Original Research Article

Morphometric Analysis of WaghoraMicro watershedof Jam river basin Using ALOS-PALSAR DEM

Abstract:

The integration of remote sensing and geographic information systems (GIS) has proven highly beneficial for analyzing morphometric parameters, particularly in prioritizing watershed management for soil and water conservation, as well as sustainable natural resources management at the micro level. Morphometric analysis delves into the linear, areal, and relief characteristics of a drainage basin. In this investigation, geospatial techniques were employed to assess the hydrological features of the Waghora Micro watershed within the Jam River basin, covering an area of 13.03 km². Utilizing the ALOS-PALSAR RTC DEM with a resolution of 12.5 m, the basin and drainage network were delineated using ArcGIS software and Spatial Analysis Tools. The analysis revealed a dendritic drainage pattern within the Waghora micro-watershed, with drainage streams delineated up to the fourth order. The bifurcation ratio (Rb) ranged from 3 to 4.66, averaging 3.76, indicating undistorted geologic structure and a drainage system characterized by moderate peaks and lower order streams. Additional morphometric parameters were assessed, with form factor (Rf), circulatory ratio (Rc), and elongation ratio (Re) values of 0.32, 0.68, and 0.62 respectively, suggesting a moderately elongated micro-watershed with moderate influence on time parameters. The estimated relief, relief ratio (Rr), relative relief (RR), and ruggedness number were determined to be 75 m, 1.2, 0.97, respectively, indicating a moderate erosion potential. Overall, the study underscores the necessity for implementing soil and water conservation measures within the watershed. These findings hold significant implications for various stakeholders, including managers and decision-makers involved in watershed management and sustainable natural resources management initiatives.

Key words: morphometric analysis, ArcGIS, remote sensing, DEM, watershed management, AlOS-DEM.

1. Introduction

The imperative of promptly addressing agricultural land degradation is underscored, coupled with advocacy for the implementation of production systems aimed at conserving soil quality to guarantee the long-term sustainability of agriculture [1]. In order to effectively address and mitigate the impacts of land degradation, watershed planning is essential. Watershed planning involves the careful management and organization of land use within a specific watershed area to ensure that it continues to provide essential goods and services without compromising soil productivity and water resources [2]. Effective land and water management strategies tailored to each watershed are essential[3].

Watershed morphometric analysis is employed to characterize the hydrological response behavior [4],soil water conservation measure [5]Diverse morphometric analyses offer insights into the physical attributes of watersheds, facilitating applications in land use planning, soil conservation, terrain elevation, and soil erosion management[6] and addressing the immediate need to assess the magnitude of issues related to waterlogging, alkalinity, and salinity is imperative, necessitating the establishment of assessment norms and the identification of appropriate technologies for prevention, reclamation, and management[7].

Integrating morphometric parameters with thematic maps, including land use/cover, soil, and drainage density information, aids in the decision-making process for water resources management in areas with poor contouring, contour bunds can be constructed to enhance groundwater recharge and facilitate paddy cultivation [8]. Morphometric analysis outcomes offer a foundation for policymakers and planners to formulate erosion control strategies [9][10]. These measures also furnish valuable insights for decision-makers and policymakers to devise pre-assessment strategies for peak flooding events and sustainable land-use policies [11].Remote sensing and GIS-based approaches are superior to conventional methods for evaluating drainage morphometry, landforms, and land resources, as well as understanding their interrelationships for river basin planning and management [8][12][13][14][15].

The Waghora micro watershed Jam River basin showcases a diverse array of physiographic units [40,41]. However, the management of this area suffers from inconsistent land use practices and inadequate oversight. Understanding the linear, aerial, and relief features of the watershed is crucial for effectively characterizing it and directing developmental efforts towards optimizing its natural resources. With this goal in mind, an endeavor was undertaken to evaluate the watershed's morphometric parameters utilizing Remote Sensing (RS) and Geographic Information System (GIS) tools.

2. Methodology

2.1 Study area

The Waghora microwatershed is situated in the southern region of Sausar tehsil within the Chhindwara district of Madhya Pradesh, India. It constitutes a part of the Jam river basin and is situated between 21º 33' 36" to 21 º 36' N latitude and 78 º 45' 36" to 79 º 48' 36" E longitude. The watershed covers an area of about 1303 ha, this watershed is identified and labeled as 4E8E5a3 according to the Soil and Land Use Survey of India (2017). Within this area, elevations vary from 328 meters to 479 meters. The region experiences an annual rainfall of 1211.7 mm, characterized by a subtropical, dry, and subhumid climate, featuring distinct seasons including summer (March to May), monsoon (June to September), post-monsoon (October to November), and winter (December to February). The mean annual temperature stands at 25.4 °C, with summer reaching a mean maximum of 41.70 °C and winter recording a mean minimum of 11.70 °C. The study area map is shown below in Figure 1.

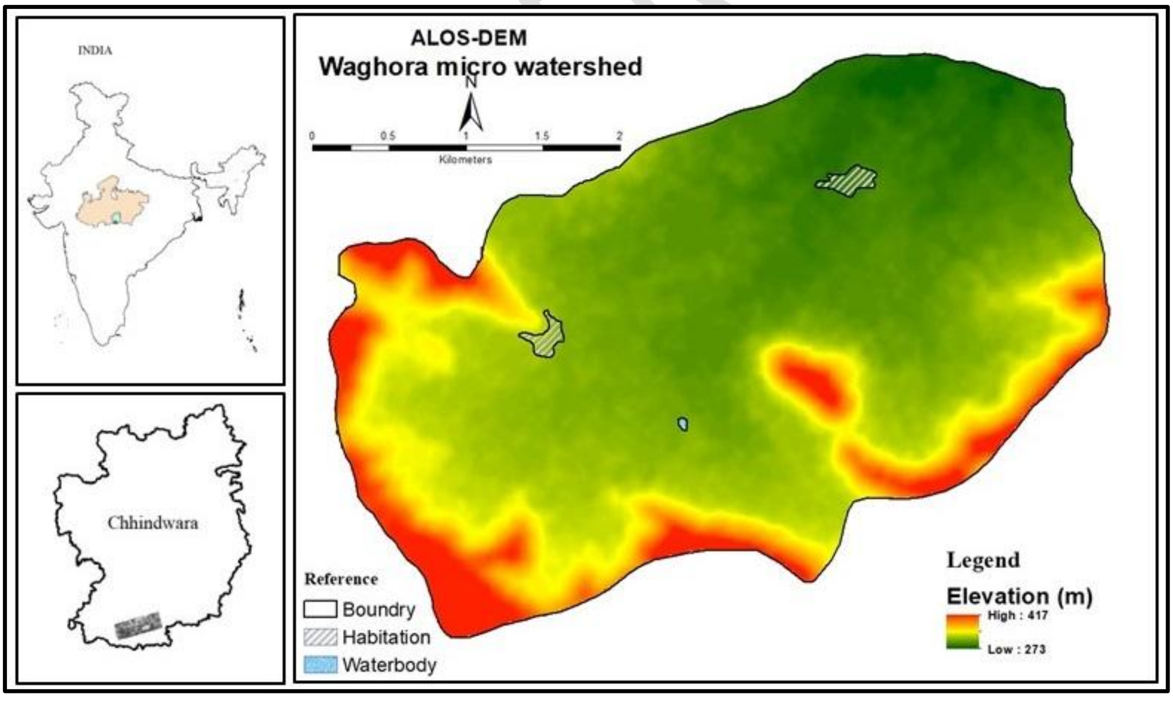

Fig 1 Location map of Waghora micro-watershed of Jam river basin

2.2 Materials and methods

The study utilizes the High-Resolution ALOS-PALSAR RTC DEM obtained from the Alaska Satellite Facility, featuring a spatial resolution of 12.5 meters, for the purpose of identifying and extracting the drainage network to conduct morphometric analysis. The use of the PALSAR active microwave sensor operating at L-band frequency facilitates the generation of high-resolution DEM products immune to weather conditions and suitable for day and night observations. Additionally, the ALOS-PALSAR RTC DEM undergoes processing, including conversion from orthometric height to ellipsoid height, to ensure consistency with other DEM elevations. This dataset's fine spatial resolution enables the detection of even shallow and narrow drainage networks that may be missed by coarser resolution products. The extraction of the watershed and stream networks from the ALOS-PALSAR DEM is automated using the Model Builder tool in ArcGIS 10. This toolset employs a graphical interface where various geoprocessing tools and their respective parameters are interconnected to process input data. Preprocessing steps involve utilizing a fill tool to rectify sinkhole errors in the input DEM, followed by flow direction analysis for each pixel using a deterministic eight-node approach [16], which analyzes the eight directions from a pixel where water flows outward. This flow direction raster output is also employed to compute flow accumulation, which in turn aids in generating streams by setting a critical threshold as per recommendations from previous studies for morphometric analysis [17][18][19][20]. Subsequently, generated streams are used for snapping pour points, facilitated by a point shapefile, which serves as input for extracting the watershed. Additionally, the input DEM is utilized to extract aspect, contour, and slope information for the study area.

2.3 Morphometric Indices

The morphometric indices include calculation of majorly three aspects, namely, linear, areal, and relief which consists of various parameters, respectively. Linear aspects include morphometric parameters such as stream order (Nu), stream length (L), bifurcation ratio (Rb), stream length ratio (Rl), mean stream length (Lμ), Rho coefficient (ρ), whereas areal aspects include stream frequency (Fs), drainage density (Dd), drainage texture (Rt), circularity ratio (Rc), form factor (Ff), and elongation ratio (Re), and the relief aspects includes relief ratio (Rh), relative relief (Rhp), ruggedness number (Rn), and length of overland flow (Lg). The respective mathematical formulas used to assess the morphometric indices are given in Table 1.

Table 1 formula for calculating morphometric parameters

Sr No.	Morphometric Parameters	Formulae	Reference
(A)	***Linear aspect***		
1.	Stream Order	Hierarchical rank	[21]
2.	Stream number (Nu)	Nu = N1 + N2 + …… + Nn where N1 = Order of stream	[22]
3.	Stream Length (Lu)	Lu = L1 + L2 + …… + Ln where L = Length of the basin	[22]
4.	Mean stream length (Lsm)	Lsm = Lu/Nu where Lu = Total stream length of order 'u' Nu = Total no. of stream segments of order 'u'	[21]
5.	Stream length ratio (Lur)	Lur = Lu/Lu – 1 where Lu = Total stream length of order 'u'	[22]
6.	Bifurcation Ratio (Rb)	$Rb=N_u/N_{u+1}$ where Nu = Total steam segments of order 'u' Nu + 1 = stream length of its next higher order	[23]
7.	Rho coefficient (ρ)	ρ = RL/Rb where RL = stream length ratio; Rb = bifurcation ratio	[22]
(B)	***Areal aspect***		
1.	Basin area (A), km2	Area enclosed within the boundary of watershed divide	[21]
2.	Basin length (Lb), km	Lb =Distance between outlet and farthest point of basin boundary	[22]

3.	Basin perimeter (P),km	P = Outer boundary of drainage basin	[23]
4.	Drainage Density (D)	D=Lu/A where Lu = Total stream length of all orders; A = Basin area	[22]
5.	Length of overland flow (Lg)	Lg = 1/2 × Dd where Dd = Drainage density	[22]
6.	Stream Frequency (Fs)	Fs=Nu/A where Nu = Total no. of streams of all orders; A = Basin area	[24]
7.	Drainage Texture (Rt)	Rt=Nu/P where Nu = Total no. of streams of all orders; P = Perimeter (km)	[22]
8.	Elongation Ratio (Re)	Re=2/Lb sqrt (A/π) where A = Basin area; Lb = Basin length	[23]
9.	Form Factor (Rf)	Rf=A/Lb2 where A = Basin area; Lb2 = Square of basin length	[24]
10.	Circularity Ratio (Rc)	Rc=4*π *A/P2 where A = Basin area (km2); P2 = Square of the perimeter (km2)	[25]
11.	Constant of channel maintenance	C = 1/Dd where Dd = Drainage density	[23]
12.	Compactness coefficient	Cc = 0.2821P/A0.5 where P = Basin perimeter; A = Basin area	[22]
(c)	***Relief aspects***		
8.	Basin relief (H)	(Maximum elevation – Maximum elevation)	[21]
9.	Relief Ratio(Rh)	Rh = R/L where H = Maximum basin relief; Lb = Basin length	[23]
10.	Ruggedness number (Rn)	Rn = Dd*(Rh/1000) Where Dd= drainage density; Rh=relief ratio	[21]

3. Result and discussion

This research presents a morphometric analysis of the Waghora micro watershed, examining it from three distinct perspectives: Linear, Areal, and Relief. Additionally, the study evaluates the slope, aspect, and drainage density of the basin, providing crucial insights into watershed management. These parameters are explained further based on various hydrological factors listed below:

3.1. Linear Aspects

The linear aspect encompasses all linear features within a drainage basin, including Stream Order (w), Stream Number (Nu), Bifurcation Ratio (RbF), Stream length (km), and their respective means, as illustrated in Table 2.

3.1.1. Stream order and number of streams

Establishing the stream order (Nu) serves as the initial phase in morphometric analysis of a watershed. As depicted in Table 2 and presented in fig 2(a), the data reveals that the Waghora micro-watershed exhibited a fourth-order drainage stream. Specifically, there were 51 streams of first order, while the second, third, and fourth-order streams numbered 14, 3, and 1 respectively. The decrease in the number of stream segments with ascending stream order aligns with the principles outlined in Horton's laws [26].

3.1.2. Stream length

In the Waghora micro-watershed, the lengths of streams of orders 1, 2, 3, and 4 measured 19.74 km, 7.87 km, 5.59 km, and 3.36 km respectively. The combined length of all streams in this watershed was calculated to be 36.57 km. Notably, it was observed that the total length of stream segments was highest for first-order streams and decreased progressively with higher stream orders. This pattern echoes findings reported by Deka et al. [15] in their study conducted in the Dhemaji District of Assam, India.

3.1.3. Mean stream length

The mean stream length values for the Waghora micro-watershed were computed for all four orders, yielding 0.38, 0.56, 1.86, and 3.36 as shown in Table 2 for stream orders 1, 2, 3, and 4 respectively. Notably, these values exhibit an increasing trend with the order. This finding is consistent with the results reported by Premanand et al. [5]

3.1.4. Stream length ratio

The stream length ratio within the Waghora micro watershed ranged between 0.39 and 0.70. Notably, there was an observed ascending trend in the stream length ratio from lower to higher orders, suggesting a mature geomorphic stage. These results align with those reported by Nayar et al. [27] in their study of the Kosasthalaiyar River in India.

3.1.5. Bifurcation ratio

The bifurcation ratio represents the ratio of stream segments of a particular order to those of the next higher order. According to various studies, a ratio of less than five (5) is typically classified as low, while a ratio exceeding five (5) falls into the high category. A low classification suggests that the drainage pattern is unaffected by geological structures, whereas a high classification indicates that geological structures influence the drainage pattern. Within this basin region, the bifurcation ratio ranges from 3 to 4.66, indicating minimal structural disturbance. The mean bifurcation ratio is calculated at 3.76.

The bifurcation ratio holds significance in examining drainage basins as it aids in interpreting basin shape and runoff behavior. Higher bifurcation ratio values correspond to increased flood risk. Therefore, the low bifurcation ratio observed in our area suggests a low flood risk.

3.1.6. Rho coefficient (ρ)

The Rho coefficient signifies the correlation between drainage density and the physiographic maturity of a watershed, offering insights into the water storage capacity within it. Elevated Rho coefficient values denote a greater capacity for water storage. In the case of the Waghora micro watershed, the computed Rho coefficient stands at 0.45, indicative of a high hydrological storage capacity, particularly during flood periods [15].

Table no. 2 Morphometric parameters (linear aspects) of Waghora micro-watershed

Stream Order (w)	No. of Streams (Nu)	Bifurcation Ratio (RbF)	Mean Bifurcation Ratio (Rbm)	Total Length of Streams (Lu) (km)	Mean Length of Streams (km)	Length Ratio (RL)	Rho coefficient (ρ)
1	51	3.64	3.76	19.74	0.38		
2	14	4.66		7.87	0.56	0.39	0.10
3	3	3		5.59	1.86	0.71	0.15
4	1			3.36	3.36	0.60	0.2
Total	69	11.3		36.57			0.45

3.2. Areal Aspects

The areal aspects of a watershed encompass diverse areal components, including Area (km²),length (km), Perimeter (km),Drainage Density (Dd), Elongation Ratio (Re), Drainage Texture (T), Stream Frequency (Fs), Form Factor (Ff), and Circulatory Ratio (Rc). These findings are detailed in Table 3.

3.2.1.Basin area, length and perimeter

The runoff rate of a drainage basin is contingent upon both its area and physiography. Generally, smaller basin areas (A) tend to yield larger runoff, whereas larger areas lead to diminished runoff. For the Waghora micro-watershed, the basin area, length, and perimeter were measured at 13.03 km², 5.63 km, and 15.55 km respectively.

3.2.2. Drainage density

Drainage density (Dd) quantifies the total length of stream segments across all orders per unit area of the watershed. In the case of the Waghora micro-watershed, the computed drainage density was determined to be 2.80 km/km². This figure may be attributed to factors such as permeable subsurface material, dense vegetation cover, and relatively low relief [28].

3.2.3. Drainage pattern

The drainage pattern (Dp) reflects the impact of slope, lithology, structure and it helps in recognizing the stage in the cycle of erosion. The drainage pattern for the Waghora micro-watershed was found to be dendritic and radial which indicates that the time of formation of the drainage basin was longer [29]

3.2.4. Length of overland flow

The length of overland flow (Lg) represents the distance water travels over the land surface before converging into distinct stream channels [22]. In the Waghora micro-watershed, the calculated length of overland flow is 1.4 km. A higher value of Lg suggests gentle slopes and longer flow paths [30], facilitating increased infiltration and reduced runoff [31] within the study area.

3.2.5. Stream frequency

Stream frequency (Fs) is influenced by lithology, slope gradient, stage of fluvial cycle, and surface runoff. In the Waghora micro-watershed, the calculated stream frequency is notably high at 5.29. This suggests the presence of impermeable subsurface materials, limited infiltration, and low relief conditions, potentially accompanied by reduced erosion [12].

3.2.6. Drainage texture

Drainage texture (Dt) denotes the spacing between drainage lines and provides insights into basic lithology, infiltration capacity, and topographic relief. In the Waghora micro-watershed, the calculated drainage texture value is 14.83, indicating a very fine texture. A watershed with a very fine texture or a high drainage texture value (>8) suggests an increased risk of soil erosion.

3.2.7. Elongation ratio

The elongation ratio (Re) serves as an indicator of the river basin's shape, influenced by both climatic and geological factors. Three classes are typically used to classify Re: less elongated (< 0.7), oval (0.8 – 0.9), and circular (>0.9) [21,33,34]. In the case of the Waghora micro-watershed in India, the elongation ratio was measured at 0.72, indicating a moderately elongated shape, with moderate relief and slope in the study area.

3.2.8. Form factor

The calculated value of the form factor for the Waghora micro-watershed was 0.41. A lower value of form factor<0.78 indicated that the shape of the basin was elongated s it has low peak flows for longer duration. A low form factor (0.32) was also observed by [5] in the Patapur Micro-watershed in North-Eastern Dry Zone of Karnataka India indicating a flatter peak of flow for a longer duration in the basin.

3.2.9 Circularity ratio (Rc)

The circulatory ratio (Rc) is primarily influenced by factors such as geology, slope, structure, relief, stream frequency, climate, length, and land use/land cover within the basin area. Higher values of the circulatory ratio correspond to increased flood hazard during peak times at the outlet point. In the case of the Waghora micro-watershed, the circulatory ratio was recorded at 0.68, suggesting an elongated basin with permeable sub-soil, associated with high discharge of runoff materials [25]. Similarly, Narmatha et al. [35] observed a comparable circulatory ratio (0.61) in the Ponnaiyar River basin of Tamil Nadu, India, indicating low runoff discharge and highly permeable sub-soil.

3.2.10. Constant of channel maintenance

The computed constant of channel maintenance (C) for the Waghora micro-watershed was determined to be moderate at 0.35 km²/m. This moderate value suggests moderate permeability, slope, and surface runoff within the area [36].

3.2.11. Compactness coefficient

The compactness coefficient (Cc) directly correlates with erosion risk assessment. Lower Cc values imply reduced vulnerability to risk factors, while higher values suggest increased vulnerability, necessitating conservation measures [37]. In the case of the Waghora micro-watershed, the compactness coefficient was measured at 1.20, indicating a moderate erosion status within the studied area.

Table 3. Areal Aspects of Waghora micro-watershed

S.no.	Areal Aspect	Value
1	Basin Area (km^2)	13.03
2	Perimeter (km)	15.44
3	Basin Length (km)	5.63
4	Drainage Density (km/km^2)	2.80
5	Length of overland flow	1.4
6	Stream Frequency (Fs)	5.29
7	Drainage Texture (T)	14.83
8	Elongation ratio	0.72
9	Form factor	0.41
10	Circularity Ratio (Rc)	0.68
11	Constant of channel maintenance (c)	0.35
12	Compactness of coefficient (Cc)	1.20

3.3. Relief aspects

The results of morphometric parameters related to relief aspects of the Waghora micro-watershed are presented in Table 3.

3.3.1. Basin relief

Basin relief (H) denotes the variation in elevation between the lowest and highest points within a basin. In the Waghora micro-watershed, the computed basin relief was 75 meters. A lower basin relief value suggests increased infiltration and reduced runoff, aligning with the conclusions drawn by Chaudhari and Kumar [36].

3.3.2. Relief ratio

The relief ratio (Rh) serves as a gauge of the general steepness of a drainage basin, aiding in the assessment of erosion intensity along its slopes. Typically, the relief ratio tends to rise with diminishing drainage area and size of the watershed within a given drainage basin [38]. In the case of the Waghora micro-watershed, the calculated relief ratio was determined to be 1.2, suggesting gentle slopes within the study area. These findings parallel those reported by Sahu et al. [38] for a comparable watershed in the Nagpur district of Maharashtra, India.

3.3.3. Ruggedness number

The ruggedness number (Rn) serves as an indicator of a basin's susceptibility to soil erosion, with higher values indicating increased proneness and vice versa. In the case of the Waghora micro-watershed, the calculated ruggedness number stood at 0.97. Watersheds characterized by high Rn values typically undergo dynamic geomorphic processes, featuring long and steep slopes punctuated by abrupt breaks due to rejuvenation. Consequently, such catchments exhibit heightened susceptibility to soil erosion, sediment load generation, mass movements, and heightened response to increased peak discharge. This finding resonates with results reported by Singh et al. [39] in the Dudhani watershed, India, suggesting very low infiltration, elevated surface runoff, and an increased risk of soil erosion

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Table 4 Morphometric characteristics (relief aspects) of Waghora micro-watershed

S.No.	Relief parameters	Value
1	Maximum elevation, m	373
2	Minimum elevation, m	248
3	Basin relief (H), m	75
4	Relief ratio (Rh)	1.2
5	Ruggedness number (Rn	0.97

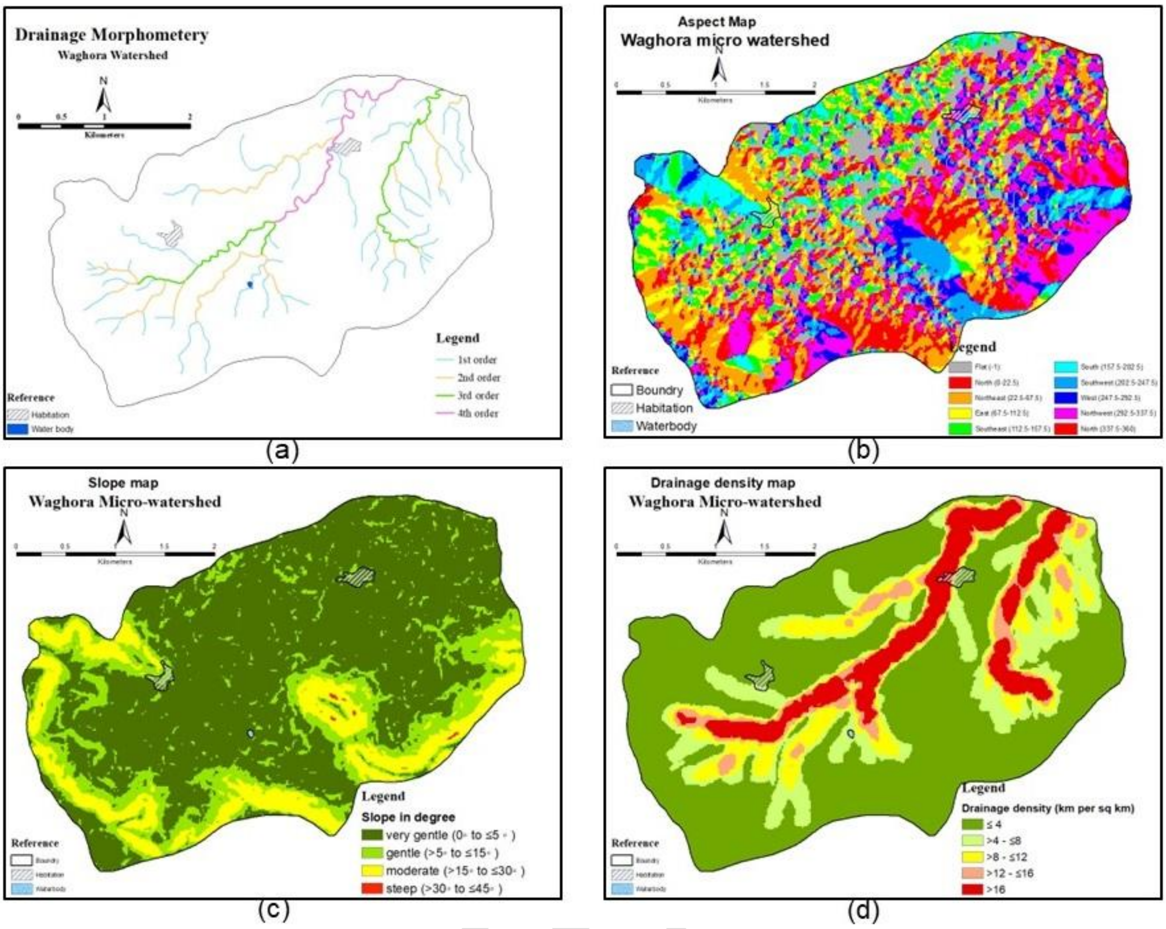

Figure 2. (a) Drainage Basin Map; (b) Slope Map; (c) Aspect Map; (d) Drainage Density Map.

3.4. Aspect

Aspect indicates the direction of a slope. In this context, slope directions are categorized based on degrees: from 0–22.5° as north, from 22.5–67.5° as northeast, and so forth. In the present study, the aspect is south-facing, as illustrated in Figure 2a. This suggests that the south-facing slope tends to have greater vegetation cover and moisture content in comparison to the north-facing slope.

3.5. Slope

Slope defines the steepness of the area. In the waghora micro-watershed, the maximum height is 417 m, whereas the minimum height is 273 m (Figure 2b). Here, the slope is divided into five classes, as shown in Figure 3: (0◦ to ≤5 ◦) is very gentle, (>5◦ to ≤15◦) is gentle, (>15◦ to ≤30◦) is moderate, (>30◦ to ≤45◦) (Figure 2). It is visible from the map that most of the basin area has very gentle to moderate slopes. A very gentle slope is good for groundwater infiltration having less runoff, whereas a steep slope or higher slope category has bad groundwater infiltration with more runoff.

3.6. Drainage Density

The drainage density of a basin is defined as the total length of streams per unit area. In this study, drainage density is classified into five categories, as illustrated in Figure 2d: very low (≤4 km/km²), low (>4 km/km² to ≤8 km/km²), moderate (>8 km/km² to ≤12 km/km²), high (>12 km/km² to ≤16 km/km²), and very high (>16 km/km² to 34.32 km/km²). The majority of the basin area exhibits very low to low drainage density. Areas with the highest drainage density, depicted in red on the map, typically coincide with the presence of gullies.

4. Conclusion

Remote sensing and GIS techniques were used to study the morphometric characteristics of the Waghora micro-watershed in Jam River basin, India. The hydrological and morphological aspects of the watershed can be understood by its drainage morphometric parameters. The current study provides the precise data for topography, drainage system, stream length, water division, geomorphologic setup, and other factors crucial for the classification and management of watersheds. Based on the morphometric studies, the watershed was found to have fourth-order drainage streams having a total stream length of 36.57 km. The basin's drainage system is primarily of the dendritic type, which aids in understanding a variety of topographical aspects, including infiltration rate and runoff, among others.The lower value of the bifurcation ratio and the dendritic type of drainage pattern indicates that the watershed has suffered less structural disturbance. low values of form factor, elongation ratio, as well as circularity ratio, indicated the elongated nature of the watershed. The lower drainage density shows that the area is permeable subsurface material, dense vegetation cover, and relatively low relief. The results observed from the analysis could be helpful for watershed prioritization with respect to erosion. The drainage morphology needs to be explored for locating and selecting the water storage structures like percolation tank, pond, check dams, etc. This work shall prove beneficial to the planners and decision-makers for proper natural resource management at the micro-level. Planners and decision-makers of sustainable watershed development programs will find this work greatly valuable for managing natural resources at the micro level on any terrain.The study suggests that in the near future, hydrogeological and geophysical investigations are crucial for effective and efficient watershed management.

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