GIS based Comparative Morphometric Analysis of Selective Upper and Lower Watersheds of Jhelum Basin India

Muzamil Ahmad Rather[1]
Department of Civil Engineering
SRM University, Chennai, Tamil Nadu, India

Majid Farooq[2]
Department of Environment and Remote Sensing J&K, India

Mohammad Muslim[3]
Department of Environment and Remote Sensing J&K, India

Abstract— **Morphometry is the most important technique to study a drainage basin. It incorporates quantitative study of the various components such as, stream segments, basin length, basin parameters, basin area, altitude, volume, slope, profiles of the land which indicates the nature of development of the basin. The basin morphometric parameters are believed to be very important for surface processes. These parameters are very useful in various studies of geomorphology and surface-water hydrology, such as flood characteristics, sediment yield, and evolution of basin morphology. The Jhelum basin is bounded between the Himalayas and Pir Panjal mountain ranges. The Jhelum basin has 24 tributaries and some of them drain from the slope of the Pir Panjal range and join the river on the left bank and some others flowing from Himalayan range and join the river on the right bank. The present work is a comparative study of four watersheds of Jhelum basin, two from upper catchment and two from lower catchment of Jhelum basin. The outcome as per various shape parameters like form factor ratio, circulatory ratio, elongation ratio etc reveals that Arin watershed is very less elongated, which means there will be early hydrograph peak flow, followed by Bringi and Madhumati. The Sandran watershed is highly elongated which means there will be delayed hydrograph flow. Drainage parameters like stream frequency, infiltration number etc indicates that Arin watershed is highly permeable watershed with high infiltration rate and low runoff, followed by Bringi and Madhumati where as Sandran is impermeable with low infiltration rate and high runoff From the integrated analysis of the morphometric parameters, important hydrologic behavior of four watersheds could be inferred. These studies are very useful for watershed management.**

Key words: Morphometry, Jhelum Basin, watershed

INTRODUCTION

A watershed is an area of land and water bounded by a drainage divide within which the surface runoff collects and flows out of the watershed through a single outlet into a lager river on the other hand measurement and mathematical analysis of the configuration of the earth's surface shape, and dimension of its landforms is called morphometry [1]. Several quantitative methods have been developed in order to understand the evolution and behavior of drainage patterns [2]. In hydrology, basin drainage characteristics are fundamental in understanding various hydrological processes. Since watershed is the basic unit in hydrology therefore, morphometric analysis at watershed scale is advantageous and preferable rather carry it out on individual channel or inconsistent segment areas. Hydrologic and geomorphic processes occur within the watershed, and morphometric characterization at the watershed scale reveals information regarding formation and development of land surface processes [3]. Using conventional techniques, morphometric characterization of many river basins and sub basins in different parts of the globe has been carried out [4].The morphometric analysis is of immense importance in river basin evaluation, watershed prioritization for soil and water conservation and natural resources management. The influence of drainage morphometric system is very significant in understanding the landform processes, soil physical properties and erosion characteristics. Drainage characteristics of many river basins and sub basins in different parts of the globe have been studied using conventional methods [5].With the advancement in the field of science and technology particularly in geospatial and computer technology, the drainage basin morphometry analysis has been more accurate, precise and less time consuming. Nowadays, using Geographical Information System (GIS) technique, various terrain and morphometric parameters of the drainage basins are evaluated with more ease and better accuracy. Remotely sensed data and GIS have been successfully employed to generate data on the spatial deviations in drainage characteristics thus providing an insight into hydrologic conditions necessary for developing watershed management strategies [6]. GIS, being a powerful tool for the manipulation and analysis of spatial information, provides a flexible environment for morphometric analysis. The morphometric characteristics at the watershed scale may contain important information regarding its formation and development because all hydrologic and geomorphic processes occur within the watershed [7]. Morphometric analysis of a watershed provides a quantitative description of the drainage system, which is an important aspect of the characterization of watersheds [8]. In recent years, the Remote Sensing coupled with GIS technique has been emerged as a tool in river morphometric analysis [6]. All these studies have portrayed only the individual significance of the morphometric parameters, while the present makes a comparison of the morphometric parameters of different upper watersheds of Jhelum basin.

STUDY AREA

The valley of Kashmir constitutes the north western part of Himalayas, situated between 33° 55′to 37° 05′ N latitude and 74° 30′ to 75° 35′ E longitude. The Kashmir valley is surrounded by the lofty peaks of Pir Panjal in the west and Zanskar ranges in the east and north east. The geomorphology of valley is controlled mainly by regional setting. The influence of tectonic movements on the Kashmir valley has predominantly carved the present geomorphology of the valley. The Kashmir valley, which forms a composite Jhelum basin, has a fairly well established drainage system headed by the Jhelum, the main channel of drainage. The river is initially formed by the junction of 3 streams, the Arapal, the Bringi and the Sandran which rise at the south-east end of the valley. Out of 24 watersheds of the Jhelum basin the Bringi, Sandran watersheds of upper Jhelum basin and Arin and Madhumati of lower watersheds of upper Jhelum basin form the study area for the present work (figure 1). Table 1 shows Latitudinal and Longitudinal extend of study area.

Table 1 Latitudinal and Longitudinal extend of selective watersheds

Name of Watershed	Longitude		Latitude	
	From	To	From	To
Arin	74° 36′01″ E	74° 53′30″ E	34° 18′ 45″ N	34° 27′ 40″ N
Madhumati	74° 31′01″ E	74⁰ 56′30″ E	34° 24′ 09″ N	34° 36′ 30″ N
Sandran	75° 05′30″ E	75⁰ 26′08″ E	33° 22′ 07″ N	33° 44′ 30″ N
Bringi	75° 05′05″ E	75⁰ 32′ 03″ E	33° 22′ 30″ N	33° 46′ 06″ N

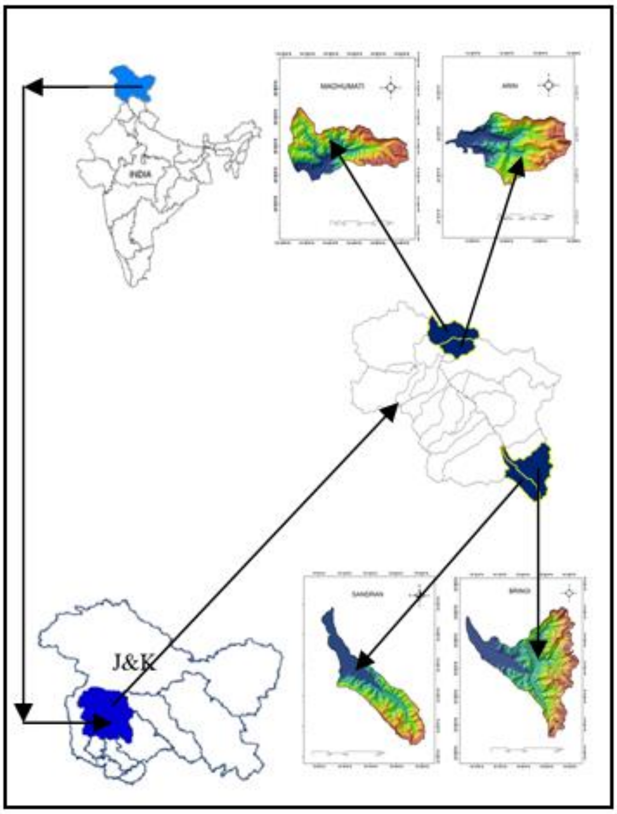

Fig. 1 Location of Study Area

MATERIALS AND METHODOLOGY

The data set used in this study for accomplishing the respective objective is the ASTER (Advanced Space borne Thermal Emission and Reflection Radiometer) DEM with 30m spatial resolution. In order to accomplish the research objectives it is important to device a proper methodology. In the present study the morphometric parameters were estimated using drainage generated from Advanced Space borne Thermal Emission and Reflection Radiometer (ASTER) with 30m spatial resolution Digital Elevation Model (DEM). After the processing of DEM, the steps like fill sink, flow direction, flow accumulation, Thresholding and stream grid were followed one after the other. For proper determination of flow direction and flow accumulation, DEM sinks were identified and filled. The critical threshold is the minimum upstream drainage required to initiate a stream. In the present study a threshold of greater than two hundred fifty was used to generate drainage. Figure 2 shows the flowchart of methodology adopted. Morphometric parameters were derived using different mathematical formulae (Table 2). For stream ordering Strahler's scheme has been used in this study. Strahler's scheme was originally introduced by Horton and later on modified by [5], [6].

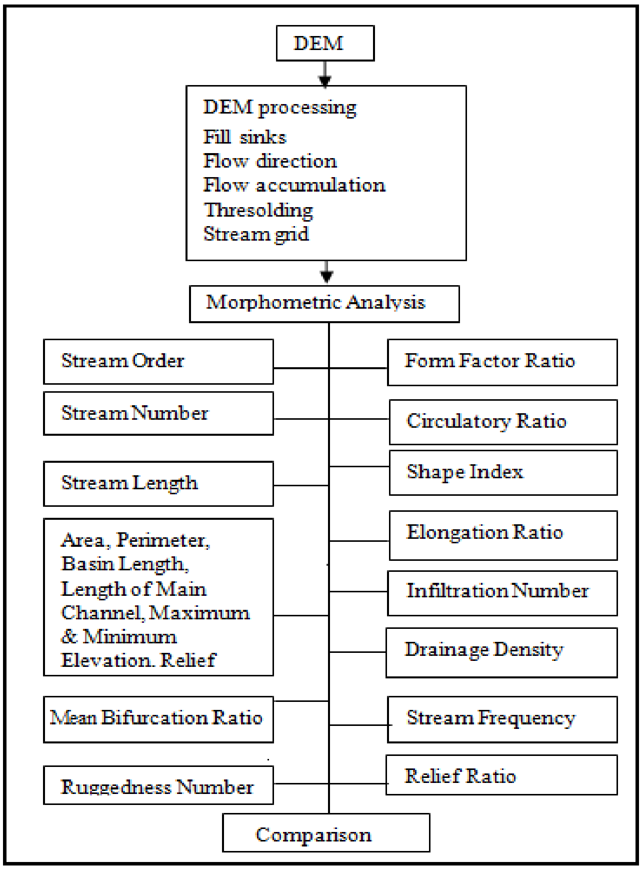

Fig. 2 Flowchart of methodology

Table 2: Methodology adopted for computation of morphometric parameters

S. NO	Morphometric Parameter	Formulae	Reference
1	Stream Order (*U*)	Hierarchical rank	[5]
2	Stream Length (*Lu*)	Length of the stream	[5]
3	Bifurcation Ratio (*Rb*)	*Rb* = *Nu/Nu+1* , Where, *Rb*= Bifurcation Ratio, *Nu*= Number of Streams of Order u, *Nu+1*= Number of Streams of u+1	[9]
4	Mean Bifurcation Ratio (*Rbm*)	Average of bifurcation ratios of all orders	[5]
5	Form Factor Ratio (*Rf*)	$Rf = A/Lb^2$ where *Rf*= Form Factor Ratio, A=area of watershed Lb=Length of watershed	[10]
6	Circularity Ratio (*Rc*)	$Rc = 4*\pi*A/p^2$ *where* *Rc*= Circularity Ratio A=area of watershed, P=Perimeter of watershed, *Π*=Constant (3.14)	[11]
7	Elongation Ratio (*Re*)	*Re* = *2/Lb sqrt (A/π)* where *Re*= Elongation Ratio, A= area of watershed Lb=Length of watershed, *Π*=Constant (3.14)	[9]
8	Shape Index (*Sw*)	$Sw = Lb^2/A$ where *Sw*= Shape Index, *Lb* = Length of watershed, A=area of watershed	[12]
9	Drainage Density (*Dd*)	*Dd* = *Lu/A where Dd*= Drainage Density, *Lu*= Length of Streams of all orders	[10]
10	Stream Frequency (*Fs*)	*Fs* = *Nu/A* where *Fs* = Stream Frequency, *Nu*= Number of Streams of all orders	[10]
11	Infiltration Number (If)	If = Fs*Dd where If = Infiltration Number, Fs= Stream Frequency, *Dd*= Drainage Density	[8]
12	Relief Ratio (*Rh*)	*Rh* = *H/Lb Rh* = Relief Ratio *H*= Relief of watershed	[9]
13	Ruggedness number (*Rn*)	*R n* = *Bh* * *Dd* , *R n* = Ruggedness number, *Bh*= Relief of watershed, *Dd*= Drainage Density	[7]

RESULTS AND DISCUSSION

The basic parameters like maximum and minimum elevation of watershed, watershed area, watershed perimeter, watershed length, watershed relief and length of main channel of the watersheds study area which were used in the formulae to compute various morphometric parameters are given in Table 3 below.

Table 3 Important Basin characteristics of four selective watersheds of Jhelum basin

Basin Characteristics	Arin	Madhumati	Sandran	Bringi
Max. Elevation (km)	5.05	4.49	4.08	4.41
Min. Elevation (km)	1.53	1.55	1.57	1.57
Basin Relief (km)	3.52	2.94	2.51	2.84
Basin Perimeter(Km)	81.31	118.89	120.67	162.19
Basin Area (Km2)	245.10	460.34	333.47	652.18
Basin Length Lb(Km)	26.21	36.15	50.10	53.16

The various morphometric parameters which were computed in the present study are discussed below.

Stream order (U)

The primary step in drainage-basin analysis is to designate stream orders [12]. According to the Strahler (1964) ordering scheme, Arin, Madhumati and Sandran all the three are fifth-order watersheds where as Bringi is a sixth-order watershed (Table 4). Higher stream order is associated with greater discharge and higher velocity of the stream flow. It is deduced that the surface runoff and sediment load from Bringi is more as compared to other three watersheds. Also the total number of stream segments decreases with increase in stream order. This is referred to as Horton's law of stream numbers. Any deviation indicates that the terrain is typified with high relief and/or moderately steep slopes, underlain by varying lithology and probable uplift across the basin. In the present study all the four watersheds obeys this law. The figures from 3 to 6 shows stream order maps of the watersheds considered for the present study.

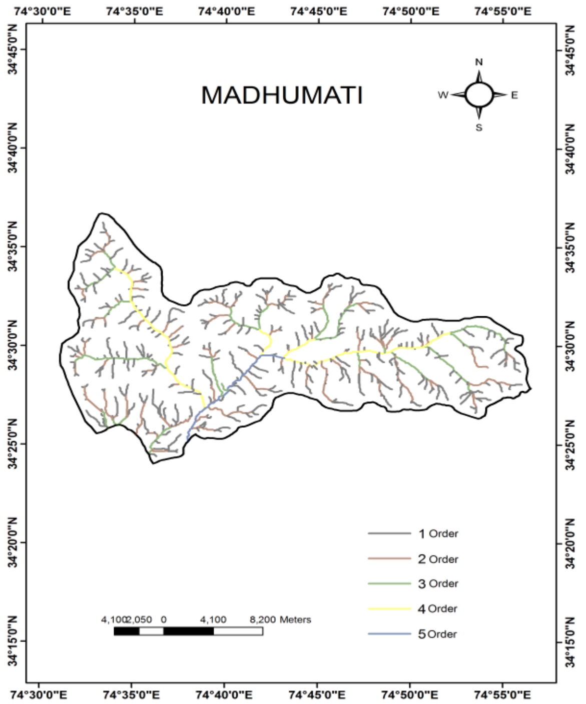

Fig. 3 Stream Order map of Madhumati watershed

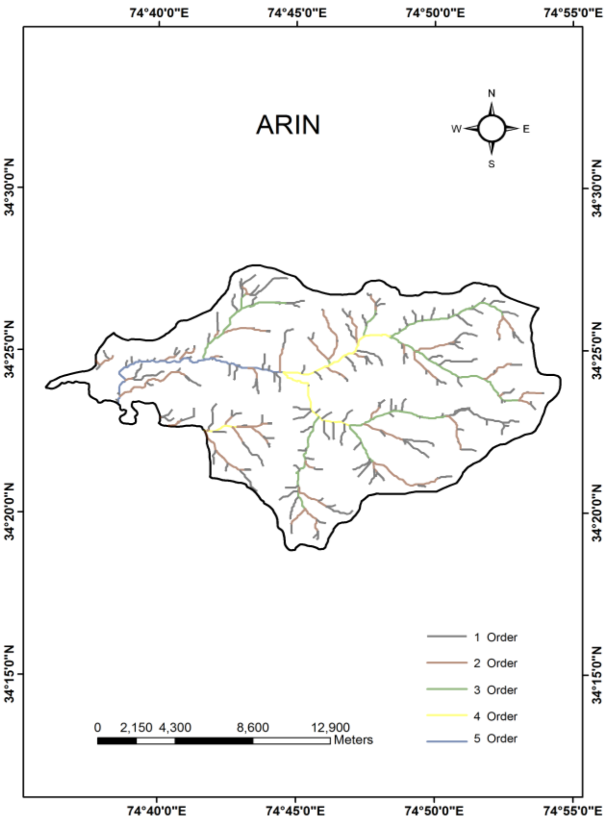

Fig. 4 Stream Order map of Arin watershed

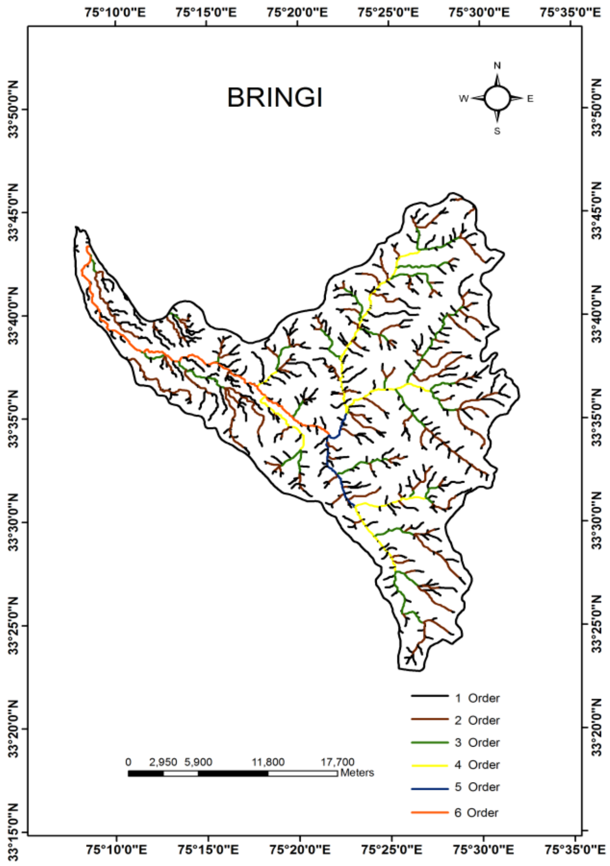

Fig. 5 Stream Order map of Bringi watershed

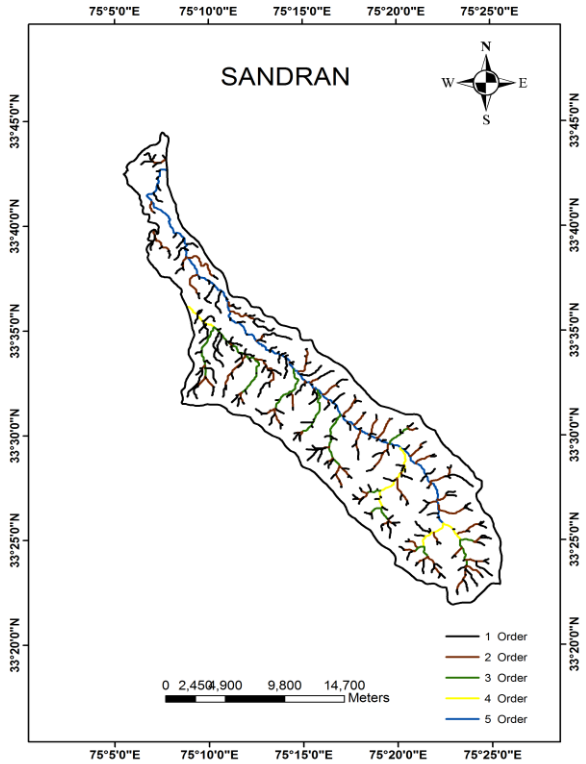

Fig. 6 Stream Order map of Sandran watershed

Stream Length (Lu)

Generally the total length of stream segments is maximum in first order streams and decreases as the stream order increases and the Arin, the Madhumati and the Bringi watersheds agrees with this general observation, where this observation is not true for Sandran watershed (Table 4). The stream length ratio can be defined as the ratio of the mean stream length of a given order to the mean stream length of next lower order and having important relationship with surface flow and discharge and erosion stage of the basin [12]. The stream length ratio of all four watersheds does not show any increasing trend and there is a change from one order to another order, it indicates their late youth stage of geomorphic development [3].

Bifurcation Ratio (Rb)/ Mean Bifurcation ratio (Rbm)

The bifurcation ratio is the ratio of the number of the stream segments of given order 'Nu' to the number of streams in the next higher order (Nu+1). Bifurcation Ratio calculated for all four watersheds are shown in Table 5 .The mean bifurcation ratios of Arin, Madhumati, Sandran and Bringi are 4.01, 4.44, 4.20 and 3.74 respectively. It is generally observed that the Rb value varies between 3 and 5 and irregularities in the values of Rb are attributed to geological and lithological control over the drainage development. The high values of Rb indicate strong structural control on the drainage pattern, while the lower values project the watersheds which suffered less/no structural disturbances. The high values of bifurcation ratio can be found in areas with the presence of young tectonic movements. The high bifurcation ratio indicates early hydrograph peak with a potential for flash flooding during the storm events (Rakesh *et al* 2000). Therefore, the watershed with higher bifurcation ratio indicates its vulnerability to flooding

Table 4 Stream Order, Stream Number and Stream Length of four selective watersheds of Jhelum basin

S.No	Watershed Name	Stream order	Stream Number	Stream Length(Km)
1	Arin	First	213	123.67
		Second	46	63.26
		Third	8	40.18
		Fourth	3	14.81
		Fifth	1	12.28
			271	**254.2**
2	Madhumati	First	385	249.6
		Second	98	111.35
		Third	22	67.16
		Fourth	5	39.59
		Fifth	1	13.26
			511	**480.96**
3	Sandran	First	305	166.63
		Second	75	85.3
		Third	15	39.8
		Fourth	4	15.31
		Fifth	1	47.98
			400	**355.02**
4	Bringi	First	554	370.75
		Second	122	191.93
		Third	33	86.36
		Fourth	6	48.16
		Fifth	2	27.44
		Sixth	1	24.52
			718	**749.16**

Table 5 Bifurcation ratio of four selective watersheds of Jhelum basin.

Watershed Name	N1/ N2	N2/ N3	N3/ N4	N4/ N5	N5/ N6	(Rbm)
Arin	4.63	5.75	2.66	3	-	4.0
Madhumati	3.92	4.45	4.4	5	-	4.4
Sandran	4.06	5	3.75	4	-	4.2
Bringi	4.54	3.69	5.5	5	2	3.7

Where NI,N2,N3,N4,N5,N6 are the number of streams of 1,2,3,4,5 and 6 order respectively and Rbm is the mean bifurcation ratio.

Form Factor (Ff)

According to Horton form factor ratio may be defined as the ratio of basin area to square of the basin length. The value of form factor would always be less than 0.754 (for a perfectly Circular watershed). Smaller the value of form factor, more elongated will be the watershed. The watershed with high form factors have high peak flows of shorter duration, whereas watershed with low form factor indicate watershed is elongated in shape and flow for longer duration. The form factor values of Arin, Madhumati, Sandran and Bringi watersheds are 0.35, 0.35, 0.13 and 0.23 respectively (Table 6) which indicates that Sandran watershed is highly elongated out of these four watersheds. The elongated watershed with low value of Ff indicates that the basin will have a flatter peak flow for longer duration. Flood flows of such elongated basins are easier to manage than from the circular basin.

Elongation Ratio (Re)

It is defined elongation ratio as the ratio between the diameter of the circle of the same area as the drainage basin and the maximum length of the basin. Analysis of elongation ratio indicates that the areas with higher elongation ratio values have high infiltration capacity and low runoff. A circular basin is more efficient in the discharge of runoff than an elongated basin [3]. The values of elongation ratio generally vary from 0.6 to 1.0 over a wide variety of climate and geologic types. Values close to 1.0 are typical of regions of very low relief, whereas values in the range 0.6 to 0.8 are usually associated with high relief and steep ground slope [5]. These values can be grouped in to three categories namely (a) circular (>0.9), (b) oval (0.9 to 0.8), (c) less elongated (<0.7). The values of Re in present study area varies from 0.40 to 0.67 (Table 6) indicates that the catchment falls accordingly in the less elongated category. The analysis reveals that Arin watershed has high infiltration capacity and low runoff. The analysis suggests that Sandran watershed has high ground water potential.

Circulatory ratio, Rc

Circulatory ratio R*c* defined as the ratio of watershed Area A*u* to the area of a circle A*c* having the same perimeter as the watershed, thus, R*c* = A*u* / A*c* [11]. Low R*c* values indicate strongly elongated and highly permeable homogenous geological materials while high values indicate low relief with impermeable surface . In the present study circulatory ratios of Arin, Madhumati, Sandran and Bringi watersheds are 0.46, 0.40, 0.28 and 0.31 respectively (Table 6) and indicate that they are elongated and are characterized by moderate to low relief.

Shape Index (Sw)

Shape Index is equal to the square of the length of the watershed (Lb) divided by the area of the watershed (A) [12]. This study shows Shape factor ratio for Arin, Madhumati, Sandran and Bringi watersheds as 0.68, 0.63, 0.53, and 0.55 respectively (Table 6). The shape of the drainage watershed along the length and relief affect the rate of water and sediment yield. It gives an idea about the circular character of the basin. The greater the circular character of the basin greater is the rapid response of the watershed after a storm event.

Drainage density (Dd)

The drainage density of Arin, Madhumati, Sandran and Bringi are 1.10 Km/km2, 1.06 Km/km2, 1.12 Km/km2 and 0.96 Km/km2 respectively (Table 6). The higher values of drainage density indicates that the regions under these watersheds are composed of impermeable subsurface material, sparse vegetation and mountainous relief while as the lower drainage density of reveals that these watersheds are composed of permeable subsurface material, good vegetation cover and low relief which results in more infiltration capacity and can be the good sites for ground recharge sites. In general, the hydrology of a watershed changes significantly in response to the changes in the drainage density. A high drainage density reflects a highly dissected drainage watershed with a relatively rapid hydrological response to rainfall events, while a low drainage density means a poorly drained watershed with a slow hydrologic response [14]. Carlston observed that there is a very close relationship between drainage density and mean annual flood [15].

Stream frequency, (Sf)

Horton introduced stream frequency as the number of stream segments *Nu* per unit area *Au*, thus, F = S Nu/Au (expressed per km2). The stream frequencies of Arin, Madhumati, Sandran and Bringi are 1.10, 1.11, 1.19 and 1.10 respectively (Table 6). Stream frequency is related to permeability, infiltration capacity and relief of watersheds [16]. Higher values indicate that watershed has rocky terrain and very low infiltration capacity where as Lower values (as in this study) reveal that these watersheds are covered by vegetation and have very good infiltration capacity.

Table 6 Comparative morphometry of four selective watersheds of Jhelum basin.

S. No.	Morphometric Parameter	ARIN	Madhu-mati	Sandran	Bringi
1.	Maximum Stream Order	5	5	5	6
2.	Total Number of Streams	271	511	400	718
3.	Total Stream Length (Km)	254.20	480.96	355.02	749.16
4.	Mean Bifurcation Ratio	4.01	4.44	4.20	3.74
5.	Relief Ratio (Rh)	0.13	0.09	0.05	0.05
6.	Drainage Density (Dd) km/km2	1.0	1.04	1.06	1.14
7.	Stream Frequency (Fs) km2	1.10	1.11	1.19	1.10
8.	Form Factor (Rf)	0.35	0.35	0.13	0.23
9.	Circularity Ratio (Rc)	0.46	0.40	0.28	0.31
10.	Elongation Ratio (Re)	0.67	0.66	0.40	0.54
11.	Ruggedness number (Rn)	3.52	2.82	2.36	2.49
12.	Shape Index (Sw)	0.68	0.63	0.53	0.55
13	Drainage Intensity (Di)	1.10	1.06	1.12	0.96
14.	Infiltration Number	1.10	1.15	1.26	1.25

Infiltration number (If)

The infiltration number of a watershed is defined as the product of drainage density and stream frequency .Infiltration number plays a significant role in observing the infiltration character of basin. It is inversely proportional to the infiltration capacity of the basin. The infiltration numbers for Arin, Madhumati, Sandran and Bringi watersheds are 1.10, 1.15, 1.26, and 1.25 respectively (Table 6). The results reveal that Sandran watershed has low infiltration capacity as compared to other three watersheds .Arin watershed has high infiltration capacity among the four watersheds. It indicates that runoff will be very high in case of Sandran followed by Bringi and Madhumati. It also means that downstream areas of Sandran shall be flooded very quickly followed by Bringi and Madhumati.

Drainage Intensity (Di)

It is defined as the ratio of the stream frequency to the drainage density. This study shows drainage intensity for Arin, Madhumati, Sandran and Bringi watersheds as 1.10, 1.06, 1.12, and 0.96 respectively (Table 6). This low value of drainage intensity implies that drainage density and stream frequency have little effect (if any) on the extent to which the surface has been lowered by agents of denudation.

Relief Ratio (Rh)

The relief ratio may be defined as the ratio between the total relief of a basin and the Basin length Lb [9]. There is a correlation between hydrological characteristics and the relief ratio (Rh) of a drainage basin. The values of relief ratio ranges from 0.13 (for Arin) to 0.05(for Bringi) (Table 6).The low value of Rh indicates moderate relief and the presence of basement rocks that are exposed in the form of small ridges and mounds with moderate to lower degree slopes Low value of relief ratios are mainly due to the resistant basement rocks of the basin and low degree of slope.

Ruggedness Number (Rn)

The ruggedness number is the product of the basin relief and the drainage density and usefully combines slope steepness with its length. Calculated accordingly, the values of ruggedness number for Arin, Madhumati, Sandran and Bringi watersheds as 3.52, 2.82, 2.36, and 2.49 respectively (Table 6). The high values of ruggedness number occurs when both basin relief and the drainage density are large, this is when slope are not steep but long as well [17].The low ruggedness value of watershed implies that area is less prone to soil erosion and have intrinsic structural complexity in association with relief and drainage density.

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CONCLUSION

The study reveals that remotely sensed data (ASTER-DEM) and GIS based approach in evaluation of drainage morphometric parameters is more appropriate than the conventional methods. The various shape parameters calculated for watersheds indicates that Sandran is highly elongated followed by Bringi and then Madhumati where as Arin is least elongated. Drainage parameters like stream frequency, infiltration number etc indicates that Arin watershed is highly permeable watershed with high infiltration rate and low runoff, followed by Bringi and Madhumati where as Sandran is impermeable with low infiltration rate and high runoff. These studies are very useful for planning and drainage basin management.

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