



Quantitative morphometric analysis of Veshav and Rembi Ara watersheds, India, using quantum GIS

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Received: 18 August 2021 / Accepted: 10 January 2022 / Published online: 15 January 2022
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Abstract

Quantitative drainage morphometric analysis has assumed tremendous significance as it plays an important role in understanding the hydrological response behaviour of a drainage basin. Different potential hazards like floods and soil erosion can be predicted by software-based quantitative drainage morphometric analysis. The present study deals with the measurement of linear, areal and relief quantitative morphometric parameters of Veshav and Rembi Ara watersheds. These two watersheds were taken into consideration because of their high contribution of water flux to the main trunk stream especially during a flood event. The quantitative morphometric parameters were derived in GIS environment by using ASTER DEM (30 m resolution) data of United States Geological Survey (USGS). GIS has emerged as an effective, time saving and accurate technique for morphometric analysis of a watershed. GIS-based morphometric measurements are more accurate and precise than manual measurements. The raster data in the form of Digital Elevation Model (DEM) was processed and analysed in a QGIS software by using different algorithmic methods. Based on the morphometric analysis, it is implied that out of the two watersheds, Veshav has more potential of discharging efficiently the flux in the form of surface runoff. The observation was supported by the values calculated for various reliable morphometric parameters such as mean bifurcation ratio, form factor and texture ratio associated with the basins. The circulatory and elongation ratios of the watersheds also indicate that Veshav River drains a large amount of water due to its more circular basin shape than Rembi Ara River which has an elongated shape. The relief and areal morphometric parameters like basin relief and length of overland flow reflected that Rembi Ara has a more flow velocity than Veshav due to differentials in quantitative drainage morphometric controls. The outcome of the study could be helpful in proper decision-making and sustainable management of the study area.

Keywords Watershed · Flood · Morphometric analysis · Parameters · Hazard

Introduction

Drainage morphometric analysis refers to the quantitative measurement and numerical analysis of linear, areal and relief parameters associated with a drainage basin. It plays an important role in analysing geo-hydrological processes of a drainage basin in relation to its terrain features and flow patterns (Prakash et al. 2019; Asfaw and Workineh 2019). The history of drainage morphometry or micro-morphometry dates back to Horton (1945) when advanced mathematical and statistical methods were applied to analyse the morphometry of small morphological units such as drainage basins. Before this, simplified methods were applied to study some selected parameters such as terrains, slopes and valleys by using small and large-scale topographical maps.

Currently, GIS and remote sensing (RS) have emerged very effective techniques as they help planners and policy

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makers to make efficient and correct decisions (Meshram and Sharma, 2015). These are powerful tools to identify resource imbalances in a watershed caused either by natural factors or anthropogenic activities (Prabhakar et al. 2019). The present focus of morphometric analysis is the application of remote sensing and geographic information system in order to accurately measure the different morphometric parameters with time and cost viability (Biswas et al. 1999; Bogale 2021). The measurement and analysis of morphometric parameters with the help of GIS and RS prove a feasible method for analysing the hydrological response behaviour of watersheds. It is ascertained that satellite data analysis through GIS and RS emerged as the most efficient, time saving, accurate and precise technique for morphometric analysis of a drainage basin (Ramaiah et al. 2012, Sujatha et al. 2013; Rai et al. 2014; Patil et al. 2019; Arefin et al. 2019). GIS- and RS-based drainage morphometric measurements and analysis are found to be cost-effective and time-saving approaches to characterise drainage basins as an alternative, complementary and accurate source of knowledge (Sahu et al. 2017; Kabite and Gessesse 2018). These techniques have proven to be effective tools in the delimitation of drainage basins and morphometric analysis (Mahala 2020; Resmi et al. 2019). The technology has assumed more significance for understanding the geomorphological features with the help of morphometric analysis due to diversity of data by using digital mapping which help in conversion of remote sensing data base to get a different data type like distance, area, point features, line features and polygon features. This has decreased the manual errors in morphometric analysis (Muliki and Basavarajappa 2007). The role of GIS and RS technology to prepare inventory, and management planning of geology is all over recognising technologies. We are more concerned with this modern technology because water availability is most significant thing, may be in particular situation, may be in particular season, if it is excess (flood), it may be issue, if it is less (drought), it may be issue (Sangle and Yannawar 2014).

Using watershed as a basic unit of study in drainage morphometric analysis is a logical choice because all hydrological and geomorphic processes occur within a watershed (Iqbal et al. 2013; Vyas and Singh 2020). Well-delimited drainage basins are a crucial factor in numerous natural resource studies such as assessment of floods, usage of water, basin protection, preservation and resource management planning (Angilieri and Fernandez 2017). Watersheds are basic units for management and development of resources (Chandra and Gidde 2019). They also serve as fundamental units to conserve natural resources (Chandrashekar et al. 2015).

Morphometric analysis of drainage basins is very important in the present world as different dynamic variables

directly or indirectly can be predicted well with morphometric analysis. Morphometric analysis is employed for prediction and assessment of floods, soil erosion and sediment yield of drainage basins (Sangeetha et al. 2019). The study of morphometry of a drainage basin helps in deciphering the erosion condition (Mahadevaiah and Narendra 2014). It is important in comprehending the interaction and inter-relationship of operating different processes and landform characteristics (Gabale and Pawar, 2015). Morphometric parameter analysis and estimation of runoff are useful in appropriate planning for optimum water utilization, conservation, ground water recharge, reduction in soil erosion and flood management (Shivaswamy et al. 2019). It helps to estimate the infiltration and runoff and other hydrological characteristics of a watershed like erosion and sediment yield which has a strong implication for natural resource management (Asfaw and Workineh, 2019). Runoff and flood potential of a drainage basin depend on its morphometric characteristics (Abdulkareem et al. 2018). This is a useful technique for rainwater harvesting and watershed development (Pande and Moharir, 2015). It can also prove a significant tool for assessment of groundwater zones and consequent development of groundwater (Prasad et al. 2008; Hajam et al. 2013; Singh et al. 2013; Kudnar and Rajasekhar 2020). To analyse the dynamics of a drainage basin, watershed prioritization and management in terms of soil erosion studies, groundwater potential assessment and flood hazard risk reduction in mountainous areas, morphometric analysis is essential (Biswas et al. 2014). Prioritization of watersheds, planning and development is very much dependent on drainage morphometric analysis (Fenta et al 2017; Suma and Srinivasa 2017; Chaubey et al. 2019; Odiji et al. 2021). For proper planning, management and development of soil and water resources, prioritization of a watershed is essential (Briceno et al. 2020). Prioritization of a watershed and its morphometric analysis proved to be important aspects of planning for implementation of management programmes (Said et al. 2018). Morphometric analysis of a watershed is important to identify and assess seasonal fluctuations in watershed characteristics, to analyse the potential of groundwater and to address issues related to management of soil erosion due to floods during peak seasons (Mangan et al. 2019).

A number of research works have been carried out on different watersheds in the valley of Kashmir. Some of the studies have focussed on the measurement of simple morphometric and morphotectonic values (Malik et al. 2011; Iqbal et al. 2013; Lone 2017) while some others have unearthed morphological and hydrological characteristics from the calculated morphometric parameters (Ahmad et al. 2013; Altaf et al. 2013; Meraj et al. 2019). A couple of studies (Malik et al. 2011; Altaf et al. 2013) have mainly focussed on southeastern Lidder catchment to investigate

the hydrological behaviour of the watershed in relation to geomorphological descriptors. However, the southwestern tributaries emerging from the eastern flanks of Pir Panjal have been less stressed from the viewpoint of morphometric analysis. The Veshav and Rembi Ara watersheds are equally important feeder channels to the main trunk stream that have been ignored in the previous studies. Moreover, in terms of the runoff potential, the selected watersheds are among the major contributors to the Jhelum River especially during peak flows (Meraj et al. 2019). Being present in a similar physiographic setting, the catchment scale plays an important role in defining various landscape and climatic descriptors that have a direct bearing on the surface hydrology of the streams. The current study was carried out with a similar intent to fill the missing gap in literature while understanding the hydrological behaviour of the selected watersheds with varied configuration by linking them with landscape descriptors. Such studies have become extremely important in the area especially after the disastrous September 2014 floods in the valley. The study can prove helpful to the planners in solving several scale-dependent issues including the risk of flooding in downstream areas.

Geographical setting

Veshav and Rembi Ara are the two important upstream tributaries of river Jhelum. The major watershed portion of Veshav falls in the Kulgam district. While as, watershed of Rembi Ara falls mostly in Shopian and Pulwama district of

South Kashmir. The watersheds of two rivers are consecutive in location having latitudinal extension of $33^{\circ} 82' N$ to $33^{\circ} 47' N$ and longitudinal extension of $74^{\circ} 51' E$ to $75^{\circ} 11' E$ (Fig. 1). The aggregate geographical area of the two watersheds is 9158.59 km^2 Fig. 2.

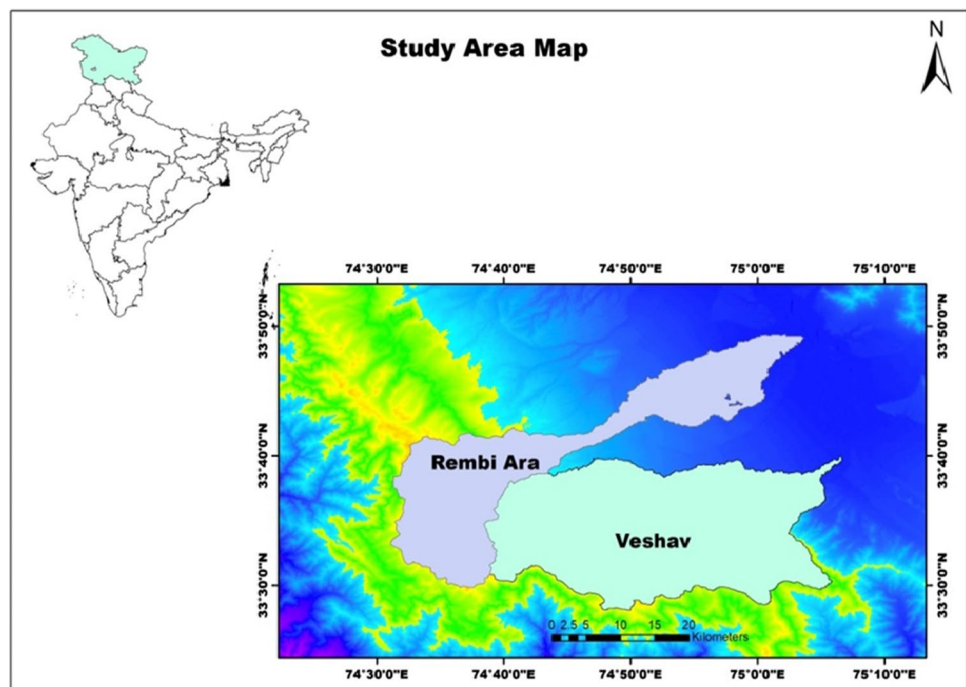
The maximum average temperature in the study area goes up to 35°C and average minimum temperature falls down to -10°C . The average annual precipitation is almost 2853 mm. Snow is the common form of precipitation during winter and early spring season and precipitation falls in the form of rain during rest seasons of a year (Shah and Lone 2019). River Veshav is a spring-born river which originates from a spring known as Kounsernag which is a perennial spring located in Pir Panjal Range. Therefore, the river also exhibits perennial character. While, river Rembi Ara is a seasonal river which originates from snow peaks and glaciers in the Rupri Ridge of Pir Panjal Range and Naba Pir Pass to the north of origin of river Veshav. The two rivers confluence at Sangam and finally join with Jhelum. Major part of watersheds of Veshav and Rembi Ara is engulfed in apple cultivation and there are also some patches where rice cultivation is done.

Materials and methods

Data sources

The remote sensing data (ASTER DEM of 30 m spatial resolution) obtained from earth explorer, United States

Fig. 1 Geographical setting of Veshav and Rembi Ara watersheds



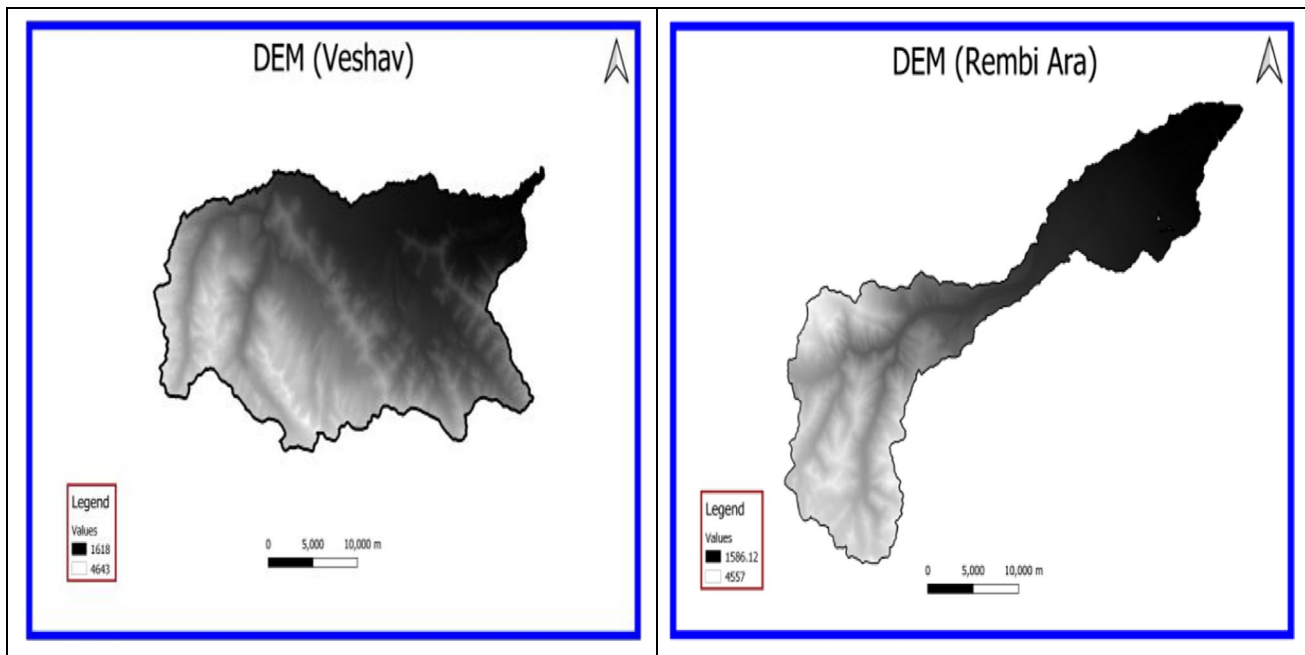


Fig. 2 Digital elevation model of Veshav and Rembi Ara watersheds

Geological Survey (USGS). The data tiles were merged in QGIS software by Mosaic Tool of Saga to form single raster data layer as per area of interest. Geospatial-based morphometric analysis provides more accurate and precise results in comparison to manual methods. The use of Geospatial software-based morphometric analysis has grown tremendously in recent past because of time and resource viability.

Methods

The methodological framework of the study was divided into two parts.

Delimitation of watersheds

DEM data was processed according to algorithmic procedure for watershed delineation in QGIS software. The mosaicked DEM was re-projected into WGS-84/UTM zone 43 N (EPSG 32,643). Fill sinks method of Wang and Liu was employed to fill sinks of the re-projected DEM. Wang and Liu method is regarded as the most accurate method to fill sinks of DEM. Strahler order was derived at the threshold level of ≥ 8 to easily identify n th order stream in mesh of small streams. Filled DEM was taken as an input layer for Channel networks and Drainage Basins tool to derive channels and basins. To identify n th order channel (main stream) and accurate pour point location, Open Street Map (OSM) was imported from the Quick Map Service Tool. The two drainage basins were delimited by taking the pour points

downstream. Pour point of Veshav was taken at $33^{\circ} 66' N$ latitude, $75^{\circ} 11' E$ longitude and that of Rembi Ara pour point was taken at $33^{\circ} 80' N$ latitude, $75^{\circ} 06' E$ longitude. The deduced raster basins were converted into vector format by a conversion tool in QGIS software.

Extraction and analysis of drainage morphometric parameters

Various quantitative drainage morphometric parameters were derived by using different algorithms in QGIS software. For drainage morphometric analysis, Strahler threshold level of ≥ 5 was taken into consideration. Threshold level of ≥ 5 is regarded as a feasible threshold for analysis of Himalayan drainage networks. The main parameters were obtained directly while as the derived parameters were calculated by applying various respective morphometric formulas in Microsoft excel. Stream orders, number of stream segments, stream lengths, flow direction and flow accumulation were calculated directly by Channel Network and Drainage Basins tool in QGIS software and area of the basin, basin perimeter, basin length and relief of the basin were calculated by using the Raster Calculator tool. While as, average stream length, bifurcation ratio, stream length ratio, average bifurcation ratio, relief ratio, drainage density, ruggedness number, stream frequency, texture ratio, form factor, circulatory ratio, elongation ratio, length of overland flow and constant channel maintenance were calculated by applying respective drainage morphometric formulas in Microsoft excel. The methods for derivation of primary

morphometric parameters, topographic position index and topographic wetness index are shown in Fig. 3. Topographic position index was directly calculated by inbuilt algorithm in QGIS software Figs. 4 and 5.

The topographic wetness index was derived by following algorithmic procedure in QGIS software by using the Raster Calculator tool.

Topographic wetness index equation:

$$TWI = \ln \left\{ \frac{(FlowAccumulation + 1 \times 30)}{\tan(ModifiedSlope \times 0.1745)} \right\}$$

here,

TWI = topographic wetness index.

Modified slope = (slope in degrees ≤ 0) \times 1 + (slope in degrees > 0) \times slope in degrees.

Flow accumulation = calculated by Flow Accumulation (QM of ESP) tool, using filled DEM as input.

A multiple of 30 was taken because ASTER DEM 30 m spatial resolution was used as input.

Results and discussion

Quantitative drainage morphometric analysis of Veshav and Rembi Ara watersheds was carried out with the help of QGIS software. Some of the morphometric parameters were directly chalked out from QGIS and some of them were calculated by using respective morphometric formulas in Microsoft excel. Various deduced morphometric parameters of two watersheds like linear, relief, areal, topographic position index and topographic wetness index are discussed below.

Linear drainage morphometric parameters of Veshav and Rembi Ara

Linear parameters of a drainage basin are one-dimensional morphometric characteristics (Asfaw and Workineh, 2019). Linear parameters are related to channel patterns of streams (Hajam et al. 2013; Patil et al. 2015). The primary linear parameters of stream order, stream length, basin perimeter and basin length were calculated by using various algorithmic procedures in QGIS software and the derived parameters of mean stream length, stream length ratio, bifurcation ratio and mean bifurcation ratio were calculated in Microsoft excel, using imported attribute data from QGIS software Table 1.

Stream order (U)

The hierarchical rank of stream segments of a drainage basin is known as stream order. It is one of the primary parameters of a drainage basin. Stream order is the 1st step for quantitative evaluation of a drainage basin (Singh et al. 2013; Iqbal et al. 2013; Meshram and Sharma 2015; Hajam et al. 2013;

Rai et al. 2019; Mahala 2020). Stream orders of Veshav and Rembi Ara watersheds were calculated by processing of DEM (30 m) in QGIS software. The Strahler stream order algorithm was employed to find stream order. In Strahler stream order, the threshold of > 5 was taken in Channels Network and Basin tool. The threshold level of > 5 is regarded as one of the best threshold algorithms for Himalayan drainage basins for calculating stream orders. At the same threshold value, stream order for Veshav was obtained as 6 while that of Rembi Ara it was obtained as 5 (Table 2). The stream segment of n th order is the main river of a basin. There exists a direct relationship between the stream order and river discharge. A higher stream order corresponds to a significantly greater discharge in comparison to a lower stream order (Costa 1987). Between the two watersheds, Veshav showed a higher stream order than Rembi Ara that concludes a greater contribution of flux by Veshav to the main Jhelum.

Stream number (N_U)

The number of stream segments corresponding to each order of a drainage basin is termed as stream number (Rai et al. 2019; Lama and Maiti 2019; Borkotoky et al. 2020). The number of stream segments is estimated individually for each order of a drainage basin (Chougale and Sapkale 2017). There is an inverse relationship between stream order and stream number, i.e. the higher the stream order, the lower is the stream number and the lower the stream order, the higher is the stream number (Meshram and Sharma 2015). Stream number is directly proportional to the basin size (Hajam et al. 2013). Out of the total stream segments for the Veshav watershed, 494 (50.36%), 253 (25.79%), 91 (9.28%), 97 (9.89%), 31 (3.16%), 15 (1.53%) belong to 1st, 2nd, 3rd, 4th, 5th and 6th order, respectively. Similarly for Rembi Ara watershed, out of the total streams, 355 (51.45%), 152 (22.03%), 75 (10.87%), 72 (10.43%), 36 (5.22%) belong to 1st, 2nd, 3rd, 4th and 5th order, respectively (Table 2). The number of streams for n th order of any drainage basin is 1. As QGIS divides the n th order of any drainage basin into various segments, the number of stream segments for the 6th order of Veshav was obtained as 15 and the number of stream segments for the 5th order of Rembi Ara was obtained as 36. A comparative analysis of the computed stream numbers especially for lower stream orders (like 1st and 2nd order streams) for the two watersheds reveals that Veshav receives increasing amount of water by having a larger number of feeders. Rembi Ara on the other hand shows lesser number of primary and secondary tributaries which becomes a genuine reason of lesser output to the main trunk stream. Besides, Veshav with higher stream number than Rembi Ara corresponding to almost each order has lesser permeability and infiltration or more runoff.

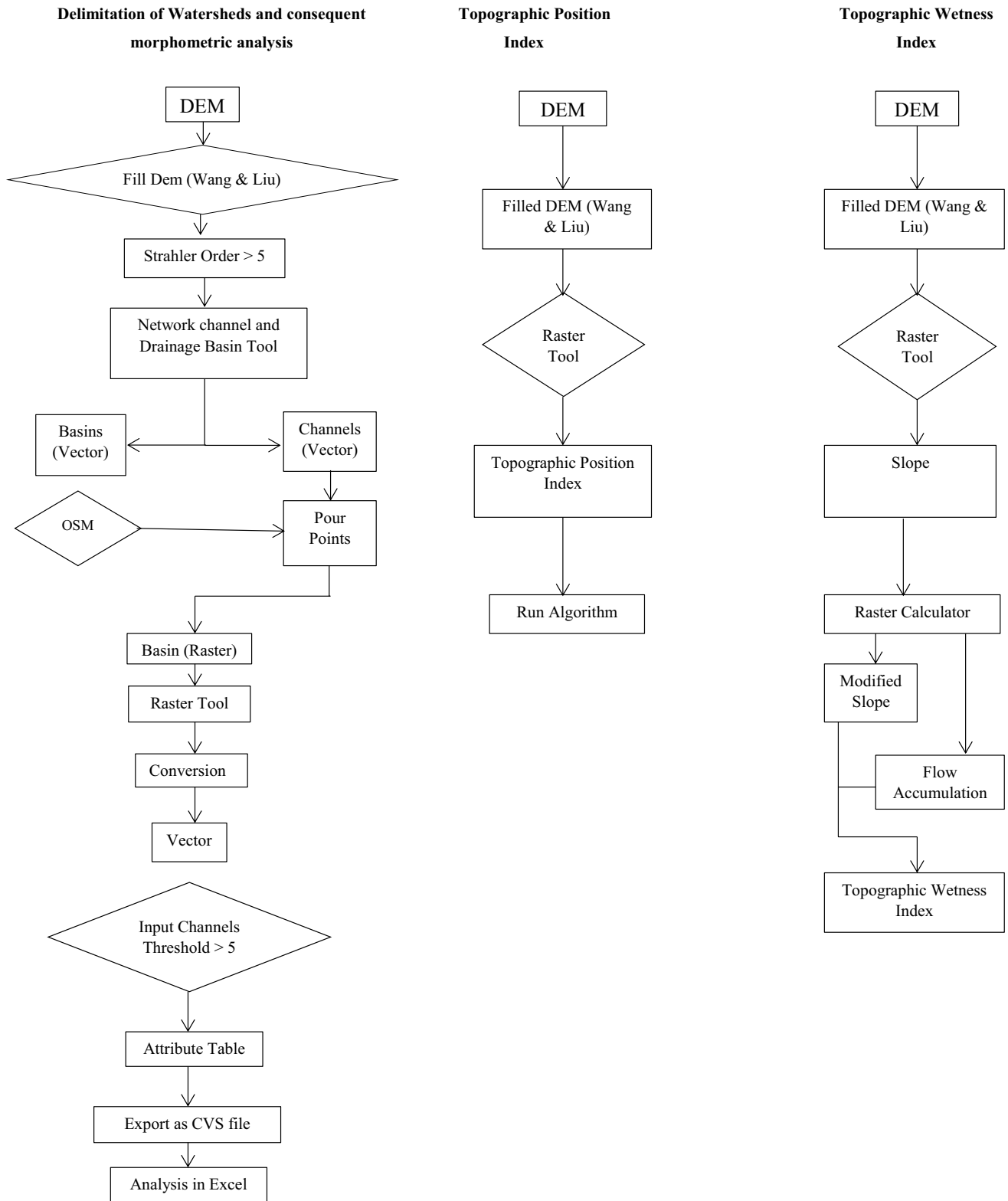


Fig. 3 Procedure for delimitation of watersheds and consequent morphometric analysis in QGIS software

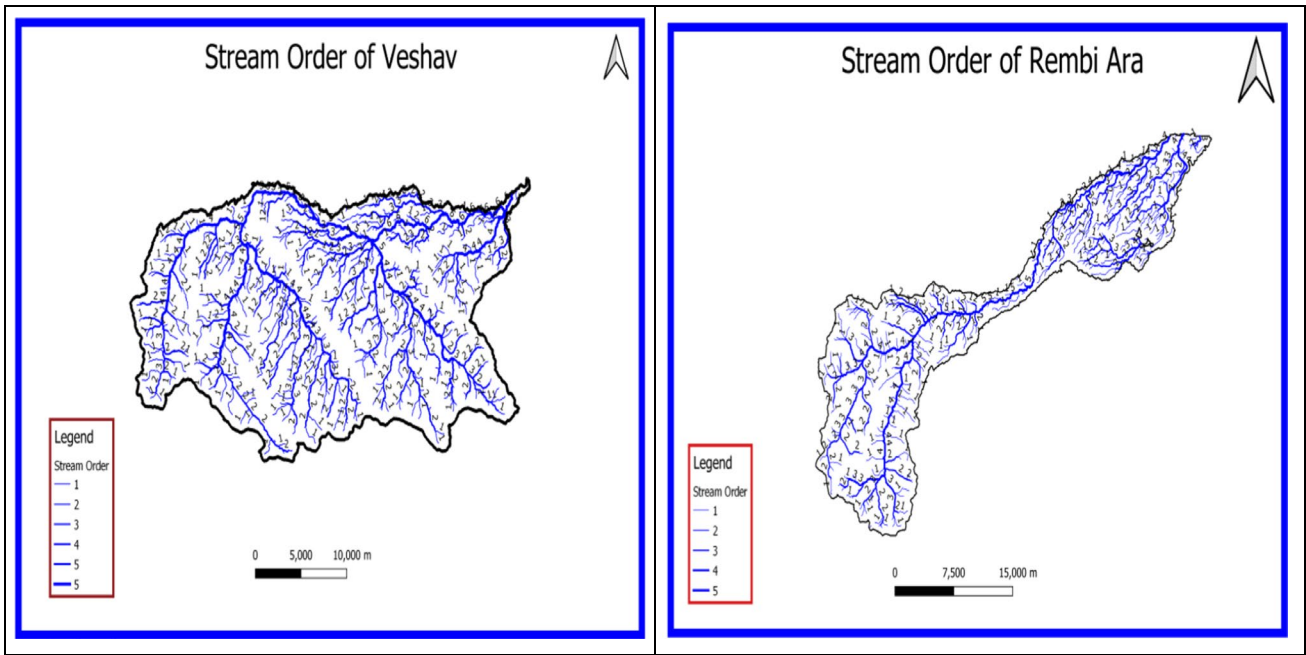


Fig. 4 Stream orders, number of stream segments of Veshav and Rembi Ara watersheds

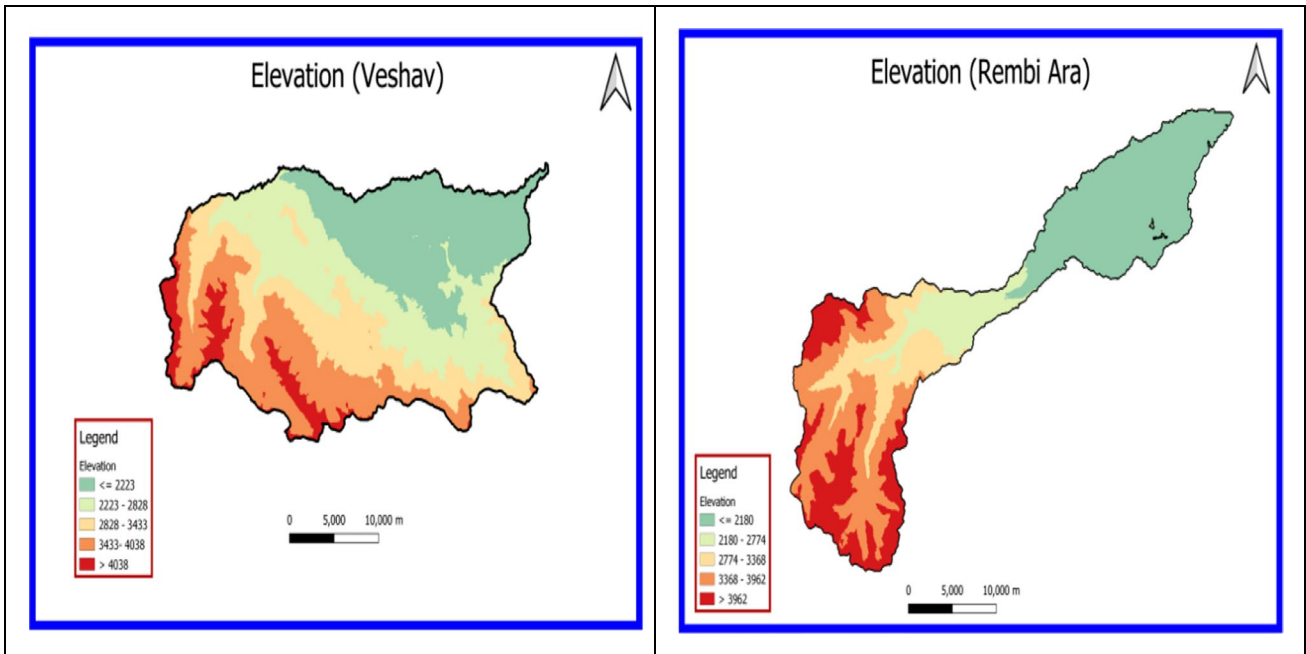


Fig. 5 Relief of Veshav and Rembi Ara watersheds

Stream length (L_U)

Stream length is the aggregate of all stream segment lengths of a given order is termed as stream length of that order (Chougale and Sapkale 2017; Lama and Maiti 2019). Stream

length also exhibits inverse relationship with stream order, the higher the stream order, the lower is stream length and the lower the stream order, the higher is the stream length (Iqbal et al. 2013). Stream length depicts the hydrological characteristics of bedrock and drainage extent (Rai et al.

Table 1 Methods for derivation of morphometric parameters

S. no	Type of parameter	Morphometric parameter	Methods
1		Stream order (U)	QGIS (channel network and drainage basins tool)
2		Stream number (N_U)	QGIS (attribute table, excel)
3		Stream length (L_U)	QGIS (attribute table, excel)
4		Basin perimeter (P)	QGIS (Raster Calculator)
5		Basin length (L)	QGIS (Raster Calculator)
6		Mean stream length (L_{sm})	$L_{sm} = \frac{L_u}{N_u}$ where, N_u L_u = total stream length of all stream segments of order 'u' N_u = total no. of all stream segments of the order 'u'
7		Stream length ratio (R_L)	$R_L = \frac{L_u}{L_{u-1}}$ where, L_{u-1} L_u = total stream length of all stream segments of order 'u' L_{u-1} = total stream length of all stream segment of order preceding 'u'
8		Bifurcation ratio (R_b)	$R_b = \frac{N_u}{N_{u+1}}$ where, N_{u+1} N_u = total no. of all stream segments of order 'u' N_{u+1} = total no. of all stream segments of order succeeding 'u'
9		Mean bifurcation ratio (R_{bm})	$R_{bm} = \frac{\sum R_b}{n \times u}$ where, $\sum R_b$ = sum of all bifurcation ratios of all orders $n \times u$ = sum of all orders
9		Basin relief (B_r)	$B_r = H - L$ where, H = highest point of the basin L = lowest point of the basin
10		Basin relief ratio (R_h)	$R_h = \frac{B_r}{L_b}$ where, B_r = basin relief L_b = basin length
11		Ruggedness number (R_n)	$R_n = B_r \times D_d$ where, B_r = basin relief D_d = drainage density
12		Area of basin (A)	QGIS (Raster Calculator)
13		Drainage density (D_d)	$D_d = \frac{L}{A}$ where, L = total length of all stream segments A = area of basin
14		Stream frequency (F_s)	$F_s = \frac{N_u}{A}$ where, N_u = total no. of stream segments of all orders A = area of the basin
15		Texture ratio (T)	$T = \frac{N_1}{P}$ where, N_1 = total no. of all stream segments of 1st order P = perimeter of the basin
16		Form factor (R_f)	$R_f = \frac{A}{L_b^2}$ where, A = area of the basin L_b = basin length
17		Circulatory ratio (R_c)	$R_c = \frac{4\pi A}{P^2}$ where, A = area of the basin P = perimeter of basin
18		Elongation ratio (R_e)	$R_e = \frac{\sqrt{\frac{A}{\pi}}}{L_b}$ where, A = area of basin L_b = length of basin
19		Length of Overland Flow (L_g)	$L_g = \frac{1}{2D_d}$ where, D_d = drainage density
20		Constant channel maintenance (C)	$C = \frac{1}{D_d}$ where, D_d = drainage density

2014; Lama and Maiti 2019). Stream length depends upon the permeability of bedrocks and formations. Small numbers of longer streams are formed where the bedrock and formation are permeable and in other areas, where the bedrock and formation are relatively less permeable, a large number of relatively small length streams are formed. The stream length of Veshav watershed for 1st, 2nd, 3rd, 4th, 5th and 6th orders was calculated as 415.43 km, 233.77 km, 86.03 km, 65.12 km, 24.06 km and 21.5 km, respectively. Similarly, the stream length for Rembi Ara watershed was computed as 318.44 km, 147.56 km, 71.08 km, 48.12 km and 24.11 km for 1st, 2nd, 3rd, 4th and 5th orders, respectively (see Table 3). Stream lengths of both the watersheds decrease with increasing stream order. Table 3 clearly shows that stream length of Veshav watershed dominates Rembi Ara in every order. A regular decrease in stream length from lower to higher order in both the watersheds is indicative of lithological consistency of the catchments. The regularity in the stream lengths across various orders also indicates a strong control of drainage characteristics on moving water. In other words, there is a lesser geological and morphological control on the movement of water passing through the two basins. Altaf et al. (2013) have reported a similar observation for Lidder watershed. It also becomes clear from the above data about stream lengths that the bedrock and formation of the Veshav basin are relatively less permeable compared to bedrock and formation of Rembi Ara basin.

Mean stream length (L_{sm})

Mean stream length is one of the derived linear parameters that depicts the characteristic size of components of a drainage basin (Rai et al. 2014; Chougale and Sapkale 2017; Lama and Maiti, 2019). It is a dimensionless morphometric measurement calculated by dividing the total length of all stream segments of a given order by respective number of stream segments of that order (Mahala, 2020). Mean stream length is derived average quantity computed from stream length of a watershed. Therefore, it also exhibits inverse relationship with stream order. Mean stream length of Veshav watershed was calculated as 0.84 km, 0.92 km, 0.94 km,

0.67 km, 0.77 km and 1.43 km for 1st, 2nd, 3rd, 4th, 5th and 6th orders, respectively. For Rembi Ara watershed, the mean stream length of 1st, 2nd, 3rd, 4th and 5th orders was calculated as 0.89 km, 0.97 km, 0.97 km, 0.66 km and 0.66 km, respectively (see Table 3). It becomes clear from the calculated L_{sm} values that both the watersheds violate the Horton’s law of stream lengths especially for the higher orders (like 4th and 5th orders). The discrepancies arising in the L_{sm} values across various orders indicate sudden changes in water flux characteristics due to changes in slope and geological setup of the basins. Moreover, high L_{sm} values of Rembi Ara watershed in comparison to Veshav watershed especially in the upper reaches (1st, 2nd and 3rd orders) are an indicator of low erosion potentialities for the basin.

Stream length ratio (R_L)

It is defined as the ratio of mean stream length of all stream segments of a given order and mean stream length of all stream segments of its preceding order and extends up to n th order as a series (Mahadevaiah and Narendra 2014). It is also derived linear morphometric parameter which is derived from mean stream length of n orders. The stream length ratio of a drainage basin changes according to the variations in slope and topography (Hajam et al. 2013). Stream length ratio of Veshav was calculated as 0.56, 0.36, 0.76, 0.36 and 0.89 for 1st to 2nd, 2nd to 3rd, 3rd to 4th, 4th to 5th and 5th to 6th orders, respectively (see Table 3). While calculating for the Rembi Ara watershed, 1st to 2nd, 2nd to 3rd, 3rd to 4th and 4th to 5th orders showed 0.46, 0.48, 0.67 and 0.50 as their respective stream length ratios. Both the watersheds showed changes in stream length ratio values. The fluctuating nature of the R_L values indicates that both the watersheds are characterised by early stages of geomorphic development. The anomalous R_L values across various orders for Veshav watershed give an indication that the catchment has a high potential of recurring changes in future that can further effect the hydrological behaviour of the watershed. In comparison, Rembi Ara has showed an almost constant R_L values especially for the lower orders (like 1st

Table 2 Stream orders, bifurcation ratios and mean bifurcation ratios of two watersheds

S. no	Stream orders	No. of stream segments		Bifurcation ratio		Mean bifurcation ratio	
		Veshav	Rembi Ara	Veshav	Rembi Ara	Veshav	Rembi Ara
1	1st order	494	355	1.95	2.33	2.16	1.84
2	2nd order	253	152	2.78	2.02		
3	3rd order	91	75	0.93	1.04		
4	4th order	97	72	3.12	2		
5	5th order	31	36	2.06			
6	6th order	15					

and 2nd) which means a regular hydrological behaviour specifically for the upper reaches.

Bifurcation ratio (R_b)

Bifurcation ratio is one of the most important derived linear morphometric parameters of a drainage basin which is derived from stream number of successive orders. It is calculated as a ratio of a number of streams of a given order to the number of stream of next higher order and extends as a series up to n th order (Schumm, 1956). Bifurcation ratio is related to the branching pattern of streams (Iqbal et al. 2013; Hajam et al. 2013; Prabhakaran and Raj 2017). Bifurcation ratio is a dimensionless quantity which shows degree of integration among stream number of various orders of a drainage basin (Rai et al. 2014; Lama and Maiti, 2019). Bifurcation ratio of Veshav for 1st to 2nd, 2nd to 3rd, 3rd to 4th, 4th to 5th and 5th to 6th orders were obtained as 1.95, 2.78, 0.93, 3.12 and 2.06, respectively. Similarly, for Rembi Ara, the bifurcation ratio was calculated as 2.33, 2.02, 1.04 and 2.00 for 1st to 2nd, 2nd to 3rd, 3rd to 4th and 4th to 5th orders, respectively (Table 2). It may be pointed out that bifurcation ratio for last order of a drainage basin is not calculated because it is a ratio which shows how many times the number of stream segment are in a given order with respect to number of stream segments of its next higher order. Both the watersheds showed low and have meagre difference in bifurcation ratios in different orders means both these watersheds have little control of structure on drainage morphometric development. Comparative to Rembi Ara watershed, Veshav showed a high bifurcation ratio in the 4th order that indicates a greater amount of water received in upper basin area.

Mean bifurcation ratio (R_{bm})

Mean bifurcation ratio is a derived linear morphometric quantity which is derived from bifurcation ratio. It is defined as average of bifurcation ratios and is calculated by dividing the total of bifurcation ratios of $n-1$ orders by $n-1$ orders (Rai et al. 2014). Mean bifurcation ratio of Veshav was calculated as 2.16 and that of Rembi Ara as 1.84 (Table 2). Veshav with high mean bifurcation ratio attains early hydrographic peak and has high potential of causing floods than Rembi Ara.

Relief morphometric parameters of Veshav and Rembi Ara

Relief morphometric parameters are three-dimensional morphometric characteristics of a drainage basin (Asfaw and Workneh, 2019). The primary relief morphometric parameters of basin relief and area of the basin were directly chalked out in QGIS software and the derived relief morphometric

parameters of basin relief ratio, ruggedness number, drainage density and stream frequency were calculated in Microsoft excel using respective morphometric formulas.

Basin relief (B_n)

Basin relief is one of the most important relief morphometric parameters of a drainage basin. It is important to analyse geomorphological processes of the area concerned (Hajam et al. 2013). It refers to the range between the highest and lowest point of the basin (Lama and Maiti, 2019). Basin relief was directly worked out in QGIS software by using ASTER DEM (30). Difference between the highest and lowest point of Veshav was calculated as 2916 m and that of Rembi Ara, it was calculated as 2970.89 m (Table 4). It needs to be stressed here that the calculated relief figures for the two watersheds represent their relative relief and not absolute. From the calculated figures, it becomes clear that stream channel slope and consequent flow velocity are relatively higher in Rembi Ara watershed than Veshav.

Basin relief ratio (R_r)

It refers to the ratio between basin relief and basin length which measures the overall steepness of a drainage basin and is regarded as one of the best indicators of erosion (Hajam et al. 2013; Ahmed et al. 2018). It is a dimensionless quantity. The basin relief ratio calculated for two drainage basins was 0.06 for Veshav and 0.05 for Rembi Ara watersheds (Table 4). Keeping other factors constant, a slightly higher relief ratio value for Veshav would indicate more intensity of erosion on the slopes of the watershed than Rembi Ara.

Ruggedness number (R_n)

Ruggedness number is defined as the product of basin relief and drainage density. It is an indicator of slope steepness together with its length (Strahler and Chow, 1964). The ruggedness number value for Veshav was calculated as 3.66 where as for Rembi Ara it was calculated as 4.57 (Table 4). Relatively higher R_n value for Rembi Ara watershed than Veshav indicates steeper and longer slopes for Rembi Ara which has a profound impact on the flow velocity of the concerned basin. Besides, a higher R_n value indicates a greater susceptibility of the basin area for soil erosion.

Areal morphometric parameters of Veshav and Rembi Ara

Areal morphometric parameters are the two-dimensional morphometric characteristics of a drainage basin. Areal

Table 3 Stream lengths, average stream lengths, stream length ratios and mean stream length ratios of two watersheds

S. no	Stream orders	Stream length (km)		Average stream length (km)		Stream length ratio	
		Veshav	Rembi Ara	Veshav	Rembi Ara	Veshav	Rembi Ara
1	1st order	415.43	318.44	0.84	0.89	0.56	0.46
2	2nd order	233.77	147.56	0.92	0.97	0.36	0.48
3	3rd order	86.03	71.08	0.94	0.97	0.76	0.67
4	4th order	65.12	48.12	0.67	0.66	0.36	0.50
5	5th order	24.06	24.11	0.77	0.66	0.89	
6	6th order	21.51		1.43			

parameters are governed by the area of the drainage basin (Patil et al. 2015). The areal morphometric parameter of basin area was directly calculated from QGIS software while the derived areal morphometric parameters of drainage density, stream frequency, texture ratio, form factor, circulatory ratio, elongation ratio, length of overland flow and constant channel maintenance were calculated by using respective methods in Microsoft excel.

Drainage density (D_d)

Drainage density is one of the most important areal morphometric parameters of a drainage basin which is calculated by dividing the total length of all stream segments of a drainage basin by the total area of the basin (Strahler and Chow, 1964; Waikar and Nilawar 2015). Drainage density measures the texture of a drainage basin and shows the equilibrium between erosive power of overland flow and the resistance of underlying rock (Lama and Maiti, 2019). The drainage density value calculated for Veshav is 1.26 km/km² while, for Rembi Ara, it was calculated as 1.36 km/km² (Table 4). Low drainage density indicates coarse drainage texture while high drainage density indicates fine drainage texture. Moreover, a direct link is established between the drainage density and the process of erosion taking place in a watershed (Ahmed et al. 2018). In the present study, Veshav watershed with relatively low value of drainage density is indicative of low relief, high infiltration capacity and low slope than Rembi Ara. Besides, the higher drainage density of Rembi Ara watershed also makes the catchment more susceptible to the risks of erosion.

Stream frequency (F_s)

Stream frequency is the measure of the total number of all stream segment of a drainage basin per unit area (Horton, 1932; Waikar and Nilawar 2015). It is also known as channel frequency or drainage frequency. It mainly depends on rock structure, vegetation cover, relief, nature and amount

of rainfall and subsurface material permeability and reflects the texture of the basin (Hajam et al. 2013). The stream frequency value of Veshav was calculated as 1.46 km/km² and that of Rembi Ara, it was calculated as 1.54 km/km² (Table 3). A lower F_s value for Veshav basin reflects lower permeability and low slope for Veshav in comparison to Rembi Ara watershed.

Texture ratio (T)

Texture ratio is defined as the total number of all stream segments of the 1st order of a drainage basin divided by perimeter of the basin (Horton, 1945). It mainly depends on climate, rainfall, type of rock, relief of the area, and stage of river development (Horton, 1945). The texture ratio values for the two drainage basins were calculated as 2.49 for Veshav and 1.51 for Rembi Ara (Table 4). A high texture ratio of Veshav than Rembi Ara indicates lesser permeability of rock and a higher discharge.

Table 4 Other drainage morphometric parameters of two watersheds

S. no	Other parameters	Veshav	Rembi Ara
1	Highest point	4534.00 m	4557.00 m
2	Lowest point	1618.00 m	1586.11 m
3	Basin relief	2916.00 m	2970.89 m
4	Relief ratio	0.06	0.05
5	Basin area	670.30 km ²	445.55 km ²
6	Basin perimeter	197.85 km	235.01 km
7	Basin length	45.48 km	57.94 km
8	Drainage density	1.26 km/km ²	1.36 km/km ²
9	Ruggedness number	3.66	4.57
10	Stream frequency	1.46 km/km ²	1.54 km/km ²
11	Texture ratio	2.49	1.51
12	Form factor	0.32	0.13
13	Circulatory ratio	0.21	0.10
14	Elongation ratio	0.32	0.20
15	Length of overland flow	0.39	0.36
16	Constant channel maintenance	0.79	0.73

Form factor (R_f)

One of the most important areal morphometric parameter of a drainage basin is form factor. It is defined as the ratio of basin area to the square of basin length (Horton, 1932). It is measurement of circularity of a drainage basin. The higher the value of form factor, the more circular is the basin, the lower the value of form factor, the more elongated is the basin (Choudhari et al. 2018). In other words, a higher value of form factor indicates a wider basin while as a lower value corresponds to a narrow basin (Chandrashekar et al. 2015). The value of form factor for Veshav was calculated as 0.324 while, for Rembi Ara, form factor was calculated as 0.132 (Table 4). Rembi Ara watershed is more elongated than Veshav. It is evident from results that accumulation of water in Veshav would be rapid than Rembi Ara because elongated drainage basins generally have lower peak flow of longer duration while basins with high form factor have high peak flows of shorter duration. Therefore, Veshav watershed has a higher flood-causing capacity than Rembi Ara watershed.

Circulatory ratio (R_c)

Circulatory ratio is the ratio of area of the basin to area of circle having same circumference as the perimeter of the basin (Miller, 1953). It is a significant areal morphometric parameter which shows different stages of a watershed

development. High, medium and low circulatory ratio indicates the old, mature and young stages of a watershed. Circulatory ratio of a drainage basin is influenced by geological structure, slope of the basin, climate, relief and land cover (Choudhari et al. 2018). Besides, the parameter shows an inverse relationship with the erodibility factor associated with a particular watershed (Ahmed et al. 2018). The circulatory ratio of Veshav and Rembi Ara was calculated as 0.215 and 0.101, respectively (Table 4). The relatively higher R_c values for Veshav watershed indicates more circular character and high peak flow runoff than Rembi Ara watershed. The lower circulatory ratio shown by Rembi Ara produces a greater influence on erodibility when compared to Veshav.

Elongation ratio (R_e)

Elongation ratio is defined as the ratio between diameter of the circle of the same area as drainage basin and maximum length of drainage basin (Schumn, 1956). It is an indicator of basin shape, infiltration capacity and runoff. The higher the value of elongation ratio, the more circular is the basin and the more is discharge and less infiltration. The lower the value of elongation ratio, the more elongated is the basin and high infiltration and less runoff (Choudhari et al. 2018). Elongation ratio calculated for Veshav was 0.321 and that of Rembi Ara, it was calculated as 0.205 (Table 4). The results reveal that Rembi Ara is a more elongated basin than Veshav and is less efficient at

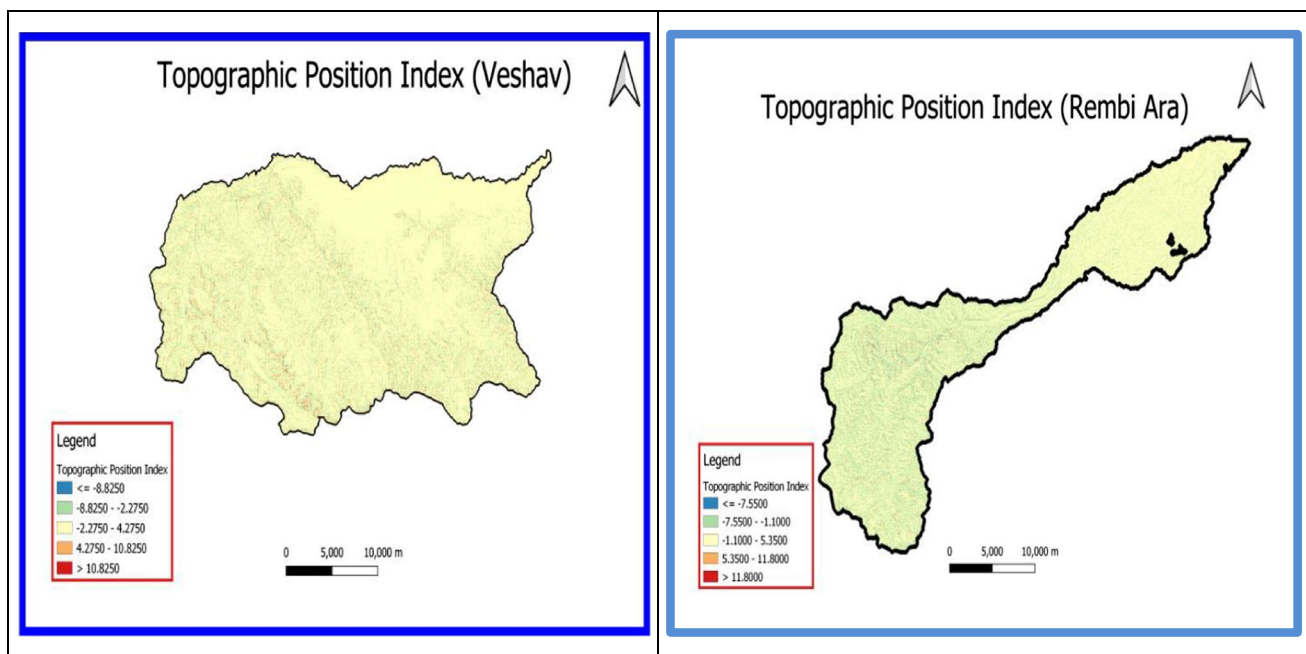


Fig. 6 Topographic position index of Veshav and Rembi Ara watersheds

discharging the runoff. In other words, Rembi Ara would show lower flood regime than Veshav watershed in case of a specified storm event.

Length of overland flow (L_g)

Length describes the length of flow of water over ground before it gets accumulated in definite stream segments. It determines the erosion threshold of a drainage basin. It is defined as half of the reciprocal of drainage density (Horton 1945). There exists an inverse relationship between length of overland flow and average slope of channel (Ramaiah et al. 2012). Length of overland flow affects hydrological and hydrographic development of a drainage basin (Altaf et al. 2013). The length of overland flow calculated for river Veshav and river Rembi Ara was 0.396 (Veshav) and 0.365 (Rembi Ara) (Table 4), respectively. Lower L_g value for Rembi Ara watershed indicates steep slopes and shorter flow paths in comparison to Veshav watershed that showed relatively higher value for the parameter.

>Constant channel maintenance (C)

Constant channel maintenance describes requirements of units of a watershed surface to bear one unit of channel length (Schumn 1956; Lama and Maiti 2019). It is an inverse of drainage density and has dimension of length.

Therefore, it increases in magnitude as the scale of drainage basin increases (Adhikari, 2020). Higher value of constant channel maintenance indicates low value of drainage density and lower value of constant channel maintenance indicates high value of drainage density. Constant Channel Maintenance value for Veshav was calculated as 0.793 and that of Rembi Ara, it was calculated as 0.731 (Table 4). A higher value of C for Veshav indicates more resistant soils, good vegetation and relatively plain terrain when compared to Rembi Ara watershed.

Topographic position index

Topographic position index (TPI) is a geo-spatial algorithm used to measure slope positions. It determines physical processes acting on landscape of a drainage basin. Elevation of each cell in a DEM is compared with mean elevation of around that cell with the help of topographic position index. TPI was directly computed from inbuilt algorithm in QGIS software. TPI values calculated for two watersheds range from -8.82 to 10.82 (Veshav) and -7.55 to 11.80 (Rembi Ara) (Fig. 6).

Negative TPI values indicate the areas which are lower than their neighbourhood (valleys) while the positive TPI values indicate areas which are higher than their neighbourhood (ridges). A higher range of TPI for Rembi Ara watershed indicates greater unevenness of the surface and hence higher flow velocity as compared to Veshav.

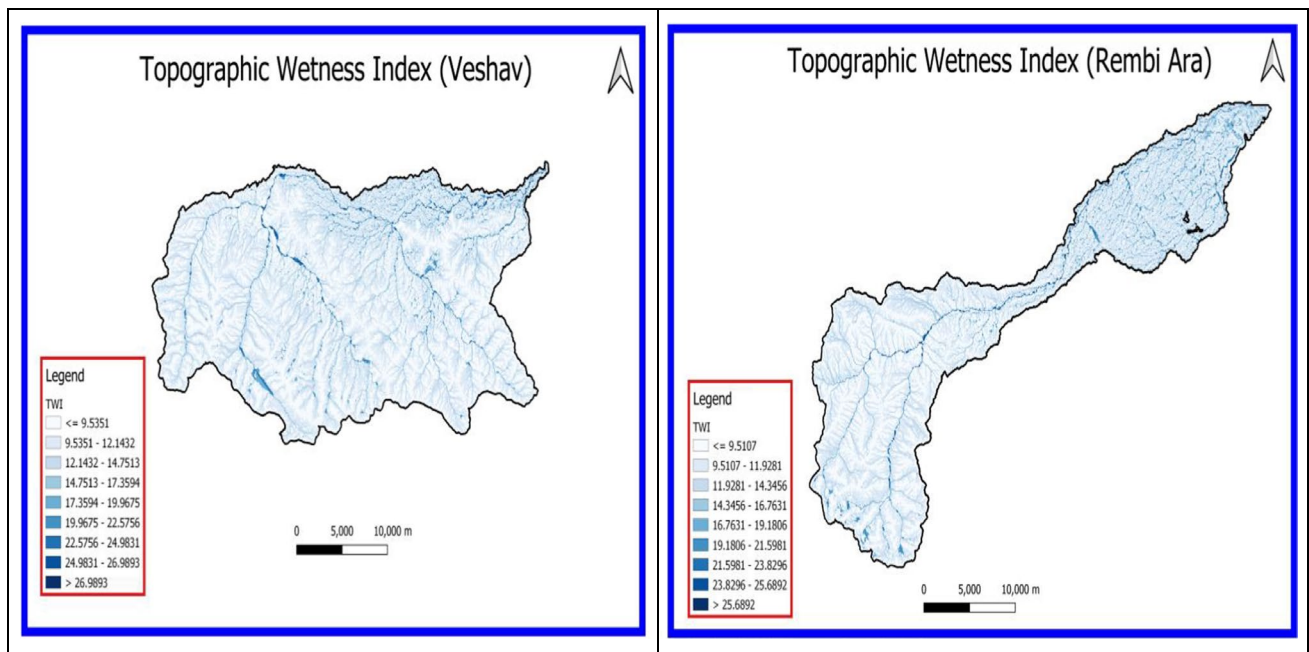


Fig. 7 Topographic wetness index of Veshav and Rembi Ara watersheds

Topographic wetness index or compound topographic index

Topographic wetness index (TWI) is used to measure topographic control on hydrological processes. It indicates the tendency of an area to accumulate water (Mattivi et al. 2019). Slope and upstream contributing area are the two determinants of topographic wetness index. High TWI value means more runoff and consequent high flow while low TWI value means high infiltration and low flow. In other words, there is direct positive correlation between TWI and water flow. The maximum TWI values for two drainage basins were calculated as 26.98 (Veshav) and 25.68 (Rembi Ara) (Fig. 7), respectively. A higher value of TWI or compound topographic index (CTI) for Veshav indicates higher accumulation of water in the basin upon comparison with Rembi Ara.

Conclusion

Watershed is selected as a basic unit for drainage morphometric analysis because of its geomorphic and hydrological unity. Morphometric analysis of Veshav and Rembi Ara watersheds was carried out by using remote sensing and GIS technology using QGIS software. Morphometric characteristics of two watersheds were classified into three aspects linear, relief and areal. Both the watersheds of Veshav and Rembi Ara located in same geographical setting having difference in morphometric characteristics show different hydrological behaviour. Veshav having more favourable morphometric characteristics for high flow accumulation, high runoff, efficient discharge and less infiltration has high flood potentiality than Rembi Ara. A number of linear (like stream order, stream number, stream length, mean bifurcation ratio) and areal (like drainage density, form factor, elongation ratio) morphometric parameters support the observation. The relief parameters such as basin relief and ruggedness number indicate a higher flow velocity of Rembi Ara than Veshav. The bifurcation ratio computed between consecutive stream orders of Veshav also reveals a greater contribution of 2nd and 4th order streams to discharge during a rainstorm event while as the same was provided by 1st and 2nd order streams for the Rembi Ara watershed. Furthermore, with sustained water flow in comparison to Rembi Ara, Veshav watershed is more suitable for the development of water supply systems especially for the downstream areas that can prove highly beneficial during prolonged dry spells.

Acknowledgements The authors are highly grateful to the United States Geological Survey (USGS) for providing free of cost raster data set in the form of Digital Elevation Model (DEM). The authors are also thankful to the Sher-e-Kashmir University of Agricultural Sciences and

Technology (SKUAST), Kashmir, for providing necessary training in QGIS software.

Author contribution MI prepared the basic methodological framework and chalked out the results; HS did the formal analysis; IF wrote the draft; NY generated different map layers and prepared the necessary tables.

Funding The study was financially supported by the University Grants Commission (UGC), Government of India, by providing fellowship to 1st and 3rd authors of study in the form of JRF Fellowship.

Declarations

Conflict of interest The authors declare no competing interests.

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