Morphometric Analysis of the Hasdeo Subbasin

ABSTRACT

"Morphometry" is the analysis of forms that presents a quantitative description of a landform. To assess the Hasdeo subbasin's hydrological features and water potentials based on the morphological characteristics, morphometric analysis of the Hasdeo subbasin was conducted in the current study. ALOS Palsar DEM data were used to reveal details on the Hasdeo subbasin's morphometry. Spatial information from Geographic Information Systems (GIS) was utilized to conduct the study. The linear, areal, and relief characteristics of the basin are taken into account as morphometric parameters for the analysis. The Hasdeo subbasin contains a river network that is classified as being of 6th order (according to Strahler's classification) and has a dendritic drainage pattern, according to morphometric analysis of the river network and the subbasin. The calculated values for the bifurcation ratio (1.93), drainage density (0.63), circularity (0.32), elongation (0.46), form factor (0.16), and stream frequency (43.86) were obtained in that order. This value demonstrates the subbasin's length, which results in low peak flows for a longer time, a significant danger of soil erosion, and a basin's extensive hydrographic network with numerous tributary streams that respond quickly to precipitation. Prioritizing a region based on morphometric analysis is very valuable.

Keywords: Hasdeo subbasin, Morphometric analysis, Spatial data, Geographical Information system.

1. INTRODUCTION

A river basin's drainage system, which is a significant factor of the basin, can be quantitatively described by morphometric analysis (Strahler, 1964). An area of land known as a drainage basin has three dimensions, where surface water from precipitation, including rain, snow, sleet, hail, and frost, converges to a single place or joins another water body before leaving the basin through the processes of surface runoff, through flow, and groundwater movement. Groundwater, transpiration, evaporation, transpiration by plant, and surface storage, all contribute to the storage to basin system. The drainage basin is primarily influenced by the physical, climatic, and anthropological factors. The physiographic features of drainage basins, such as size, form, slope of the drainage area, drainage density, size and length of the tributaries, etc., can be used to relate a variety of significant hydrologic phenomena (Rastogi & Sharma, 1976). The basin's elevation and slope, rock and soil types, drainage density, types and intensities of rainfall, antecedent circumstances, rates of evapotranspiration, urbanization, afforestation and deforestation, and water extraction are some other controlling elements. For the analysis of the drainage basin features, crucial factors are taken into consideration. These include stream order, stream length, bifurcation ratio, basin area and length, perimeter, drainage density, stream frequency, elongation ratio, circularity ratio, texture ratio, and form factor ratio. These parameters are given based on linear, areal, and relief aspects (Shreve, 1966). The intent of this article is to characterize the drainage features of the Hasdeo subbasin. Prioritization of the watershed of the

Hasdeo subbasin is one of the goal of this study in order to preserve soil and water conservation for the preservation of the subbasin.

2. MATERIAL AND METHODS

The Hasdeo subbasin covers an area of approximately 9484 km². The Hasdeo flows from north to south, and the basin is located between 21°45'N to 23°37'N Latitude and 82°00' E to 83°04' E Longitude. Detailed knowledge of the basin's morphometric parameters is essential during the hydrological modelling process. With the measurement of the several watershed parameters, the morphometric parameters of the watershed are analyzed. Miller (1953), Strahler (1957), and others used the morphometric properties to prioritize individual watershed for development. Drainage channels and other parameters were extracted using the ArcGIS 10.3 software's Hydrology tool, which is part of the Spatial Analyst Working framework. After a number of processes, including DEM, fill, flow accumulation, stream order, and drainage network, the automated approach for delineating streams was accomplished. Fig. 1 provides a description of the drainage extraction and delineation technique. The stages involved in the morphometric investigation of the Hasdeo subbasin and map development, scanning, geo-referencing, spatial data collection, and topology creation. Three factors, namely linear, relief, and aerial parameters make up morphometric analysis. However, only stream order, stream length, stream length ratio, and bifurcation ratio are taken into account under linear parameters, basin relief and relief ratio are considered to be relief parameters, and drainage density, stream frequency, form factor, circulatory ratio, elongation ratio, and length of overland flow are taken into consideration under aerial parameters, which are in charge of characterizing the basin. Table 1 (a) provides the recommended formula and the empirical connection that was utilized to analyze the morphometric parameters. The Hasdeo subbasin drainage has given in Fig. 3. The methodology adopted for morphometric analysis of Hasdeo sub-basin was described through the flow chart given in Fig. 2.

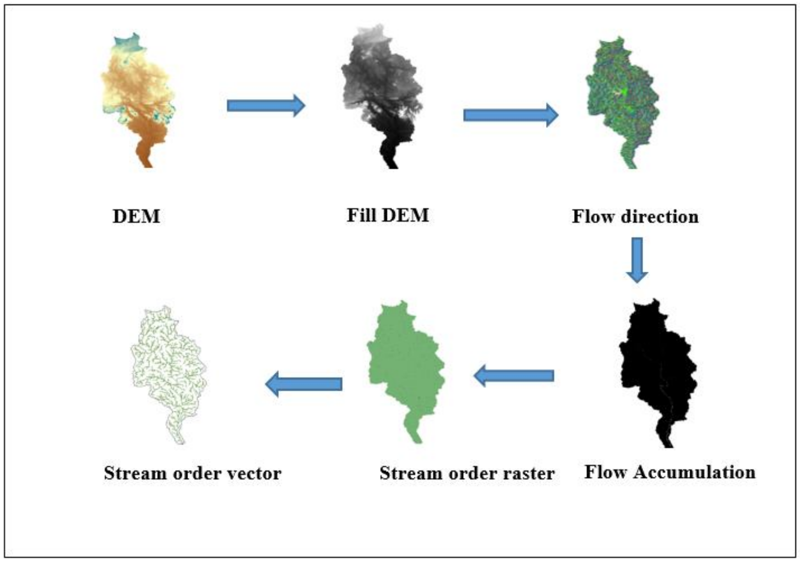

Fig 1. Steps for extraction of drainage network

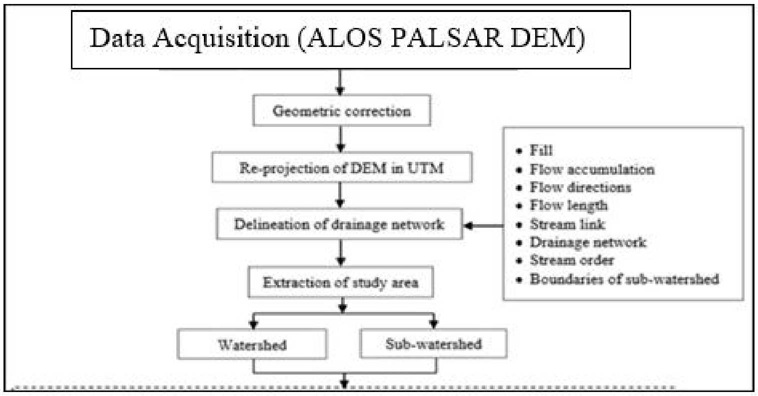

Fig. 2: Methodology adopted for extraction of drainage map of the Hasdeo subbasin

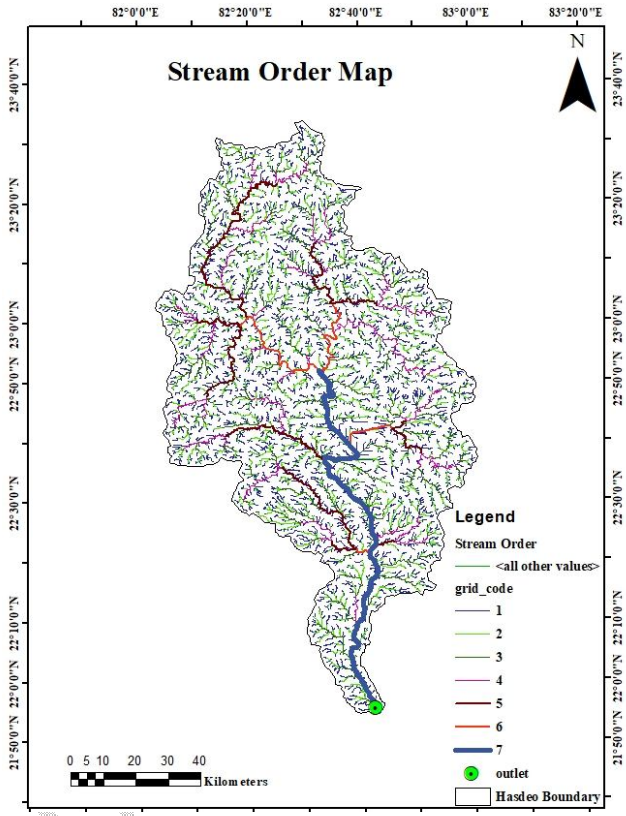

Fig. 3: Drainage network with stream ordering of Hasdeo subbasin

Table 1: Methods of calculating morphometric parameters

Morphometric parameter	Formula	Reference
Stream order	Hierarchical rank	Strahler (1964)

Streams number (N_u)	Number of streams	
Stream length (L_u)	Length of stream	Horton (1945)
Bifurcation ratio (R_b)	$R_b = \frac{N_u}{N_{u+1}}$ N_u = Total no. of stream segments of order ‘u’ N_{u+1}= no. of stream segments of the next higher order	Schumn (1956)
Length of overland flow (L_o)	$L_o = \frac{1}{2D_d}$ where, L_o = Length of overland flow D_d = Drainage density	Horton (1945)
Basin Perimeter (P_r)	Outer boundary of drainage basin measured in kilometers.	Schumn (1956)
Drainage density (D_d)	D_d = L_u /A where, D_d = Drainage density L_u = Total stream length of all orders A = Area of basin (km^2)	Horton (1945)
Basin Area (A)	Area from which water drains to a common stream.	Strahler (1964)
Stream frequency (F_u)	Fu = Nu / A where Fu = Stream frequency Nu = Total no. of streams of all orders A = Area of basin (km^2)	Horton (1932)

Texture ratio (T)	$T = \frac{N_u}{P_r}$ where, T = Texture ratio N_u = Total no. of streams of all orders P_r = Perimeter (km)	Horton (1945)
Form factor (R_f)	$R_f = \frac{A}{L_b^2}$ where, A = Area of basin (km^2) L_b^2 = Square of basin length	Horton (1932)
Shape factor (S_f)	$S_f = \frac{L_b^2}{A}$ where, L_b^2 = Square of basin length A= Area of basin (km^2)	Nookaratnam (2005)
Elongation ratio (R_e)	$R_e = \frac{\sqrt{\frac{4\,A}{\pi}}}{L_b}$ where, R_e = Elongation Ratio A = Area of basin (km^2) L_b = Basin length	Schumn (1956)
Circulatory ratio (R_c)	$R_c = \frac{12.57\,A}{P_r^2}$ where, P_r^2 = Square of the perimeter (km^2)	Miller (1953)
Compactness constant (Cc)	$C_c = \frac{P}{\sqrt{4\pi A}}$ where, A = Area of basin (km^2)	Horton (1945)

P = Perimeter (km)

3. RESULTS AND DISCUSSION

The properties of watershed are described by morphometric analysis, which uses quantitative evaluation of several criteria. The dimensions of the parameters determines the distributions of the area. The features, including relief, areal, and linear aspects were studied. By their various effects on lag time, morphometric characteristics like relief, shape, and length also have a significant impact on basin discharge patterns (Gregory and Walling, 1973). The drainage pattern, which is made up of streams in a drainage system, mostly reflects the structural or lithologic restrictions of the underlying rocks (Eesterbrooks, 1969). For studies of linear aspects, Horton (1945), Strahler (1952), and Schumm (1956) methods are employed. For studies of areal aspects, Horton (1945), Miller (1953), and Schumm (1956) methods are utilized. The following calculation and evaluation have shown the descriptions regarding the basin characteristics.

3.1 Linear morphometric parameters

The information on one-dimensional parameters such as stream order, stream number, bi-furcation ratio and stream length is provided through linear aspects. This shows that the drainage network's channel patterns have the topological features of stream segments, and the study is based on the network's open linkages.

3.1.1 Stream order (U)

It is defined as a means to quantify where a stream is in respect to other tributaries (Leopold, Wolman, & Miller, 1964). According of its clarity, the modified version of Horton's law (also known as the Strahler law) has been used for the study. First order refers to the smallest, unbranched fingertip streams, while second and third order channels are formed when two first order streams converge. The higher-order is preserved when defining the stream order between two channels with different orders. The observation reveals that the Hasdeo subbasin has up to seven orders of tributaries, with the first, second, third, fourth, fifth, sixth, and seventh streams.

3.1.2 Stream length (Lu)

The total length of the stream segment is maximum in the first order stream and decreases as the stream order increases. The 7th order streams are only present in two subbasins namely WS13 and WS7, whereas the 6th order streams are present in all subbasins except WS4 and WS8. Out of the 13 subbasins, the total stream length is observed to be highest in WS13 (3153 km), followed by WS5 (2024 km) and WS1 (1751 km).

3.1.3 Bifurcation ratio (Rb)

Bifurcation ratio describes the drainage network's branching pattern with other stream order. It is the proportion of all stream segments in a drainage basin that are of one order to those that are of the next higher order (Schumm, 1956). Strahler (1957) established with the exception of areas where the geology is dominant, the bifurcation ratio exhibits only a moderate range of variance. It has been seen that Rb changes from one order to the next. The natural drainage system within a homogeneous rock is indicated by the bifurcation ratio, which ranges between 3 and 5, according to Kale and Gupta (2001). The lower value of bifurcation ratio are characteristics of the watershed which have flat or rolling watersheds while the higher values of bifurcation ratio indicate strong structural control on the drainage pattern and have well-divided drainage basins. The higher bifurcation ratio leads to less chances of risk of flooding (Eze & Efiong, 2010). The mean bifurcation ratio for the entire subbasin is 2.08, while the highest bifurcation ratio of 2.22 is observed in the subbasin WS4, WS6 and WS9. The lowest bifurcation ratio of 1.9 is observed in subbasin WS5.

3.1.4 Drainage density (D_d)

It is the ratio of the basin's entire area to the sum of all orders' cumulative channel segment lengths, expressed in the unit Km/Km^2. In the study area, the average drainage density is 1.82, while the highest drainage density 1.92 is observed in subbasin WS2 and lowest drainage density 1.33 is observed in subbasin WS4. If the basin's D_d is low, it consists of extensive vegetation cover and extremely permeable subsoil (Nag & Chakraborty, 2003). Strong or impermeable soil, little vegetation, and hilly terrain all contribute to high drainage density and coarse drainage texture. When drainage density is higher, the drainage texture is fine. Climate, rainfall, vegetation, lithology, soil type, infiltration capacity, and stage of development all have an impact on drainage texture, which is a measurement of relative channel spacing in a fluvial landscape (Smith, 1950). D_d value of 1.82 km/km^2 denotes a low to moderate drainage texture (IBAL S.A. 2009), flat to very steeply sloping terrain, and a range in vegetation coverage including forest in the study area.

3.1.5 Stream frequency (Fs)

The total number of stream segments per square kilometre in a basin is known as its stream frequency (Fs) (Horton, 1945). The watershed's stream frequency and drainage density show a positive correlation, showing an increase in stream population as drainage density rises. The frequency and density of drainage are greatly influenced by climatic characteristics, vegetation coverage, rock and soil types, rainfall intensity, infiltration capacity, relief, run-off intensity, permeability of the terrain, and slope. Flooding is more frequent in the basins with a high drainage and stream frequency because the runoff is faster when the drainage density and stream frequency are higher (Kale & Gupta, 2001), which is also evident in our study area.

3.1.6 Texture ratio

The texture ratio for the basin is 488.74. The lowest texture ratio is observed to be 384.61 in subbasin WS4 and highest texture ratio 640 is observed in subbasin WS13. In the drainage morphometric analysis, which depends on the underlying lithology, infiltration capability, and relief aspect of the terrain, texture ratio is a significant factor (Schumm, 1956). The ratio between the first-order streams and the basin's edge is used to express the texture ratio. Higher values of texture ratio indicate 'very fine' texture which is seen in WS13, while lower values indicate coarse texture, observed in WS4.

3.1.7 Form factor (R_f)

It is the ratio of the basin area to the square of the basin length. The basin will be more elongated, the lower the form factor value, whereas the higher values correlate to a circular basin. Peak flows are greater and last for a shorter time in basins with high form factors, while peak flows are flatter and last longer in elongated watersheds with low form factors. The form factor for the Hasdeo subbasin is 0.24, indicating an elongated shape. The lowest form factor is observed to be 0.21 in subbasin WS13 and highest form factor 0.26 is observed in subbasin WS6 and WS12, which falls under category of slightly elongated shape (Bhardwaj et al 2014).

3.1.8 Elongation ratio (Re)

The ratio between the diameter of a circle with the same area as the drainage basin and the basin's maximum length is known as the elongation ratio (Re) (Schumm, 1956). Throughout a wide range of climatic and geologic types, Schumm's ratio exhibits values between 0.6 and 1.0. Round (0.9-0.10), oval (0.8-0.9), less elongated (0.7-0.8), elongated (0.5-0.7), and more elongated (0.5) are the classifications for the variable index of elongation ratio. According to Singh and Singh (1997), a circular basin discharges runoff more effectively than an elongated basin. The value ranges from 0.6 to 0.8 for regions of high relief and the values close to 1.0 have very low relief with circular shape (Magesh et al., 2013). The elongation ratio for the basin is 0.55, which indicates elongated shape of the basin. The lowest elongation ratio is observed to be 0.52 in subbasin WS13 and highest elongation ratio 0.58 is observed in subbasin WS6**.**

3.1.9 Circulatory ratio (Rc)

The ratio of a basin's area to a circle whose diameter matches its perimeter is known as the "circulatory ratio" (Miller, 1953). When the basin is shaped like a complete circle, the value of the ratio is one, and when the basin is substantially elongated and made of homogeneous geologic materials with high porosity, it is between 0.4 and 0.5. Rc is impacted by the basin's land use and land cover as well as the frequency of streams, slope, relief geologic structure, and climate. Rc is a dimensionless number. Its low, medium, and high values are indicative of the youth, mature, and old stages of the life cycle of the tributary basins (Rafiq et al., 2013). The circulatory ratio for the basin is 0.28, which indicates the basin is not circular but elongated. It also indicate that, in terms of evolution, the basin is in mature state. The lowest circulatory ratio is observed to be 0.18 in subbasin WS13 and highest circulatory ratio 0.44 is observed in subbasin WS10.

3.1.10 Length of overland flow (Lg)

The length of water over the ground prior to being concentrated into the main flow is known as the length of overland flow (Lg), and it has an impact on the physiographic and hydrologic evolution of the drainage basin (Horton, 1945). Percolation through the soil and infiltration (exfiltration), both of which vary in time and place, have a substantial impact on Lg (Schmid, 1997). As the Lg value is large, it follows that the precipitation had to travel a considerable distance before condensing into stream channels (Chitra *et al.*, 2011). Low value of Lg indicates high relief (Vinutha and Janardhana 2014), short flow paths, more runoff, and less infiltration (Chandrashekhar *et al.* 2015) which leads to more vulnerable to the flash flooding (Rai et al 2017). Meanwhile, a high value of Lg means gentle slopes and long flow paths (Rai et al 2017), more infiltration, and reduced runoff (Chandrashekhar et al 2015). The length of overland flow for the basin is 0.28, which indicate moderate infiltration. The lowest length of overland flow is observed to be 0.26 in subbasin WS2, WS5, WS9, WS12 and highest length of overland flow 0.38 is observed in subbasin WS4.

3.2 Relief morphometric parameters

Relief Aspects deals with three-dimensional parameters like relief, relief ratio, ruggedness number.

3.2.1 Basin Relief (B_h)

The elevation difference between the highest and lowest locations on a basin's bottom is known as the basin relief (B_h). Relief is calculated by subtracting the elevation of the basin's mouth from its highest point. It plays a key influence in the creation of formations, drainage patterns, surface and subsurface water flow, permeability, and the erosional characteristics of the terrain. It is vital for comprehending the erosional characteristics of the basin. The subbasin relief is 613, which indicates moderate runoff condition. The lowest basin relief is observed to be 244 in subbasin WS3 and highest basin relief 805 is observed in subbasin WS13.

3.2.2 Relief Ratio (R_h)

The ratio between the length of the basin parallel to the main drainage line and the overall relief of a basin, or the difference in elevation between the basin's lowest and highest points, is known as the relief ratio (Schumm, 1956). The relief ratio for the basin is 11.99. The lowest relief ratio is observed to be 5.14 in subbasin WS3 and highest relief ratio 21.08 is observed in subbasin WS12. High R_h values and steep slopes suggest considerable relief. There are more peaked basin discharges and more erosive power when run-off is generally faster in steeper basins (Palaka & Sankar, 2016). According to (Bhardwaj et al 2014) R_h is the dimensionless height–length ratio between the basin relief (R) and the basin length (L). The importance of relief ratio is to determine the steepness of the entire drainage basin. It is also used to determine erosion occurrence and vulnerability especially on the slopes of drainage basin. The high relief ratio of the Hasdeo subbasin is a result of the presence of highland areas especially upper parts of the subbasin which covers parts of the Koriya district of Chhattisgarh.

3.2.3 Ruggedness number (R_n)

Maximum basin relief (B_h) and drainage density (D_d), both of which are expressed in the same unit, are multiplied to produce ruggedness number. The category of index is given in table 1 a. It serves as an indicator for surface irregularity (Selvan, Ahmad, & Rashid, 2011). When both variables are significant and the slope is steep, the roughness number reaches a very high value (Strahler, 1956). The current basin's roughness score is 1.12, which indicates that the area is more likely to experience soil erosion due to its steep slope. The lowest ruggedness no. is observed to be 0.45 in subbasin WS3 and highest ruggedness no. 1.50 is observed in subbasin WS12 and WS13.

Table 2: Ruggedness index for Hasdeo Subbasin

S.no.	Elevation Range (m above msl)	Area (km^2)	Ruggedness index
1.	134-308	2130.47	Intermediate
2.	308-416	2667.44	Moderately
3.	416-514	2602.38	Highly
4.	514-640	1303.74	Highly
5.	640-1055	779.97	Extremely
Total		**9484.00**	

4. CONCLUSION

Any hydrologic research must first conduct a morphometric examination of the drainage system. In order to evaluate river basins, prioritize watersheds for soil and water conservation, and manage natural resources at the micro level, quantitative study of morphometric parameters is found to be of enormous use. According to the study, integrated Remote Sensing and GIS-based approaches are more suitable and practical than traditional methods for the evolution of morphometric parameters. Understanding the relationships between the many elements of drainage patterns and their impact on land formation processes, drainage, and land erosion qualities is made possible through the measurement of morphometric parameters at river basins. The main morphometric criteria for classifying drainage basins are drainage density and stream frequency. These elements characterize the drainage basin's runoff pattern, sediment yield, and other hydrological metrics.

The calculated values of the various drainage basin parameters for the hasdeo subbasin are summarised based on the findings results revealed that the hasdeo subbasin. The area is naturally prone to flooding into downstream area. The low bifurcation ratio and high drainage density of the drainage basin are natural characteristics that demonstrate its intrinsic capacity to produce high runoff and high sediment loss. However, human activities in the drainage basin's middle and downstream regions amplify the basin's sensitive features. The hasdeo subbasin is elongated, which is typically accompanied by high relief, a steep ground slope, and moderately high peak flows that last for a longer period of time. The drainage basin will have a faster surface runoff that will enter the streams because of the lower value of overland flow length and the higher value of infiltration ratio. The Hasdeo subbasin's ruggedness score of 1.12 indicates that has higher basin relief with gradual change In slope. GIS has proved to be an effective and efficient tool for computation and analysis of various morphometric parameters of the basin. Such studies are particularly beneficial for planning and managing drainage basins.

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APPENDIX

Table 1a

Terrain Ruggedness Index (TRI) Categories (from Riley et al. 1999)

Category Elevation Difference (m)	Level
Nearly Level	81–116
Slightly Rugged	117–161
Intermediately Rugged	162–239
Moderately Rugged	240–497
Highly Rugged	498–958
Extremely Rugged	959–4367