-	155	-	0.3312101 91	2	-	-
V	1	-	141	-	0.4190391 46	-	-	-

3.2 Areal Aspects

The basin's morphology reveals its strongly elongated nature and low runoff potential. The form factor (R_f), calculated as the ratio of basin area to the square of its length, is 0.065 well below the threshold of 0.78 indicating a distinctly elongated shape (Horton, 1932; Farhan et al., 2016). This is further supported by the shape factor (S_f) of 14, suggesting prolonged time to peak discharge during rainfall events (Altaf et al., 2013). The compactness coefficient (C_c) value of 3.66 confirms the basin's irregular outline, deviating significantly from a circular form and reflecting terrain influence on drainage compactness (Gravelius, 1914; Rai et al., 2017). Additionally, the elongation ratio (R_l) of 0.301 classifies the basin as highly elongated, indicative of low relief and extended flow paths (Schumm, 1965; Pareta & Pareta, 2011). The circularity ratio (R_c), measured at 0.074, further emphasizes an early-stage geomorphic development and limited drainage efficiency due to elongated topography and less mature terrain (Miller, 1953; Patel et al.,

S.No.	Areal Aspects	Value
1.	Total area of the basin (sq. km)	6950
2.	Form factor	0.07
3.	Shape factor	14.00
4.	Compactness ratio	7.32
5.	Drainage density	0.29
6.	Circulatory ratio	0.07
7.	Elongation ratio	0.30
8.	Constant of channel maintenance	3.39
9.	Stream Frequency	0.10

2013). Hydrologically, the drainage density (D_d) of 0.29 km/km² reflects a coarse drainage texture, often linked with low surface runoff and permeable geological formations. Correspondingly, the stream frequency (F_s) is 0.119 streams/km², indicating moderate drainage development and a controlled hydrologic response (Waikar & Nilawar, 2014). The constant of channel maintenance (C), calculated as 3.395 km²/km, suggests each kilometer of stream is supported by a relatively large land area, pointing toward high infiltration capacity and low runoff potential (Strahler, 1957). Finally, the length of overland flow (L_g) is approximately 1.697 km, consistent with regions having gentle slopes and reduced surface runoff, commonly associated with permeable soil profiles (Horton, 1945).

3.3 Relief Aspects

The relief and terrain parameters provide critical insights into the watershed's topographic variation and hydrologic behavior. The relief ratio (R_r) of the Hindon River basin is calculated as 3.23, derived from a total relief of 684 m and the longest flow path of the main stream. This relatively high value indicates the presence of moderately steep slopes, particularly in the upper basin region near the Shivalik Hills, contributing to higher energy gradients and potentially increased surface runoff (Schumm, 1956; Prabhakar et al., 2019). Complementing this, the ruggedness number (R_n), a product of relief and drainage density was found to be 0.201. Since values close to zero denote smoother terrain and those approaching one represent highly rugged landscapes, this value suggests that the Hindon basin is predominantly characterized by gentle topography with limited surface irregularities (Altaf et al., 2013; Umrikar, 2016; Nath et al., 2022). The relatively low ruggedness implies that most of the basin is flat to gently sloping, except in the upstream hilly zones near the origin.

Table 2. Areal Aspects of Hindon River Basin

S.No.	Relief Aspects	Value
1	Maximum relief	678
2	Relief ratio	3.22
3	Ruggedness number	0.20

Table 3. Relief Aspects of Hindon River Basin

3.4 Land Use Land Cover (LULC) and NDVI Analysis of the Basin

Land use land cover (LULC) analysis of the Hindon River basin was carried out using supervised classification on LANDSAT imagery. Results indicate that agricultural and vegetative land continues to dominate the basin, covering 83.53% in 2017 and 82.14% in 2024. However, a progressive urban expansion is evident, with built-up areas increasing from 15.90% in 2017 to 17.50% in 2024 (see Table 4. and Figure 4.). A significant decline in barren land was also noted, decreasing from 0.17% to just 0.04% over the same period, implying continued land conversion for urban and agricultural uses. Water bodies occupy a minor portion, shrinking slightly from 0.40% to 0.31%. These trends suggest accelerated urban development and declining open or unused land, likely influenced by infrastructure growth and population pressure. The LULC shift aligns with earlier trends observed between 2017 and 2024, reaffirming the basin's ongoing transformation driven by urbanization and land reclamation.

Negative NDVI values represent water/cloud cover, values near 0 to 0.1 indicate barren or built-up areas, and values from 0.1 to 0.5 suggest sparse vegetation (Jeevalakshmi et al., 2016). The basin lacks dense forest and large reservoirs. The spatial-temporal analysis clearly shows a shift from barren to agricultural and built-up land, highlighting ongoing anthropogenic pressure and changing land dynamics.

Table 4. Land use Land Cover classification of the basin in the year of 1990 and 2022

Year	Class	Area	Percentage (%)
2017	Agriculture land and vegetation	5796.98	83.53
	Build up	1103.46	15.90
	Barren land	11.798	0.17
	Water	27.76	0.40
2024	Agriculture land and vegetation	5700.51	82.14
	Build up	1214.5	17.50
	Barren land	2.776	0.04
	Water	21.51	0.31
Total		6940	100

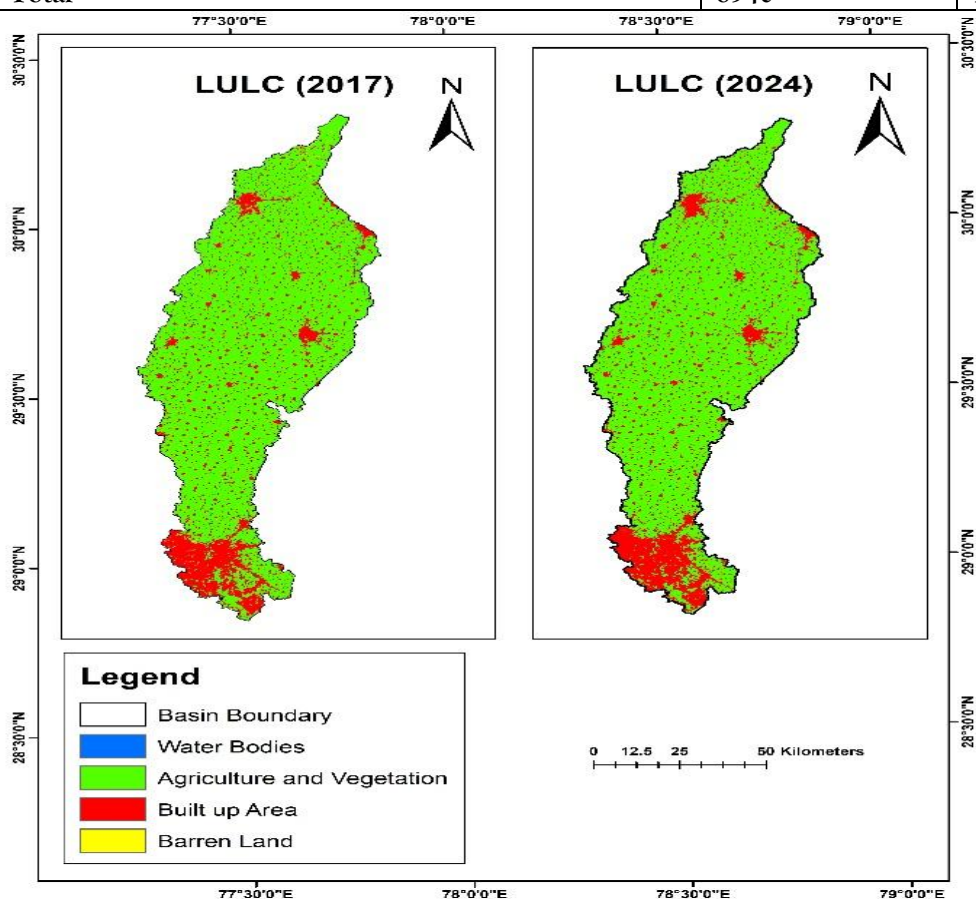


Figure 4. Temporal Changes detected in LULC

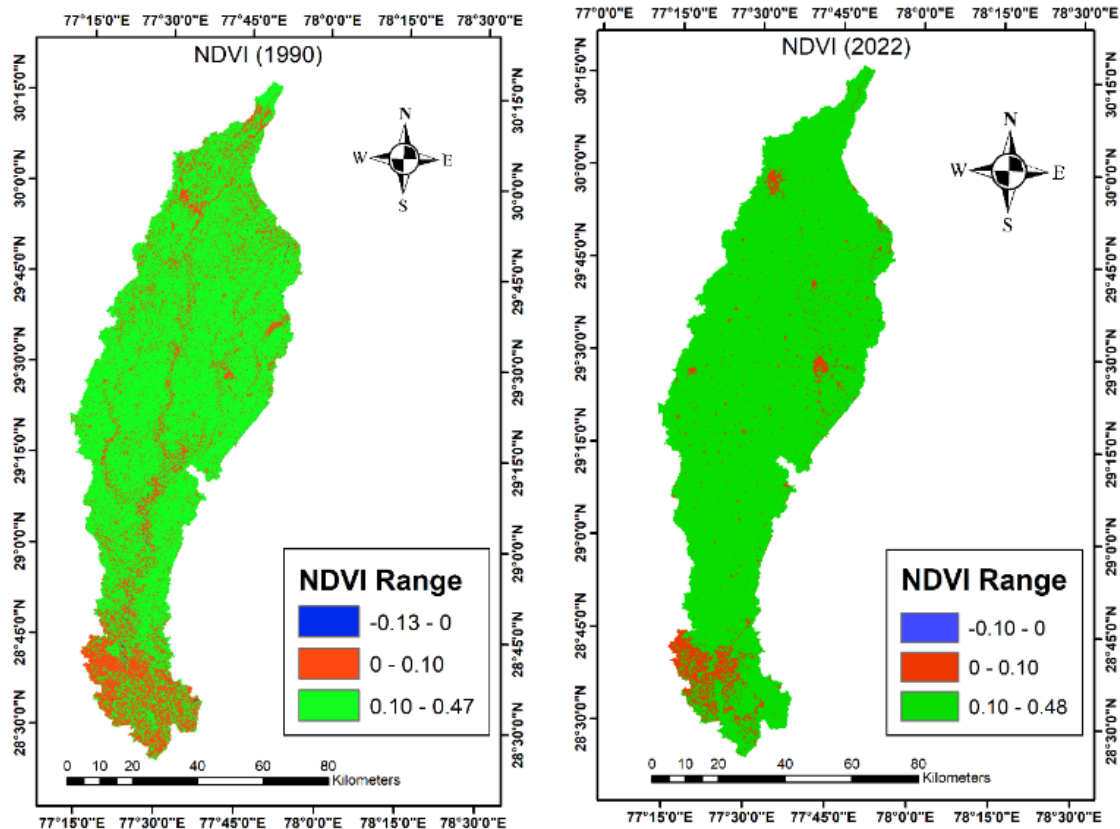


Figure 5. Temporal changes detected in Normalized Difference Vegetation Index (NDVI).

4. CONCLUSION

The River Hindon basin covers 6950 km² area, characterized by a highly elongated shape (form factor: 0.07; elongation ratio: 0.30) and a low circulatory ratio (0.07), indicating slow runoff concentration and extended flow paths. Basin's drainage density and stream frequency were obtained 0.29 km/km² and 0.10 per km² respectively reflects low drainage texture, likely due to gentle terrain and permeable surfaces. A mean bifurcation ratio of 5.70 suggests moderate structural influence on stream branching. The basin relief (678 m) and relief ratio (3.22) point to moderately steep slopes, particularly in the upper Shivalik zone. The ruggedness number (0.20) confirms that most of the basin has smooth topography, with only localized steep features. Overall, the morphometric indicators classify the Hindon River basin as a geomorphologically young, structurally controlled catchment with low to moderate runoff potential, moderate erosion risk and supporting the need for focused watershed planning in urbanizing and steep terrain zones.

This study also demonstrates that a comprehensive morphometric and LULC analysis plays a crucial role for effective watershed planning and management in the Hindon River basin. The morphometric evaluation, derived from 1 arc second digital elevation (SRTM) data, revealed that the basin covers approximately 6950 km² and is characterized by basin's elongated shape with low drainage density and a moderate relief. The network comprises 758 streams, with a maximum 5th order stream with stream length 2047 km, indicative of the basin's moderately dissected structure.

The present study highlights the dynamic transformation of land use and land cover in the Hindon River basin, with a significant increase in built-up areas and a concurrent decline in agricultural and barren lands over recent decades. The Sentinel-2. Land Cover data (~ 10 m) from 2017 and 2024 confirms ongoing urban expansion, particularly in the southern and central parts of the basin. Although agricultural land remains the dominant class, its gradual reduction reflects the pressure of urban development. The notable decrease in barren land and marginal reduction in water bodies further emphasize the intensity of land conversion. These spatial and temporal changes underscore the urgent need for sustainable land use planning and effective watershed management to mitigate future ecological and hydrological impacts in the basin.

NDVI analysis further confirms these trends by indicating a shift in the spectral signature of land surfaces; the increasing NDVI range suggests that areas previously classified as barren are transitioning to

agricultural and built-up land. However, the basin still lacks dense forest cover and large reservoirs, pointing to the need for targeted environmental management.

Overall, the integrated assessment unveils the utility of basin's morphology and remote sensing to quantifying the landscape changes. The findings provide valuable insights for water resource planning, management of climate extremes such as floods and development of urban infrastructure emphasizing the critical need for sustainable management strategies in the rapidly evolving Hindon River basin.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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