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Hydrological Behaviour Studies through Morphometric Characteristics of Panchane Watershed in Harohar Sub-basin, India

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ABSTRACT

A comprehensive morphometric analysis of the Panchane watershed, located within the Harohar sub-basin of the Middle Gangetic Plains in India were carried out using RS & GIS techniques to investigate the hydrological dynamics and terrain characteristics of the watershed to provide valuable insights for watershed management and conservation efforts. The results indicated that overall, the watershed is of 4th order with dendritic to sub-dendritic drainage pattern, showed an extensive network of streams with high stream density, facilitating efficient water flow and distribution. However geomorphological, lithological, land use/land cover, hydrologic soil group and slope characteristics of that watershed provided the favourable conditions for construction of water harvesting structures. Additionally, the elongated shape of the watershed (form factor: 0.27; shape factor: 3.67; circulatory: 0.16 and elongation ratio: 0.59) suggested potential low relief characteristics, influencing water flow patterns. However, the compact nature of the watershed, as highlighted by the compactness coefficient (2.5), may impact its vulnerability to environmental stressors. Despite efficient drainage and prompt response to rainfall events, rugged terrain (texture ratio: 2.54 and drainage texture: 4.23) posed challenges to water flow and harvesting techniques. This study contributed to the understanding of hydrological dynamics in the Middle Gangetic Plains and underscores the importance of informed decision-making in watershed management and conservation.

Keywords: Hydrological Dynamics, Morphometric Traits, Panchane Watershed, Water Harvesting

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INTRODUCTION

Geographic information system (GIS) and remote sensing (RS) techniques have been effectively employed to analyse the morphometric characteristics of drainage basins, encompassing linear dimensions, geometric features, basin texture (derived from aerial data), and relief aspects. Furthermore, it entails a mathematical and geometrical evaluation of land surface attributes, such as configuration, shape, and dimensions (Jeet et al., 2023; Chowdhury, 2024). Through morphometry, significant insights into geological, morphological, geomorphological and hydrological processes can be gleaned, offering a deeper understanding of the intricate interplay among these processes (Kumar et al., 2018; Sarkar et al., 2020; Kumari et al., 2023).

The assessment is not confined to mere calculation of morphometric parameters using established formulas; rather, it employs advanced geo-computing tools for spatial analysis, cartography, mathematical operations, geoprocessing, and geometric analysis. These methodologies are indispensable for mapping the spatial distribution of selected parameters, especially those derived from aerial data, thereby facilitating a comprehensive understanding of drainage basin characteristics and processes.

A thorough comprehension of soil physical characteristics, underlying geological and structural influences, landform evolution, and erosional processes can be achieved through the analysis of stream networks and their patterns (Bharath et al., 2021; Erosemiah and Viji, 2023). Morphometric characteristics are not only linked to a watershed's hydrological behaviour and its capacity to produce runoff but also play a crucial role in understanding the evolution of stream networks, which is vital for effective water management. Geospatial analysis enables the measurement of mathematical and geometrical values of extracted parameters (Rajasekhar et al., 2020). Fundamental parameters such as basin area, basin length, stream network structure and order, stream lengths, and elevation variations within drainage basins are routinely measured through geospatial and hydrological analysis within a GIS environment (Nikolova et al., 2021; Patel et al., 2023; Jeet et al., 2024).

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Globally, there's extensive research on determining automated watershed features using remote sensing (RS) and geographic information system (GIS) technologies. These approaches are cost-effective, accurate, and time-saving, making them valuable for prioritizing watersheds and implementing water conservation strategies. For instance, Sharma et al. (2010) utilized RS and GIS tools for morphometric analysis and prioritization of eight sub-watersheds of the Uttala river watershed, a tributary of the Son River in the middle Gangetic plains (MGP). Similarly, Kumar et al. (2018) delved into examining the morphometric characteristics and neotectonics of the Kalyani basin located in the Ganga plain. Meanwhile, Kumari et al. (2023) conducted a study focusing on the morphometric analysis and prioritization of watersheds for water management, employing the Weighted Sum Approach and geospatial tools within the Harohar Sub-basin in India. Despite the significant importance of understanding the morphometric characteristics of drainage basins, there has been limited research conducted in the Middle Gangetic plains. This highlights a potential area for further exploration and study within these regions. In the MGP, agriculture is predominant, but it faces challenges due to its reliance on continuous monsoonal rainfall, leading to uncertainties in flood and drought outcomes. Consequently, there's a pressing need for water resource conservation and expansion in these regions to address these challenges effectively. Keeping in view, the current study aims to investigate the hydrological dynamics through morphometric analysis of Panchane watershed, part of Harohar sub-basin in THE MGP of India, utilizing remote sensing and GIS technology. The outcomes of this study are anticipated to offer valuable insights to policymakers for integrated river basin management, natural resource management and planning, sustainable agricultural planning, as well as groundwater and surface water management and planning, among other areas. Additionally, the findings are expected to provide a foundation for future research endeavors focusing on detailed morpho hydrological, investigations within the study area.

MATERIAL AND METHODS

Description of study area

The present study was conducted in Panchane Watershed, part of the Harohar basin in the MGP, situated between latitude 25°19'44.15'' to 25°0'1.18'' N and longitude 85º 27'42.47'' to 85º 41'21.68'' E, covering a total geographical area of 263.34 km² (Fig. 1). It is positioned at an elevation of 67 meters above mean sea level (msl) and featured rugged topography.

The climate in the region exhibited variation, with summer temperatures ranging from 17 to 44 °C and winter temperatures between 4 to 27 °C. The annual average temperature is recorded at 26 °C, while the average annual rainfall is reported to be 1002.2 mm.

MATERIALS AND METHODS

Manually extracting the drainage network and assigning stream orders using Survey of India (SOI) topographic maps and georeferenced satellite data can be labour-intensive and time-consuming. To address this challenge, automatic extraction approaches for analysing morphometric parameters of a basin were employed. In this study, the Panchane Watershed was delineated, and their corresponding stream networks were generated using automated extraction methods, leveraging Shuttle Radar Topographic Mission (SRTM) data retrieved from the USGS Earth Explorer website (https://earthexplorer.usgs.gov), which was cross-validated with Survey of India (1:50,000) toposheets.

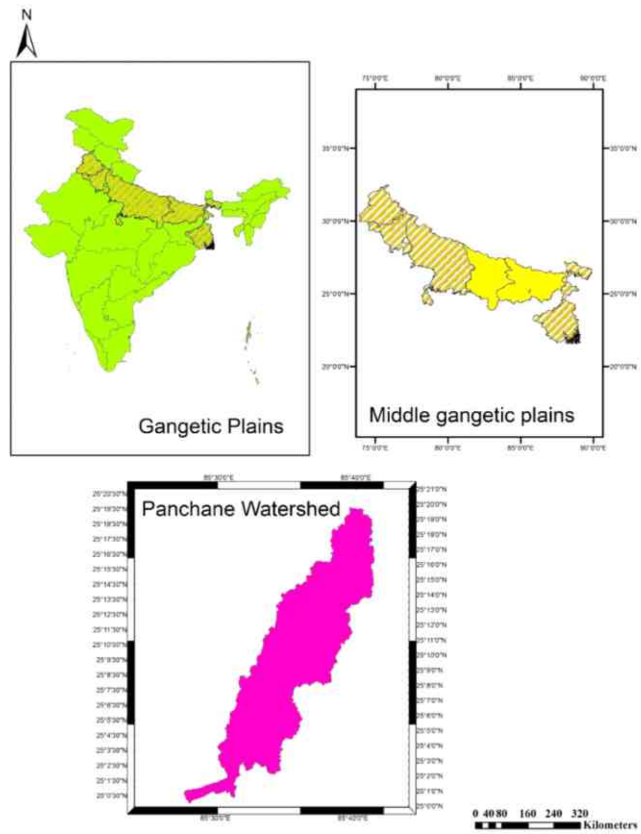

Fig 1: Location of study area

For hydrological investigations, factors such as geomorphological, lithological, land use land cover (LULC) patterns, hydrologic soil groups, slope, and morphometric characteristics of the study area are of paramount importance. Accordingly, a slope map was generated using spatial analyst tools. The drainage map was created using spatial analyst tools (Hydrology) as an Add-on to ArcGIS software. Subsequently, morphometric characteristics such as area, perimeter, basin length, total stream length, and stream order were calculated using GIS software. These parameters were then utilized to compute additional areal and relief parameters with the aid of established mathematical equations (Table 1).

Table 1: Morphological parameters of study area

Morphological parameters	Formula
Area (Km2) [A]	-
Perimeter (Km)	-
Stream Length (Km) [L]	-
Stream order	Hierarchical rank
Basin Length (Km) [Lb]	1.312
Basin relief (Hb)	Hb = Zmax - Zmin
Drainage Density (DD)	L/A
Drainage Texture	Stream number/ Perimeter
Drainage Intensity	Stream frequency/ Drainage density
Length of overland flow (Km)	1/(2DD)
Form factor	A/Lb2
Shape factor	1/ form factor
Circulatory Ratio	4 A/P2
Elongation ratio	(2/Lb) (A/)0.5
Compactness coefficient	0.2821P/A0.5
Stream frequency	Total stream number/ area
Bifurcation ratio (Rb)	Rb = Nu/Nu+ 1 Where, Nu = Total no. of stream segments of order 'u' Nu+l= Number of segments of the next higher order
Texture ratio	N1/P [number of streams of first order/perimeter]
Relief Ratio (Rh)	Rh = Hb/Lb Where, Rh=Relief Ratio H=Total relief (Relative relief) of the basin in Kilometer Lb= Basin length

RESULTS AND DISCUSSION

Geomorphological and Lithological units

The study area comprises several major geomorphological units, including the alluvial plain, flood plain, pediment-pediplain complex, and moderately dissected hills and valleys (Fig. 2a). The dominant feature in the study area is the alluvial plain, formed by fluvial processes primarily from rivers. Alongside the rivers, floodplains composed of sand, gravel, silt, and clay can be found. The presence of alluvial plains and floodplains indicated areas where surface water runoff is substantial, contributing to both surface water flow and groundwater recharge, especially during periods of high precipitation. The Pediment-Pedi plain complex is characterized by granitic formations, with Pedi plains consisting of a thin layer of alluvium. These features are typically located in hilly terrain. The pediment-pediplain complex, characterized by granitic formations and alluvial veneers, exhibits varied hydrological behaviours. While granitic formations may limit infiltration and groundwater recharge, the alluvial veneers can enhance groundwater storage and recharge. In addition, the dissected structural hills and valleys are categorized based on the density of joints and drainage patterns into highly dissected, moderately dissected, and low-dissected areas. The results of the study indicated that moderately dissected hills and valleys, which exhibit significant drainage line activity, are primarily concentrated in the lower part of the study area. Moderately dissected hills and valleys, with well-defined drainage patterns, served as important conduits for water flow, directing runoff towards rivers and streams.

However, there were four distinct lithologic units, including hard compact clay with caliche nodules, quartzite, sand, silt, and clay, as well as slate and phyllite (Fig. 2b). Hard compact clay with caliche nodules predominated across much of the study area, while sand, silt, and clay were prevalent in the adjacent river basin area. In the lower hilly regions, quartzite and slate, phyllite dominated the lithological composition. Different lithological units impacted groundwater characteristics, with hard compact clay hindering flow, while formations like quartzite and slate may acted as aquifers or aquitards, influencing groundwater movement and storage.

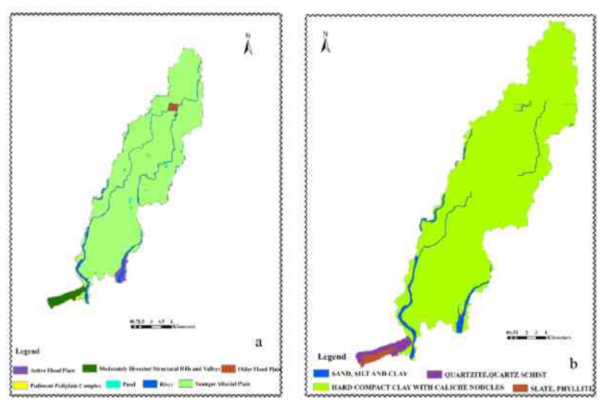

Table 2: Thematic map of (a) Geomorphological units, (b) Lithological units

Land use land cover, hydrological soil group and slope

The land use land cover (LULC) map was generated through on-screen digitization in google earth and categorized into five distinct classes: agriculture, waste/barren land, evergreen forest, settlement, and water body (Fig. 3a). Hydrological soil group (HSG) data specific to Nalanda was acquired from the global hydrologic soil groups (HYSOGs 250m) dataset for curve number (CN) based runoff modelling, and subsequently extracted for the Panchane watershed (Fig. 3b). Results revealed that the entire watershed comes under HSG D, signifying more potential for high runoff generation and suitability for water harvesting structures.

Furthermore, a slope map was derived using the Arc Hydro tool (Fig. 3c) and classified into seven distinct slope categories: very gentle (0–1%), gentle (1-3%), moderate (3–5%), moderately steep (5–10%), strong (10-15%), steep (15-35%), and very steep (>35%). The majority of the watershed area is characterized by gentle to moderate slopes, which are considered conducive for the construction of water harvesting structures. Conversely, moderately steep to very steep slopes are primarily concentrated in the lower regions of the watershed, specifically in hilly terrain. This spatial analysis provides valuable insights into the distribution of slope characteristics within the watershed, informing decisions regarding water management practices and infrastructure development. However, the morphological traits were shown in table 2.

Table 2: Morphological traits of Panchane watershed

Morphological parameters	Values
Area (Km2) [A]	263.34
Perimeter (Km)	143.96
Stream Length (Km) [L]	444.74
Stream Number	719.00
Basin Length (Km) [Lb]	31.10
Drainage Density (DD) (Km/Km2)	1.69
Length of overland flow (Km)	0.30
Form factor	0.27
Shape factor	3.67
Circulatory Ratio	0.16
Elongation ratio	0.59
Compactness coefficient	2.50
Stream frequency (Km-2)	2.50
Drainage intensity (Km-1)	6.19
Texture ratio (Km-1)	2.54
Drainage texture (Km-1)	4.23
Relief ratio (m /Km)	0.008

Morphological parameters

The Panchane watershed, covering an area of 263.34 km² with a perimeter of 143.96 km classified as a 4th order dendritic watershed underwent morphometric analysis to assess its drainage characteristics. Various morphometric metrics were calculated and summarized in Table 2.

The basin length of 31.10 km provides an indication of the overall length of the watershed. This metric, coupled with the stream length of 444.74 km and the number of streams (719), reflects the extensive network of watercourses within the watershed. The high stream number suggests a dense drainage network, facilitating efficient water flow and distribution across the area. Moreover, the computed form factor, approximately 0.27, implies an elongated shape of the watershed, suggesting a propensity for generating a prolonged, low peak flow. Similarly, the circulatory ratio, recorded at 0.16, reinforces this elongated shape, indicative of potential low relief characteristics.

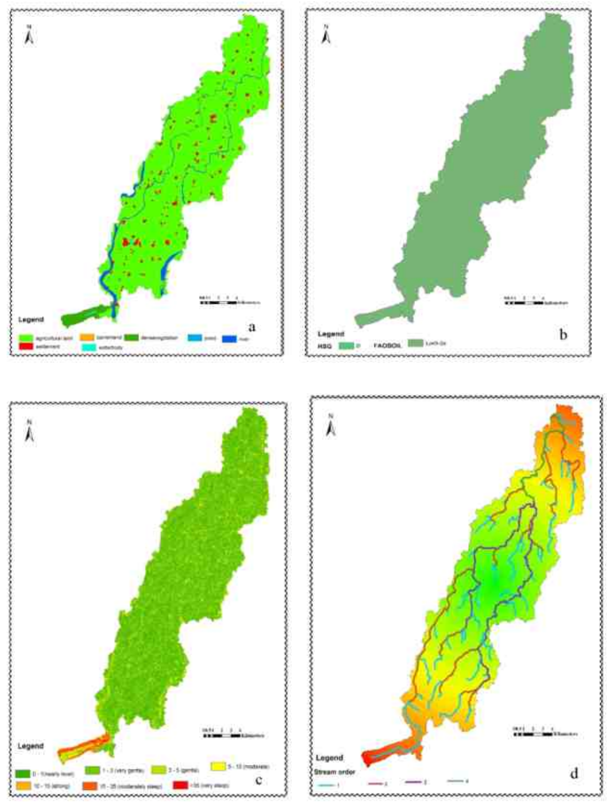

Fig. 3: Distribution of (a) Land use/land cover, (b) soil, (c) slope, (d) stream order

The interpretation of elongation ratio values aligns with previous studies by Strahler (1964), where ratios nearing one signify areas of very low relief, while ratios ranging from 0.6 to 0.8 denote moderate to steep terrain slopes. The observed elongation ratio of 0.59 in Panchane watershed signifies terrain ranging from moderated to steep.

Furthermore, the calculated compactness coefficient, with a value exceeding 1 (2.50), indicates a more compact watershed, according to Malik et al. (2019) and Kumari et al. 2023. This suggests potential implications for vulnerability, with higher values indicating increased compactness and, consequently, a greater need for attention from water resource management authorities.

The moderate drainage density recorded at 1.69 suggests efficient drainage and prompt response to rainfall events, possibly attributed to sufficient vegetative cover and moderate permeability within the watershed. Additionally, the overland flow length of 0.30 indicates moderate relief in the area. Furthermore, a stream frequency of 2.50 highlighted a dense network of streams, while a drainage intensity of 6.19 signified a well-established drainage system. However, despite the low Relief Ratio of 0.008, which suggests flat or gently sloping terrains with limited erosive forces, the texture ratio of 2.54 and drainage texture of 4.23 indicate a rugged terrain, potentially affecting water flow and the efficacy of water harvesting methods.

Overall, these findings offer valuable insights into the drainage patterns and terrain characteristics of the Panchane watershed.

CONCLUSION

Present study was conducted on the Panchane watershed within the Harohar sub-basin of the MGP yielded significant insights into its hydrological dynamics and terrain characteristics. The extensive network of streams, indicated by the high stream number and density, along with the well-established drainage system reflected in the drainage intensity, underscored the watershed's capacity for efficient water flow and distribution.

Moreover, the elongated shape of the watershed, as evidenced by the form factor (0.27) and circulatory ratio (0.16), suggested potential low relief characteristics, which can influence water flow patterns and drainage behaviour. The calculated compactness coefficient (2.5) further emphasized the watershed's compact nature, potentially impacting its vulnerability to environmental stressors and the need for effective management strategies.

Despite the efficient drainage and prompt response to rainfall events facilitated by the moderate drainage density (1.69) and relief, the rugged terrain indicated by the texture ratio (2.54) and drainage texture (4.23) may pose challenges to water flow and the implementation of water harvesting techniques.

Overall, the findings from this study provide valuable insights into their hydrological dynamics and terrain attributes, offering a foundation for informed decision-making in watershed management, conservation, and sustainable water resource utilization. Additionally, this research contributes to the body of knowledge concerning morphometric analysis in the MGP and underscores the importance of further research in understanding and addressing the complex hydrological dynamics of similar watersheds in the region.

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DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

CONFLICT OF 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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