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GEOGRAPHY

WATERSHED BASED DRAINAGE MORPHOMETRIC ANALYSIS OF LIDDER CATCHMENT IN KASHMIR VALLEY USING GEOGRAPHICAL INFORMATION SYSTEM

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Abstract
The quantitative analysis of drainage system is an important aspect of characterization of watersheds. Using watershed as a basic unit in morphometric analysis is the most logical choice because all hydrologic and geomorphic processes occur within the watershed. Lidder catchment which constitutes a segment of the western Himalayas with an area of 1159.38 km^2 (10% of the river Jhelum catchment) has been selected as the study area. Various linear and areal aspects of the catchment were computed at watershed level. This was achieved using GIS to provide digital data that can be manipulated for different calculations. The analysis has revealed that the total number as well as total length of stream segments is maximum in first order streams and decreases as the stream order increases. Horton's laws of stream numbers and stream lengths also hold good. The bifurcation ratio between different successive orders is almost constant. The drainage density values of the different watersheds exhibit high degree of positive correlation (0.97) with the stream frequency suggesting that there is an increase in stream population with respect to increasing drainage density and vice versa.

Keywords: Watershed; GIS; Lidder; Morphometry

Introduction

Morphometry is the measurement and mathematical analysis of the configuration of the earth's surface, shape and dimension of its landforms (Agarwal, 1998; Obi Reddy et al., 2002). A major emphasis in geomorphology over the past several decades has been on the development of quantitative physiographic methods to describe the evolution and behavior of surface drainage networks (Horton, 1945; Leopold & Maddock, 1953; Abrahams, 1984). Most previous morphometric analyses were based on arbitrary areas or individual channel segments. Using watershed as a basic unit in morphometric analysis is the most logical choice. A watershed is the surface area drained by a part or the totality of one or several given water courses and can be taken as a basic erosional landscape element where land and water resources interact in a perceptible manner. In fact, they are the fundamental units of the fluvial landscape and a great amount of research has focused on their geometric characteristics, including the topology of the stream networks and quantitative description of drainage texture, pattern and shape (Abrahams, 1984). 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 (Singh, 1992).

The quantitative analysis of morphometric parameters is found to be of immense utility in river basin evaluation, watershed prioritization for soil and water conservation and natural resources management at watershed level. Morphometric analysis of a watershed provides a quantitative description of the drainage system which is an important aspect of the characterization of watersheds (Strahler, 1964). The influence of drainage morphometry is very significant in understanding the landform processes, soil physical properties and erosional characteristics. Drainage characteristics of many river basins and sub basins in different parts of the globe have been studied using conventional methods (Horton, 1945; Strahler, 1957, 1964; Krishnamurthy et al., 1996). Geographical Information System (GIS) techniques are now a days used for assessing various terrain and morphometric parameters of the drainage basins and watersheds, as they provide a flexible environment and a powerful tool for the manipulation and analysis of spatial information. In the present study stream number, order, frequency, density and bifurcation ratio are derived and tabulated on the basis of areal and linear properties of drainage channels using GIS based on drainage lines as represented over the topographical maps (scale 1:50,000).

Study area

The Lidder catchment occupies the south eastern part of the Kashmir valley (Fig. 1.1) and is situated between 33º 45' 01" N - 34º 15' 35" N and 75º 06' 00" E

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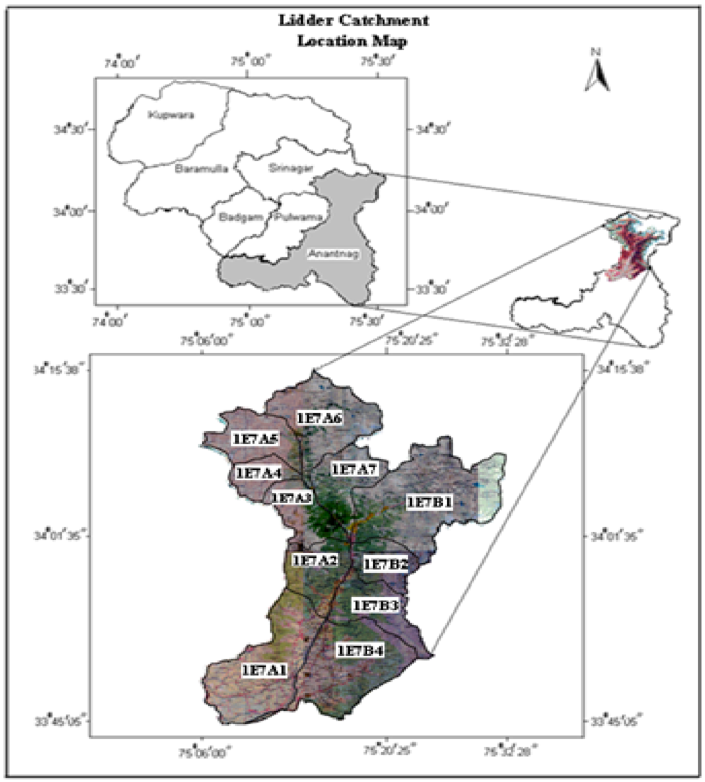
– 75º 32' 29" E. The Lidder valley forms part of the middle Himalayas and lies between the Pir Panjal range in the south and south-east, the north Kashmir range in the north-east and Zanskar range in the south-west.

Fig. 1.1: Location map of Lidder catchment



Source: Generated from SOI toposheets 1961

The Lidder valley has been carved out by river Lidder, a right bank tributary of river Jhelum. It has a catchment area of 1159.38 km^2, which constitute about 10 per cent of the total catchment area of river Jhelum (Bhat et al., 2007). The valley begins from the base of the two snow fields, the Kolahoi and sheshnag where from its two main upper streams; the West and the East Lidder originate and join near the famous tourist town of Pahalgam. It joins the Jhelum (upper stream of Indus river) at Gur village after travelling a course of 70 kms (Raza et al., 1978). The area gradually rises in elevation from south (1600 meters) to north (5425 meters).

The study area reveals a variegated topography due to the combined action of glaciers and rivers. The valley possesses distinctive climatic characteristics because of its high altitude location and its geophysical setting, being enclosed on all sides by high mountain ranges. The valley is characterized by sub-Mediterranean type of climate with nearly 70 per cent of its annual precipitation concentrated in winter and spring months (Meher, 1971).

Methodology

Morphometric analysis of a drainage system requires delineation of all existing streams. The stream delineation was done digitally in GIS (Arcview ver: 3.2a) system. All tributaries of different extents and patterns were digitized from survey of India toposheets 1961 (1:50,000 scale) and the catchment boundary was also determined for Lidder catchment. Similarly, two sub-catchments consisting of 11 watersheds were also delineated and measured for intensive study. Digitization work was carried out for entire analysis of drainage morphometry. The different morphometric parameters have been determined as shown in table1.1.

Table 1.1: Morphometric parameters with formula

S. no	Morphometric parameters	Formula	Reference
1	Stream order	Hierarchical rank	Strahler (1964)
2	Stream length (Lμ)	Length of the stream	Horton (1945)
3	Mean stream length (Lsm)	Lsm = Lμ/Nμ Where, Lμ = total stream length of order 'μ' Nμ = total no. of stream segments of order 'μ'	Strahler (1964)
4	Bifurcation ratio (Rb)	Rb = Nμ / Nμ +1 Where, Rb = Bifurcation ratio, Nμ = No. of stream segments of a given order and Nμ +1= No. of stream segments of next higher order.	Schumn (1956)
5	Mean bifurcation ratio (Rbm)	Rbm = Average of bifurcation ratios of all orders	Strahler (1957)
6	Drainage density (Dd)	Dd = Lμ/A Where, Dd = Drainage density. Lμ = Total stream length of all orders and A = Area of the basin (km^2).	Horton (1932)
7	Drainage frequency (Fs)	Fs = Nμ/A Where, Fs = Drainage frequency. Lμ = Total no. of streams of all orders and A = Area of the basin (km^2).	Horton (1932)

Results and Discussion

The drainage characteristics of Lidder catchment have been examined with particular reference to fallowing:

Stream Ordering

The designation of stream order is the first step in the drainage basin analysis. It is defined as a measure of the position of a stream in the hierarchy of tributaries (Leopord, Wolman and Miller, 1969). There are 3858 streams linked with 6 orders of streams (fig 1.2) sprawled over an area of 1159.38 km^2. A perusal of table 1.2 indicates that the Lidder river which is the trunk stream in Lidder catchment is of the sixth order. Out of the eleven watersheds, one watershed (1E7A3) is of third order, five watersheds (1E7A1, 1E7A2, 1E7A4, 1E7A5 and 1E7B3) are of fourth order, four watersheds (1E7A6, 1E7A7, 1E7B2 and 1E7B4) are of fifth order and one watershed (1E7B1) is of sixth order. The highest number of stream segments is found in watershed 1E7B1 (958 stream segments) followed by watershed 1E7B4 (460 stream segments) while the lowest number of stream segments is found in watershed 1E7A4 (137). It is observed that there is a decrease in stream frequency as the stream order increases. First order streams constitute 80.19 per cent while second order streams constitute 15.70 per cent of the total number of streams. Third and fourth order streams constitute 3.29 per cent and 0.64 per cent of the total number of streams respectively while fifth and sixth order streams together constitute only 0.18 per cent of the total number of streams. Thus the law of lower the order higher the number of streams is implied throughout the catchment.

Fig. 1.2: Map showing different stream orders in Lidder catchment

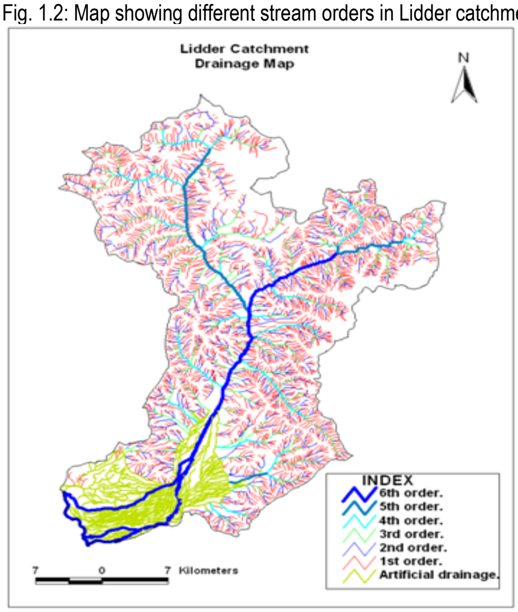


Table 1.2: Order wise Stream Number and Stream Length

Watershed Code	Area km.^{2}	1st order		2nd order		3rd order		4th order		5th order		6th order		Total	
		No.	Length	No.	Length	No.	Length	No.	Length	No.	Length	No.	Length	No.	Length
1E7A1	173.24	247	135.03	59	59.59	10	23.81	1	4.30	-	-	1	50.16	318	262.79
1E7A2	73.14	287	156.30	67	47.29	16	19.62	2	12.50	-	-	1	13.34	373	249.05
1E7A3	65.08	194	129.59	33	31.87	6	23.32	-	-	-	-	-	-	233	184.78
1E7A4	40.46	117	84.55	17	17.39	2	10.48	1	3.32	-	-	-	-	137	115.74
1E7A5	78.07	216	155.87	30	30.47	6	15.72	1	8.49	-	-	-	-	253	210.55
1E7A6	129.36	246	171.9	47	43.50	10	14.42	2	10.20	1	14.19	-	-	306	254.21
1E7A7	77.19	136	86.10	30	37.12	7	20.82	2	4.64	1	9.45	-	-	176	158.13
1E7B1	228.52	769	485.97	152	119.26	27	47.88	7	21.92	2	9.06	1	13.12	958	697.21
1E7B2	53.49	191	122.96	33	32.43	7	11.54	3	11.64	1	0.51	-	-	235	179.08
1E7B3	78.36	335	191.27	62	46.61	14	27.20	1	10.53	-	-	-	-	412	275.61
1E7B4	162.47	356	235.02	76	68.88	22	38.36	5	15.64	1	4.24	-	-	460	362.14
Lidder Catchment	1159.38	3094	1954.56	606	524.31	127	253.17	25	103.18	5	37.45	1	76.62	3858	2949.29

Stream number

The number of stream segments in each order is known as stream number. Horton (1945) gave the law of stream numbers which states that the number of stream segments of successively lower orders in a given basin tend to form a geometric series beginning with the single segment of the highest order and increasing according to constant bifurcation ratio. In other words "the number of streams of different orders in a given drainage basin tend closely to approximate an inverse geometric series in which the first term is unity and the ratio is bifurcation ratio". It is expressed in the form of negative exponential function as:

$$N\mu = Rb^{(K-\mu)} \quad \text{…………… (i)}$$

Also, the total number of stream segments of the catchment can be calculated as:

$$\Sigma\mu = Rb^{K}-1/ Rb-1 \quad \text{…………… (ii)}$$

Where,

$N\mu$ = Number of stream segments of a given order; Rb = Constant Bifurcation ratio.

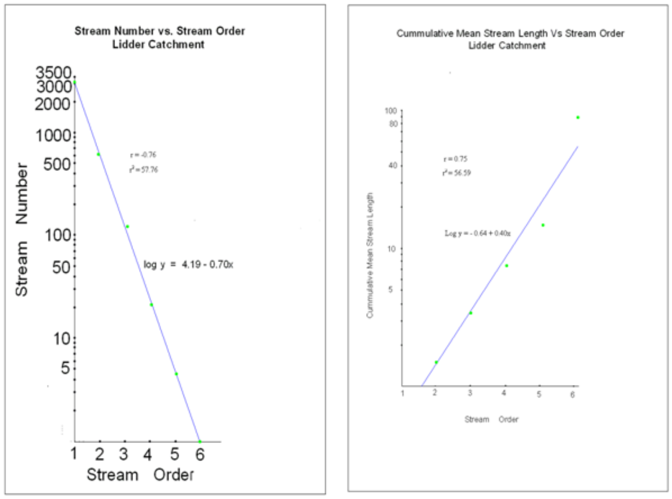
μ = Basin order and K = Highest order of the basin.

Table 1.3: Order wise actual and calculated number of Streams

Stream Order	Number of streams		Mean stream length		Calculated cumulative Mean stream length.
	Actual	Calculated	Actual	cumulative	
1st order	3094	1845.28	0.63	0.63	0.63
2nd order	606	410.06	0.86	1.49	2.24
3rd order	127	91.12	1.99	3.48	7.98
4th order	25	20.25	4.12	7.60	28.42
5th order	5	4.5	7.49	15.09	101.20
6th order	1	1	76.62	91.71	360.24
Total	3858	2372.5			

It is clear from table 1.3 that the computed values of stream numbers does not match with the actual values of stream numbers. However the deviations decrease from lower to higher orders. The regression line plotted on semi log graph (fig. 1.3) almost validates the Horton's law of stream number as the coefficient of correlation is -0.76 and the percentage variance explained is 57.76 per cent.

Fig. 1.3: Relation between stream order, stream number and mean stream length



Stream Length

Stream length is indicative of chronological developments of the stream segments including interlude tectonic disturbances. Mean stream length reveals the characteristic size of components of a drainage network and its contributing surfaces (Strahler, 1964).

Table 1.4. Order wise mean stream length

Watershed code	Mean stream length in kilometers.					
	1st order	2nd order	3rd order	4th order	5th order	6th order
1E7A1	0.55 (51.38)	0.84 (18.83)	2.38 (9.06)	4.30 (1.64)	-	50.16 (19.09)
1E7A2	0.54 (62.76)	0.70 (18.99)	1.23 (7.88)	6.25 (5.02)	-	13.34 (5.35)
1E7A3	0.67 (70.13)	0.96 (17.25)	3.89 (12.62)	-	-	-
1E7A4	0.72 (73.05)	1.02 (15.02)	5.24 (9.05)	3.32 (2.88)	-	-
1E7A5	0.72 (74.03)	1.01 (14.47)	2.62 (7.47)	8.49 (4.03)	-	-
1E7A6	0.70 (67.62)	0.92 (17.11)	1.44 (5.67)	5.10 (4.01)	14.19 (5.59)	-
1E7A7	0.63 (54.45)	1.24 (23.47)	2.97 (13.17)	2.32 (2.93)	9.45 (5.98)	-
1E7B1	0.63 (69.70)	0.78 (17.10)	1.77 (6.87)	3.13 (3.14)	4.53 (1.30)	13.12 (1.89)
1E7B2	0.64 (68.38)	0.98 (18.20)	1.65 (6.54)	3.88 (6.60)	0.51 (0.28)	-
1E7B3	0.57 (69.40)	0.75 (16.91)	1.94 (9.87)	10.53 (3.82)	-	-
1E7B4	0.66 (64.90)	0.90 (19.02)	1.74 (10.59)	3.13 (4.32)	4.24 (1.17)	-
Lidder Catchment	0.63 (66.27)	0.86 (17.78)	1.99 (8.58)	4.12 (3.50)	7.49 (1.27)	76.62 (2.60)
Cumulative mean stream length	0.63	1.49	3.48	7.6	15.09	91.71

Figures in parenthesis show Percentage stream length contributed by different stream orders

From table 1.4 it is evident that the length of first order streams constitute 66.27 per cent of the total stream length with second order (17.78 per cent), third order (8.58 per cent), fourth order (3.50 per cent), fifth order (1.27per cent) and the sixth order (2.60 per cent). The total length of 1st and 2nd order streams constitutes 84.04 per cent of the total stream length. It can be inferred that the total length of stream segments is maximum in first order streams and decreases as the stream order increases. However sixth order is an exception where the total stream length (76.62 kms) is more than that of the fifth order (37.45 kms). This anomaly is also found in watersheds 1E7A1 (between fourth and sixth orders), 1E7A2 (between fourth and sixth orders), 1E7A6 (between fourth and fifth orders), 1E7A7 (between fourth and fifth orders) and 1E7B1 (between fifth and sixth orders) where the total length of the lower order streams is less than that of the total length of their respective higher orders. Generally higher the order, longer the length of streams is noticed in nature. This is also true for Lidder catchment as well as for all the eleven watersheds (table 1.4). But the watershed 1E7B2 is an exception where the mean stream length of fourth order (11.64 kms) is much higher than that of the fifth order (0.51 kms). These variations from general observation may be due to flowing of streams from high altitude, change in rock type and variation in slope and topography (Singh and Singh, 1997; Vittala et al., 2004).

Horton's law of Stream Lengths: Horton (1945) in his law of stream lengths stated that the cumulative mean lengths of stream segments of each of the successive orders in a basin tend closely to approximate a direct geometric series in which the first term is the mean length of streams of the first order. He suggested the fallowing positive exponential function model of stream lengths.

$L\mu = L1\ RL^{(\mu-1)}$…………. (iii)

Where,

$L\mu$ = Cumulative Mean Length of the given order; L1 = Mean Length of the first order

RL = Constant length ratio and μ = Given order.

The regression line plotted on semi log graph (fig. 1.3) tends to validate Horton's Law of stream lengths as the coefficient of correlation is 0.75 and the percentage variance is 56.59. However the values obtained (table 1.3) by using equation (iii) does not match with the actual values. This is because of the fact that in nature constant mean stream length between different orders does not exist.

Bifurcation ratio (Rb)

Bifurcation ratio is related to the branching pattern of a drainage network and is defined as the ratio between the total number of stream segments of one order to that of the next higher order in a drainage basin (Schumn, 1956). It is a dimensionless property and shows the degree of integration prevailing between streams of various orders in a drainage basin. Horton (1945) considered Rb as an index of relief and dissection while Strahler (1957) demonstrated that Rb shows only a small variation for different regions with different environments except where powerful geological control dominates.

Table 1.5. Watershed wise drainage frequency, density and bifurcation ratio between different orders

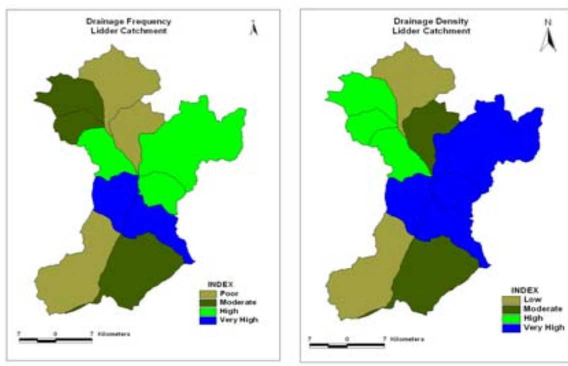
Watershed code	Drainage Frequency	Drainage Density	Bifurcation ratio between different orders					
			1st & 2nd	2nd & 3rd	3rd & 4th	4th & 5th	5th & 6th	Mean Bifurcation ratio
1E7A1	1.84	1.52	4.19	5.90	10.00	-	-	6.70
1E7A2	5.10	3.40	4.28	4.18	8.00	-	-	5.49
1E7A3	3.58	2.84	5.88	5.50	-	-	-	5.69
1E7A4	3.39	2.86	6.88	8.50	2.00	-	-	5.79
1E7A5	3.24	2.70	7.20	5.00	6.00	-	-	6.06
1E7A6	2.36	1.96	5.23	4.70	5.00	2.00	-	4.23
1E7A7	2.28	2.04	4.53	4.29	3.50	2.00	-	3.58
1E7B1	4.19	3.05	5.06	5.63	3.86	3.50	2.00	4.01
1E7B2	4.39	3.35	5.79	4.71	2.33	3.00	-	3.96
1E7B3	5.26	3.52	5.40	4.43	14.00	-	-	7.94
1E7B4	2.83	2.23	4.68	3.45	4.40	5.00	-	4.38
Lidder Catchment	3.33	2.54	5.10	4.77	5.08	5.00	5.00	5.00

A perusal of table 1.5 shows that the Rb between different successive orders is almost constant for Lidder catchment ranging from 4.77 to 5.08 with the mean bifurcation ratio of 5. This is because of the same geological and lithological development of the catchment. The highest Rb (14.00) is found between 3rd and 4th order in watershed 1E7B3 which indicates corresponding highest overland flow and discharge due to hilly metamorphic formation associated with high slope configuration. The lowest Rb is found between 4th and 5th orders in watersheds 1E7A6 and 1E7A7 and between 5th and 6th orders in watershed 1E7B1. The higher values of Rb indicate strong structural control in the drainage pattern whereas the lower values indicate that the watersheds are less affected by structural disturbances (Stahler, 1964; Nag, 1998; Vittala et al., 2004). The mean bifurcation ratio is highest in watershed 1E7B3 (7.94) while it is lowest in watershed 1E7A7 (3.58).

Drainage frequency or Stream frequency (Fs)

It is defined as the total number of stream segments of all orders per unit area (Horton, 1932). It is an index of the various stages of landscape evolution. The occurrence of stream segments depends on the nature and structure of rocks, vegetation cover, nature and amount of rainfall and soil permeability. The Fs in Lidder catchment is 3.33. It varies from 1.84 stream segments in watershed 1E7A1 to 5.26 stream segments in watershed 1E7B3. Thus it has been possible to identify four categories of Fs; Poor (below 2.5/km^2), Moderate (2.5-3.5/km^2), High (3.5-4.5/km^2) and Very High (Above 4.5/km^2) as shown in fig. 1.4. The analysis of the table 1.5 reveals that 32.76 per cent of the total catchment area of Lidder has poor Fs, while 24.23 per cent has moderate, 29.94 per cent has high and only 13.07 per cent has very high Fs.

Fig. 1.4: Distribution of Drainage frequency and Drainage density in Lidder catchment



The poor to moderate Fs in the watersheds of 1E7A1 and 1E7B4 is attributed to agricultural land use (54.23 per cent) with the consequent development of artificial drainage which is not considered here. Poor Fs in the watersheds of 1E7A6 and 1E7A7 could be attributed to rugged topography and steep barren slopes. The highest Fs in watershed 1E7B3 is because of the fact that it falls in the zone of fluvial channels and the presence of ridges on both sides of the valley which results in elongated drainage with highest Fs. The Fs decreases as we move to higher altitudes from south to north of the catchment. The watersheds falling in the zone of fluvial channels (Koal, 1990) have highest Fs as compared to the watersheds in the zone of melt water channels.

Drainage Density (Dd)

The measurement of Dd is a useful numerical measure of landscape dissection and runoff potential (Chorley, 1969). On the one hand, the Dd is a result of interacting factors controlling the surface runoff; on the other hand, it is itself influencing the output of water and sediment from the drainage basin (Ozdemir and Bird, 2009). Dd is known to vary with climate and vegetation (Moglen et al., 1998), soil and rock properties (Kelson and Wells, 1989), relief (Oguchi, 1997) and landscape evolution processes. The Dd of the Lidder catchment is 2.54 kms/km^2. It varies from 1.52 kms/km^2 in watershed 1E7A1 to 3.52 kms/km^2 in watershed 1E7B3.

The watersheds can be grouped into four categories on the basis of Dd as Low (below 2.0kms/km^2), Moderate (2.0-2.5kms/km^2), High (2.5-3.0kms/km^2) and Very High (Above 3.0kms/km^2) as shown in fig. 1.4. The analysis of the table 1.5 reveals that in Lidder catchment 26.10 per cent of the area has low Dd, 20.67 per cent has moderate Dd, 15.83 per cent has high while 37.39 has very high Dd. It is found that the watersheds of East Lidder sub-catchment have higher Dd as compared to the watersheds of West Lidder sub-catchment. The analysis has further shown that the Dd values of the different watersheds exhibit high degree of positive correlation (0.97) with the Fs suggesting that there is an increase in stream population with respect to increasing Dd and vice versa.

Conclusion

The drainage basin is being frequently selected as an ideal geomorphological unit. Watershed as a basic unit of morphometric analysis has gained importance because of its topographic and hydrological unity. GIS techniques characterized by very high accuracy of mapping and measurement prove to be a competent tool in morphometric analysis. Drainage density and stream frequency are the most useful criterion for the morphometric classification of drainage basins which certainly control the runoff pattern, sediment yield and other hydrological parameters of the drainage basin. The Drainage density appears significantly higher in 1E7B3 and 1E7B2 watershed implying the existence of impermeable rocks and high relief. It is observed that there is a decrease in stream frequency as the stream order increases. The law of lower the order higher the number of streams is implied throughout the catchment. The total length of stream segments is maximum in first order streams and decreases as the stream order increases. The study has shown that the catchment is in conformity with the Hoton's law of stream numbers and law of stream lengths. The same geological and lithological development of the catchment has resulted into more or less constant bifurcation ratio between different successive orders in Lidder catchment.

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