Quantitative Analysis and Drainage Dynamics of Mawar Basin, Northwest Himalaya, J&K, India

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Abstract

The high gradient rivers of Himalaya are the most vital source of water supply in one hand and cause of flooding on the other hand in the Himalayan provinces of India, with recent examples being Kashmir and Assam floods. Therefore, in order to understand the dynamics of the Mawar basin, the whole basin has been sub-divided into 22 sub-watersheds and consequently 28 morphometric parameters have been calculated under the four main categories: drainage network, basin geometry, drainage texture and relief characteristics. The numerous morphometric characteristics have been correlated with one another in order to better understand their underlying link and control over the hydrogeomorphology of the basin. The findings show that the area is well drained by first and second order streams, with the highest drainage area, resulting in a difficult topography with deep incised valleys. High run-offs are generated by the high and steep relief rivers, moderate to high permeability of the surface is generally in circular sub watersheds with a high circularity ratio. Sub watersheds with these parameters infer these are vulnerable to flooding, soil erosion, and debris flow. Due to increased erosion and slope characteristics, fourth and fifth order streams flowing along local fault zones may cause landslides. Furthermore, as the incision of streams along the week Karewa and fractured fault zones increases, the silt load of the streams increases, potentially triggering flash floods. Tectono-morphic landforms created along the Mawar River are influenced by abrupt topographic discontinuities along the river's 6th order stream profile at various locations. The importance of examining the morphometric features of the Mawar basin is that it will assist future watershed and hazard management studies. The region is subject to regular flash floods and landslides due to the steep topography. Hence, such type of studies will provide knowledge and database for decision making for strategic planning and delineation of prioritized hazard management zones.

Keywords: Tectono-morphic, Mawar, morphometric, hazard, drainage

Introduction

Morphometric analysis is a significant step forward in the quantitative representation of drainage basin shape. The measurement and quantitative analysis of the layout of the earth's surface, as well as the shape and dimensions of its landforms, is known as morphology. (Clarke,1966). Morphometric studies entail calculating streams by measuring numerous stream features, such as linear, areal, and relief features. The morphometric parameters describe the features and character of drainage basins and their associated drainage networks. Drainage basin morphometric features are quantitative attributes of landscape obtained from the topography/terrain or elevation surface and drainage network within a drainage basin. The applications of quantitative techniques in morphometric analysis of drainage basins was first carried out by Horton (Horton, 1932) from the topographic maps using manual methods. Geospatial techniques which include the combined approaches of Remote Sensing (RS), Global Mapper (GM), Global Positioning system (GPS) and Geographical Information system (GIS) are widely utilized to carry out the morphometric analysis of the drainage basins throughout the world. (Williams,1972; Buccolini *et al.*, 2012; Bali *et al.,* 2016; Wani and Bali, 2017).

The morphometric features of distinct drainage basins in India have been studied using quantitative methodologies (Vittala *et al.,* 2004; Pareta and Pareta, 2012). Several researchers have investigated morphometric properties of a drainage basins as an indicator of the structural effect on drainage development and neo-tectonic activity. (Ahmed *et al.*, ,2012; Bali *et al.,* 2016; Wani *et al.,* 2019; 2020). Many studies have employed morphometric analysis to analyse the basins' groundwater potentiality and to determine potential places for check dams and artificial recharge projects. (Sreedevi *et al.*, 2005; Jasim & Mallikarjuna, 2013). Prioritization of watersheds based on morphometric characteristics has also been undertaken, which aids in the mapping of high-flood-risk and erosion-prone zones. (Javed *et al.,* 2 011; Romshoo *et al.*, 2012; Malik *et al.*, 2011; Mir *et al.,* 2018). The current study connects the surface morphometry and underlying geology of a drainage basin to generate useful information for basin management.

Thus, keeping in view the above discussion, the present study was to carried out to investigate the morphometric parameters of the Mawar River basin and to determine the influence of the underlying geology on the basin's morphometric characteristics. And finally, to construct a comprehensive knowledge foundation regarding the interconnection between surface morphometry and subsurface lithology for integrated basin management in terms of soil erosion, flood hazard, landslide management and tectonics.

Drainage, tectonic setup and geology of the basin

The Mawar River basin is located in Kupwara district of Jammu and Kashmir (**Figure 1**) and situated between latitude 34° 24' 22" N-34° 15' 00" N and longitude 74° 22' 30" E-74° 58' 7.5" E. The tributaries of Mawar River, such as, Hardikhar, Batanwalanar, Kandi are fed by springs and glaciers of Kazinag range (**Figure 2)**. The basin covers catchment area of 265 km^2 and has a perimeter of 92.47 km. The region receives heavy snowfall between December and February and rainfall in March and April which varies from 510 mm -1710 mm annually (Hassan, 1999). In Kashmir valley, major NW-SE trending thrusts and the Kashmir Basin Fault (KBF) almost running along Jhelum River and Balapur fault almost running along the foot of the Pir Panjal Range crossing some mighty rivers (Rambaria, Romushi, Doodhganga, Ferozpur, Ningili) originating from PPR (Ahmed *et al.*, 2013;

Shah, 2013) are the main structural units. The KBF divides the valley into two tectonic blocks NET and SWT on the basis of geomorphology (Shah, 2013). Many other faults have been identified in the middle portion of the basin which has affected the basin geomorphologically.

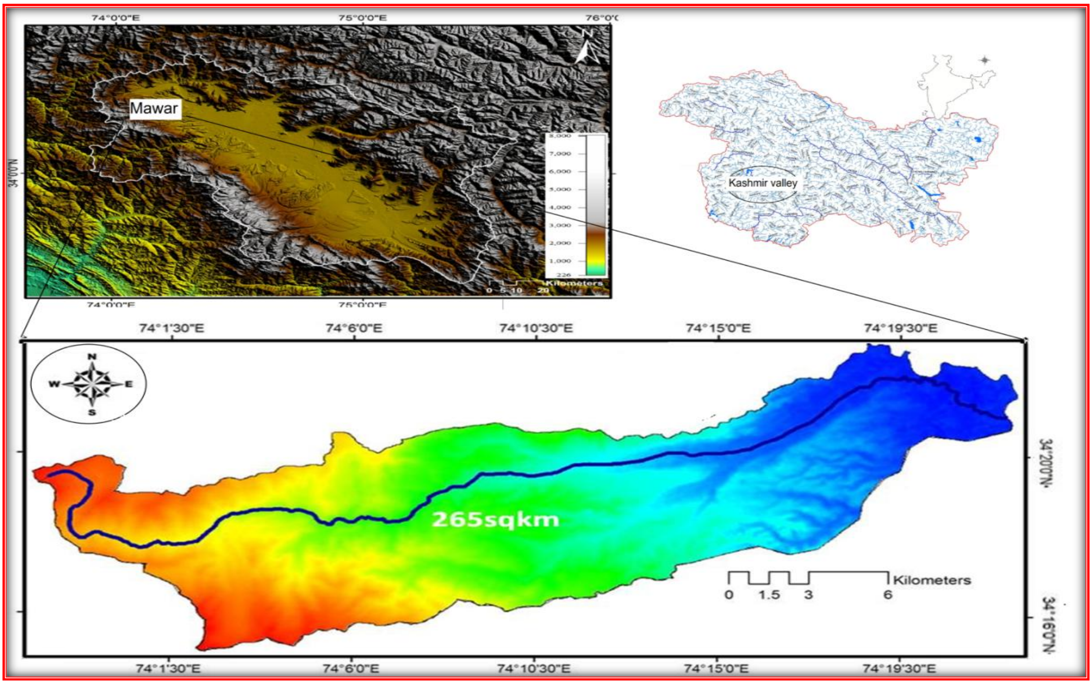


Figure 1: Location map of the study area

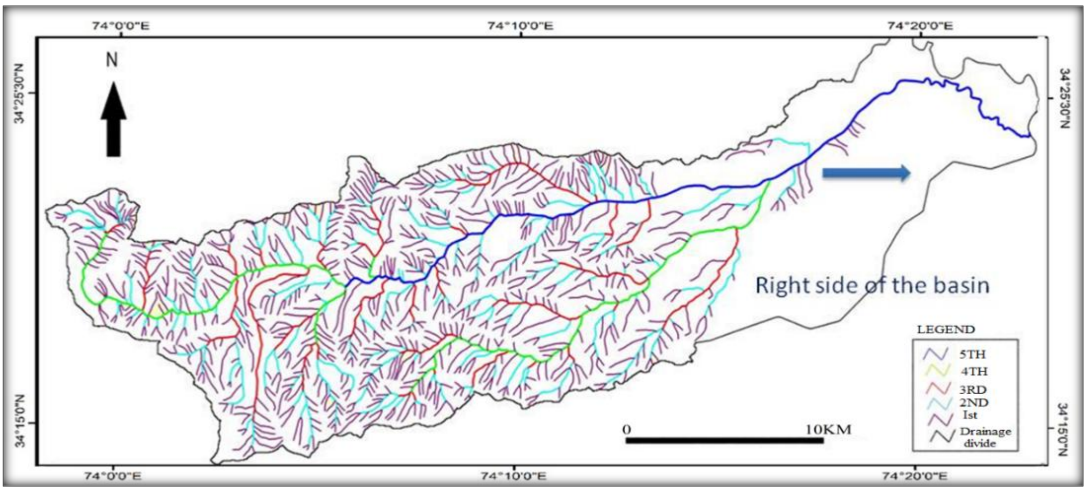


Figure 2: Stream orders of Mawar basin (ranked according to Strahler).

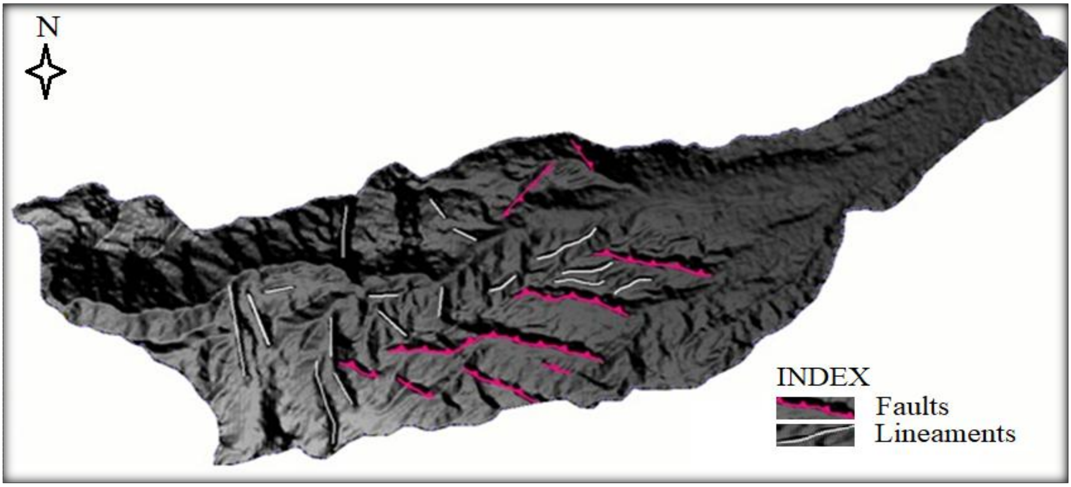


Figure 3: Faults and lineaments (after Shah, 2016; Wani *et al.,* ,2019)

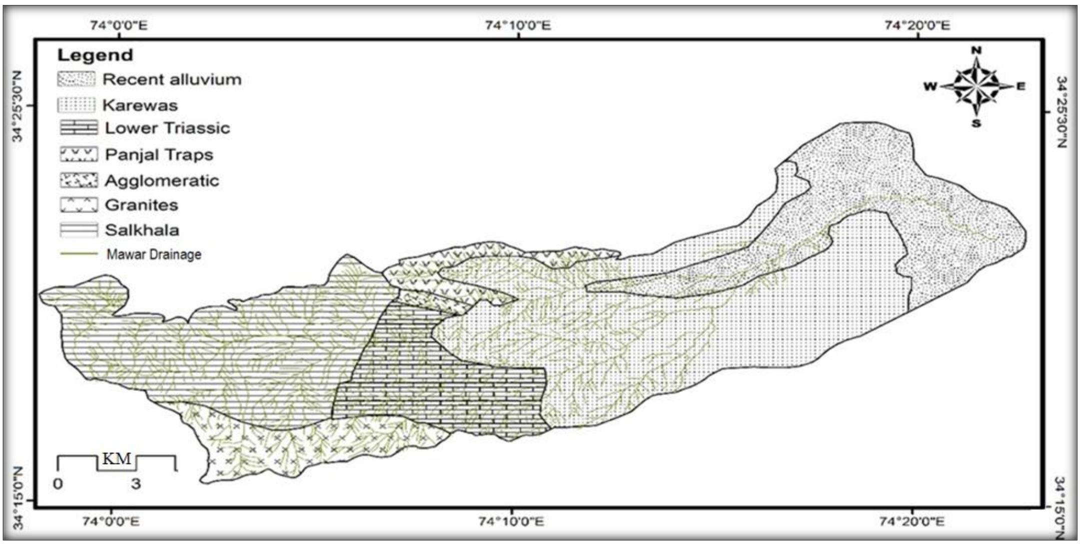


Figure 4: Geological map overlain by drainage

The basin is underlain by rocks belonging to five main geological formations: Salkhalas, Agglomeratic slates, Granites, Panjalvolcanics, Karewas and Quarternary deposits. The upstream portion of the Mawar basin, which is mainly drained by two major tributaries, namely,Kenry originating from Asthanmerg Mankul on its left bank downstream at Vehama, then flows down till it reaches Batgund where it receives Hardkhar Nala originating from Manabal, which is underlain by Salkhala series and granites. The middle portion of the basin is underlain by rocks consisting of Quarternary deposits (Karewas) and little portion is underlain by Panjal volcanic, whereas near the mouth of the basin, it consists of Agglomeratic slates and recent deposits (**Figure 4**). The presence of local faults across the drainage network of the Mawar River basin influences the drainage and relief characteristics of the Mawar River.

Methodology

The extraction of drainage network has been done from SOI Toposheets 1972 with 1:50000 scale. After drainage extraction the Mawar river was found to be 6^{th} order according to Strahler ordering scheme. Then the watershed was dived into sub watersheds. To delineate the sub watersheds, flow direction and flow accumulation raster the generation of depression less DEM is always the preliminary step. This problem can be solved through watershed process/technique by first locating and filling depressions. The standard flow routes and sub watersheds are produced by further modelling of these two rasters. Mawar river basin can be classified into 22 sub-watersheds. In this study we include only those watersheds which comprises of at least streams of three different orders. Consequently, 28 morphometric parameters mentioned in the (**Table 1**) have been computed for each of the sub watersheds. The drainage network, basin shape, drainage texture, and relief were all used to evaluate the morphometric characteristics. The various parameters were then correlated in order to determine how they interact and influence one another. Students' t-test and derived values were used to examine the reliability of the correlation of determination (**Table 2**).

To understand the drainage basin dynamics viz a viz their and their usefulness in prioritization of watersheds and management (especially in terms of ground water potential assessment, soil erosion studies, tectonic character and flood hazard risk reduction in mountainous rivers). The morphometric and tectono-morphic parameters including both surface and sub- surface characteristics have been undertaken.

Results and discussion

The River Mawar having a length of 41.08 kms covers an area of about 265 km^2 (**Table 1**) being tectonically active many structures have been identified in the middle of the basin. Knick points have been marked along the Mawar River's stream profile at a few locations when the stream's slope abruptly changes (K1 and K2) which corresponds to two local faults present along the Kenry stream (**Figure 3**). These two small local faults and other already identified faults cross the middle segment of the basin and crosses the basin in northeast-southwest direction with sub-watersheds (WS2, WS7, WS11 and WS10). Typically, these fault zones are weak, cracked, and brecciated zones that are easily carved by streams. The numerous morphometric factors have been described in the following part in order to identify soil erosion studies, groundwater potential evaluation, tectonic character, and flood hazard risk. To address the hydrodynamic features of a drainage basin, stream segmentation and hierarchical ordering are required. For the Mawar River Basin, stream ordering was done using Strahler's hierarchical ranking system. (Strahler, 1964). Two 5^{th}order streams of Kandi and Hardikhar combine to form Mawar, the 6th order stream in the basin (**Figure 2**). The Mawar basin's total stream length is 62042 km (**Table 1**), with the first and second order streams accounting for 82.70 percent. Although the study region is highly susceptible to sesimic landslide activities particularly because of the active lineaments and faults in the middle. However, because of the disturbed land use pattern and loose sediments, the area is equally vulnerable to non-seismic landslides during the rainy season. Landslide vulnerability has the same morphometric elements as erosion hazard vulnerability. The spatial distribution of the landslide vulnerability with in the sub basin is depicted in the (**Figure 5**). Out of total 22 subbasins, seven have been placed in high landslide vulnerability whereas only eight sub basins are found be moderate and seven sub basins are found to have low landslide hazard vulnerability.

Drainage network

In the Mawar basin, the stream length ratio (L_{ur}) varies from 1.05 to 2.06 and is high for 3rd and 5th order streams. (**Table 2**). With increasing stream order, the number of streams (Nu) decreases as the mean stream length increases (L_{ur}) (**Table 2**). The RHO coefficient (σ) and bifurcation ratio (R_b) values range from 1.01-1.25 and 0.5-8.0 in the study region (**Table 1**) respectively. The variation in L_{ur} between successive stream orders of Mawar River is owing to the greater number of streams in lower orders, showing that the basin is still in its early stages of development. High R_b values and trellis drainage pattern in sub watersheds belonging to WS9, WS10, WS17, WS18 and WS19 (**Table 3**) indicate structural control on the development of drainage network. The σ value represents a basin's storage capacity and establishes the link between drainage density and basin physiographic development. Sub-watersheds in the category of WS3 and WS22, which have high values of σ are at a greater risk of being eroded by the excess discharge during flood.

Basin geometry

Structure, lithology, relief, and precipitation all control shape of the basin, which ranges from narrow elongated forms with irregular basin perimeters to circular or semicircular forms. The Mawar basin's circularity ratio (KA) ranges from 0.2 to 0.6 (**Table 1**), with high values in WS4, WS8, WS12, WS14, WS17, WS18 and WS19 and low values in WS1, WS2, WS3, WS5, WS6, WS7, WS9, WS11, WS13, WS15, WS16, WS20, WS21 and WS22 (**Figure 5 a**). WS3, WS4, WS6, WS7, WS8, WS11, WS12, WS13, WS14, WS16, WS20, and WS22 have high elongation ratio (E_b) values, whereas WS3, WS4, WS6, WS7, WS8, WS11, WS12, WS13, WS14, WS16, WS20, and WS22 have low values (Figures 5(b), 5(c). The compactness coefficient (C_c) has a strong negative association with KA, whereas the compactness coefficient (F_f) has a positive association with E_b. (**Table 2**; Sreedevi *et al.,* 2005). Low K_A values are associated with high relief and steep slopes, implying that these sub watersheds are young. Sub watersheds with high K_A, E_b, F_f, R_t, and Dt values and low C_c values have a more circular form. Although circular sub watersheds are more efficient in terms of run-off discharge (Singh and Singh, 1997), due to their shorter lag time and higher peak flows than elongated basins, they are more vulnerable to flooding (Waugh, 1978). Elongated sub watersheds, on the other hand, have low side flow for a shorter period of time and a higher main flow for a longer period of time, making them less prone to flooding.

Table 1: Linear correlation among selected morphometric parameters of Mawar river basin along with the calculated t values.

Variable (X_{axis}- Y_{axis})	**Linear equation**	**r^2**	**{t}**
Circularity ratio- compactness coefficient	Y=0.0131x+2.003	0.112	21.53
Form ratio-elongation ratio	Y=0.052x+0.237	0.093	1.32
Drainage density-stream frequency	Y=0.168x+2.842	0.323	3.05
Constant of channel maintenance-stream frequency	Y=-6E-05x+0.393	1E-06	10.29
Constant of channel Maintenance - Drainage density	Y=-6E-05x+0.393	1E-06	7.04
Length of overland flow- stream frequency	Y=-3E-05x+0.196	1E-06	11.15
Length of overland flow- Drainage density	Y=0.1092x+2.364	0.1252	7.93
Relief ratio-basin length	Y=0.0743x+1.21	0.1833	0.50
Drainage texture-ruggedness number	Y=0.01x+0.924	0.0161	2.25

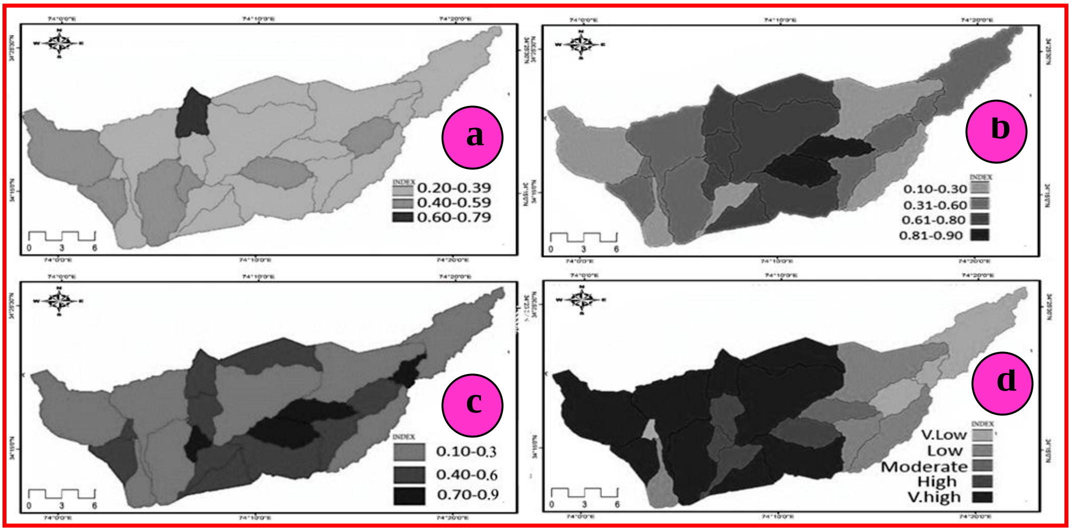


Figure 5: Map showing response of basin geometry parameters of sub-watersheds (a) Circularity ratio (b) Form factor (c) Elongation ratio (d) Drainage texture

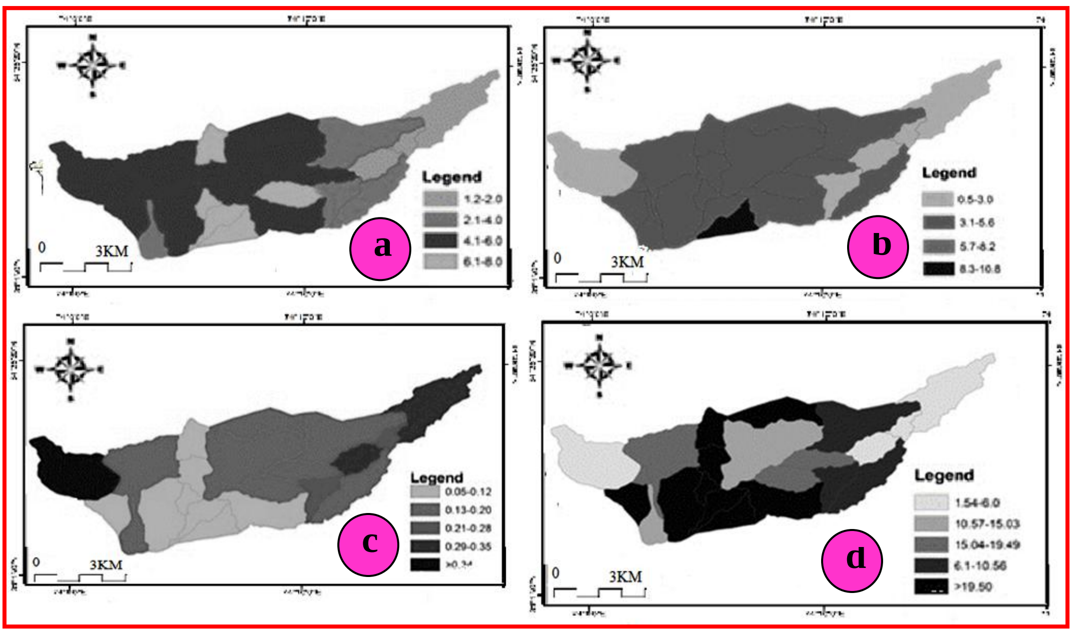
Table 2: Various morphometric parameters calculated for Mawar river basin from four aspects a) drainage network b) basin geometry, c) drainage texture and d) relief characteristics.

S. No	Morphometric parameters	Formulae	Reference	Results
	Drainage	**Network**		
1	Stream order (S_u)	Hierarchical	Strahler,1952	1 -5
2	Stream number (N_u)	$N_u = N_1 = N_2 + \ldots + N_n$	Horton,1945	918
3	Stream Length (L_u)	$L_u = L_1 + L_2 + \ldots + L_n$	Schumm,1955	62042
4	Stream length ratio (L_{ur})	$L_{ur} = L_u / L_{u-1}$	Horton,1945	
5	Mean bifurcation ratio (R_b)		Strahler,1964	
6	Minimum areal distance (A_{du})			
7	Rho coefficient (ρ)		Horton,1945	1.01-1.25
Basin geometry				
8	Basin length (L_b)		Schumm,1956	36.4
9	Basin area (A)		Schumm,1956	265
10	Basin perimeter (P)		Schumm,1956	92.4
11	Form factor (F_f)		Horton,1945	0.2-2.1
12	Elongation ratio (E_b)		Schumm,1956	0.1-2.5
13	Circularity ratio (K_A)		Muller,1968	0.2-0.6
14	Drainage texture (D_t)		Horton,1932	0.3-4.5
15	Compactness coefficient (C_c)		Gravelius *et al.*, ,1941	1.3-2.3
Drainage texture				
16	Stream frequency (F_s)		Horton,1932	1.2-7.3
17	Drainage density (D_d)		Horton,1932	0.5-10.5
18	Constant of channel maintenance (C)		Schumm,1956	0.1-1.9
19	Drainage intensity (D_i)		Faniran,1968	0.7-11.4
20	Infiltration number (I_f)		Faniran,1968	1.6-76.6
21	Length of overland flow (L_g)		Horton,1945	0.05-0.96
Relief characteristics				
22	Minimum elevation at mouth (z)			1577
23	Highest elevation (Z)			4135
24	Total basin relief (H)		Strahler,1952	2558
25	Relief ratio (R_h)		Schumm,1956	0.07-0.51
27	Ruggedness number (R_n)		Strahler,1964	0.26-16.08
28	Dissection index (D_{is})		Singh and Dubey, 1994	0.07-0.62

Drainage texture analysis

Texture indicates the amount of landscape dissection by a channel network and includes stream frequency (F_s), drainage density (D_d), constant of channel maintenance (c), length of overland flow (L_g) and infiltration number (I_f). High values of F_s and D_d are found in WS7, WS8, WS9, WS11, WS12,WS13,WS14,WS15,WS16,WS17,WS19 and WS20, whereas low values of are found in WS1, WS2, WS3, WS4, WS5, WS6, WS10, WS18, WS21 and WS22 (**Figures 6 a & 6 b**). The C value of Mawar basin varies from 0.10 to 1.9 (**Table 1**). The l_g value of Mawar basin value from 0.05 to 0.96 and L_f value ranges from 1.6 to 76.6 (**Table 1**). Low L_g values and high I_f values are found in WS2, WS5, WS7, WS8, WS9, WS10, WS11, WS12, WS13, WS14, WS15, WS16, WS17, WS18, WS20 and WS22 (**Figure 6 c and 6 d)** which have corresponding high Fs and D_d values. F_s and D_d provide a numerical measurement of landscape dissection and run-off potential (Vijith & Sateesh, 2006) and bears an inverse relationship with L_g and I_f (**Table 2**). Sub-watersheds belonging to WS2, WS5, WS7, WS8, WS9, WS10, WS11, WS12, WS13, WS14, WS15, WS16, WS17, WS18, WS20 and WS22 with low values of L_g and c have developed numerous drainage lines on the surface. The high values of F_s and D_d in these sub watersheds may be due to high relief, steep slopes, and also hard rock landscape and low infiltration of the underlying rocks.

Figure 6: Map showing response of various drainage texture parameters in sub watersheds of Mawar river basin (a) Stream frequency (b) Drainage density (c) Length of overland flow (d) Infiltration number.



Relief characteristics

In morphometric analysis, relief parameters take into account the effects of aspect and height over a large basin region. The erosion potential of the processes functioning within a drainage basin is indicated by the relief ratio (R_h), roughness number (R_a), and dissection index (D_{is}).The Mawar basin has total calculated total basin relief (Z-z) of about 2558 m (**Table 1**). The R_h value for the Mawar basin varies from 0.03–0.51, with high values in WS7, WS8, WS9, WS10, WS11, WS12, WS13, WS14, WS15, WS16, WS17, WS18, WS20, WS21, and WS22 and low values in WS1, WS2, WS3, WS4, WS5, WS6, and WS19. (**Figure 7 a**). WS9, WS10, WS11, WS15, WS16, WS17, and WS19 have high R_n and D_{is} values, indicating steep slopes and a high degree of dissection, whereas WS1, WS2, WS3, WS4, WS5, WS6, WS7, WS8, WS12, WS13, WS14, WS18, WS20, WS21, and WS22 have low R_n and D_{is} values, (**Figures 7 b and 7 c**). R_h has negative correlation with basin length and is connected to the channel gradient. Sub watersheds having high values of D_t also have high values of R_n since R_n has a positive correlation with D_t (**Table 2**). The low D_{is} of Mawar basin (0.14–0.62) indicates that the basin is moderately dissected (**Table 1**).

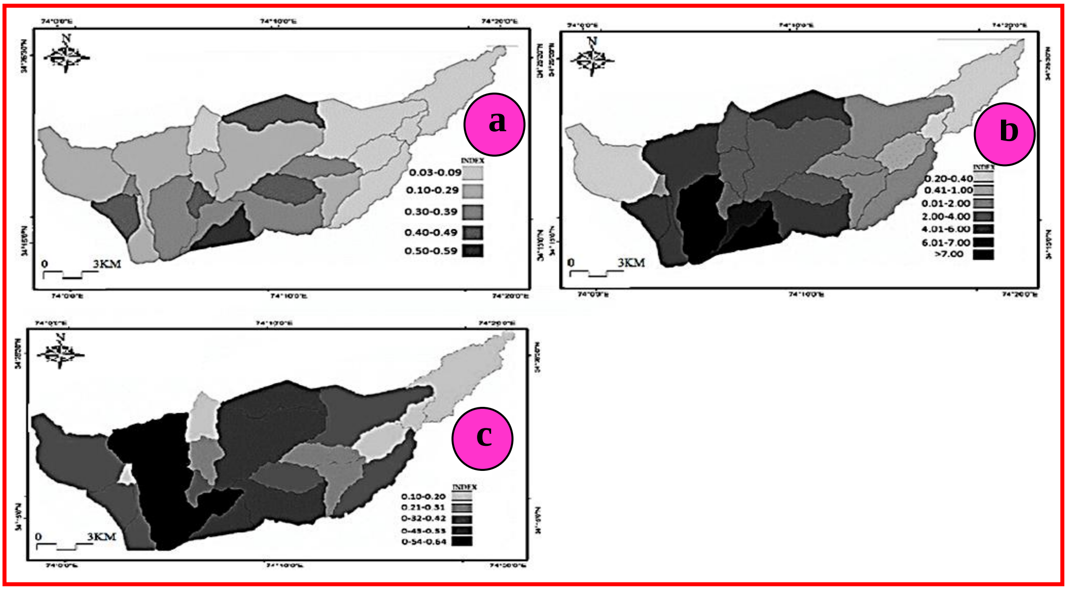


Figure 7: Map showing response of various parameters of relief characteristics in sub watersheds of Mawar River basin. (a) Relief Ratio (R_h). (b) Ruggedness Number (R_n). (c) Dissection Index (D_{is}).

Hypsometric analysis

Hypsometric analysis is a useful method for determining the stages of geomorphic evolution and geological history of a river catchment, as well as determining the watershed's erosional proneness. Younger stages are indicated by convex hypsometric curves, mature stages by S-shaped curves, and peneplain stages by concave curves. (Strahler, 1964). Twenty-two fourth order sub-basins of the Mawar basin were chosen for this study and hypsometric analysis was performed using a 30 m ASTER DEM. Within the Global Mapper Environment, the hypsometric integral values were calculated manually. The hypsometric integral values range from 0.36 to 0.62. The hypsometric curves, on the other hand, show remarkably upward convex shapes, indicating that all sub-basins including the Mawar basin are in the early stages of geomorphic development. As a result, they are prone to erosion, incised channel erosion, and mass movement activity. Variations in tectonic action, lithology, and rejuvenation processes account for minor variances in mass loss from the watershed among the 22 sub-basins. These findings will aid in the development of appropriate soil and water conservation measures across the watershed and its sub-basins to limit sediment discharge, prevent soil erosion, and conserve water.

The hypsometric curve's calculated parameters are sensitive to small variations in overall basin slope and basin growth as material is eroded away over a long geological time period. The current study demonstrates that headward development of the main stream and its tributaries results in high hypsometric skewness values as in case of Harlin, (1980). The density function of the curve, on the other hand, is directly linked to rates of change in overall basin slope and the tendency toward geomorphic equilibrium (Harlin, 1980). The behavior of slope change in the basin is interpreted by density skewness and the presence of fluvial dominance over the region's landforms is indicated by a positive density skewness score. The value of the hypsometric Kurtosis supports the dominance of erosional processes in both the upper and lower reaches of the basin (Luo, 2000). Due to the platy kurtic nature of density Kurtosis value, the mid basin slope is moderate. The Mawar basin's HI value of (0.58) suggests that it is still in its early stages of development (Strahler,1964). A few sub-watersheds showing the low values of H1 (**Figure 8**) have reached a mature stage and are in the process of achieving dynamic equilibrium The majority of the sub watersheds with high HI are near faults identified in the field and faults reported by Shah (**Figure 3**) Which also indicate a subsurface control on the Mawar River basin's maturity. The result thus generated provides adequate knowledge base required for decision making during planning and delineation of prioritized hazard management zones in mountainous terrains.

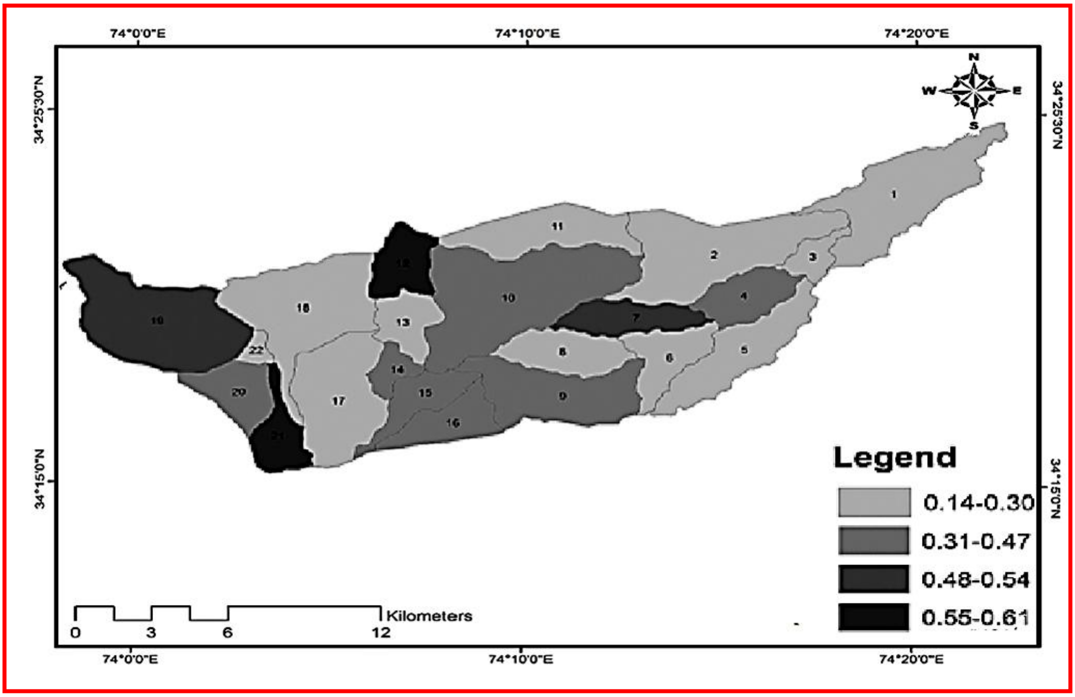


Figure 8: Map showing the variation of hypsometric integral among the sub-watersheds of Mawar basin.

Conclusion

There is a structural influence on drainage development with trellised pattern being the dominant drainage pattern with parallel type towards. The basin shows some anomalous values of hypsometric and other variables suggesting the structural control on the basin. Many structures like faults, joints, folds, strath terraces, Knick points in the Karewa beds indicates the neo-tectonic activity in the basin. Other geomorphological features viz deeply incised valleys, In this hilly terrain, meandering is mostly caused by headward erosion, which is typical of basins in their youthful stages of development. The area is well drained by the first and second order streams, which have the largest drainage area, resulting in a rugged topography with deep incised valleys. High run-offs are generated by high relief, moderate to high surface permeability, and somewhat circular sub watersheds with a high circularity ratio, making these sub watersheds more vulnerable to floods, soil erosion, and debris flow. Due to increased erosion and slope characteristics, fourth and fifth order streams flowing along local fault zones may cause landslides. Furthermore, as the incision of streams along the week Karewa and fractured fault zones increases, the silt load of the streams increases, potentially triggering flash floods. Tectono-morphic landforms created along the Mawar River are influenced by abrupt topographic discontinuities along the river's 6th order stream profile at various locations.

The importance of examining the morphometric features of the Mawar basin is that it will aid future watershed and hazard management studies. The region is subject to regular flash floods and landslides due to the steep topography. As a result, such research will provide knowledge and data for strategic planning and the delineation of prioritized hazard management zones. Through the understanding of the relationship between basin morphometry and subsurface structure, the authors suggest that the lower middle area of the basin underlain by Karewas has substantial groundwater potential, which might be harnessed to aid the residents of neighboring villages. It may also assist in identifying the region's groundwater potential and identifying effective water harvesting sites. Other mountainous river basins throughout the world could be also benefited from these morphometric techniques. In the Mawar watershed, which is an important tributary of the Pohru river, morphometric analysis has a wider application in watershed prioritization and management, soil erosion research, groundwater potential evaluation, and flood hazard risk reduction.

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