ASSOCIATION OF PUNJAB GEOGRAPHERS
1999
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punjab geographer

A JOURNAL OF THE ASSOCIATION OF PUNJAB GEOGRAPHERS, INDIA

VOLUME 2 OCTOBER 2006

PUNJAB GEOGRAPHER Volume 1 Number 2 October 2006

QUANTITATIVE ANALYSIS OF SOLANI WATERSHED USING REMOTE SENSING AND GIS TECHNIQUES

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Abstract

The present study is aimed at analyzing the morphometric characteristics of Solani watershed employing remote sensing and GIS techniques. The present study is based on remote sensing data which include ASTER FCC image (Dec. 2003) of 15m spatial resolution. The topo sheets of 1:50,000 scales were used for georeferencing the ASTER image. The field surveys have also been conducted to know the ground realities. In the present study, an endeavour has been made to study quantitatively the linear and areal morphometric characteristics of Solani watershed.

The study reveals that the Solani river is a seventh order stream. About more than three-fourth of total streams in the watershed are of first order largely due to structural weaknesses and varying topographic conditions. The weighted mean bifurcation ratio indicates that the geological structures have not distorted the drainage pattern by far in the study area. It is noted that mean stream length increases as the stream order decreases except seventh order. The highest drainage density is observed in hilly areas mainly due to the dominance of first order streams. On the basis of quantitative symbolization of shape indices viz., form factor, circularity ratio and elongation ratio it is inferred that basin configuration of Solani watershed is elongated. Hence, it does not support stronger and higher velocity floods and more discharge of run- off. As such, there is less possibility of erosion and transport capacities. Consequently, the suspended load is lesser and the evolution of such watersheds thus occurs at a slow rate.

Introduction

The surface drainage pattern characteristics of various basins and sub-basins have been studied using conventional methods in earlier studies. Such studies lack time effectiveness of data for a large drainage network over a whole river basin. Remote sensing technology provides an unique data set for studying the geomorphometry of any watershed (Agarwal, 1998). A watershed is an area from which runoff resulting from precipitation flows past a single point into large stream, river, lake or ocean. Hence, 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 (Biswas *et al.* 1999). A watershed is an ideal unit for management of natural resources like land and water and for mitigation of the impact of natural disasters for achieving sustainable development. The important factors for the planning and development of a watershed are its relief structure, drainage, soils, land utilization pattern and available water resources (NookaRatnam *et al.* 2005).

In particular, remotely sensed data can be utilized directly for obtaining information concerned with the quantitative description of drainage basins and channel network (Astaras, 1985). Drainage characteristics express stage of development, the distribution pattern of the landforms, texture of the surface material and water resources (Singh, et al 1985). It seems justified to give more weightage to the mathematical symbolization of landform characteristics, for mere descriptive assessment of landform may not be helpful in adopting similar scale of observation in other areas (Asthana, 1967).

Dury (*1952)* also supports these arguments in his words: "Subjective assessments, however, can be of very little use in comparing one drainage system with another, unless they are made by a single observer who maintains a constant standard of judgment. It is now possible to supersede subjective assessment and qualitative descriptions by quantitative measurement". In quantitative geography, the employment of precise data concerning landforms is essential for basic research into the laws governing relief development, for elaborate mathematical models, and for practical applications such as forecasting discharge, and the regional modelling of hydrological features (Zavoianu, 1985).

Morphometry is a quantitative measure of the attributes of landforms and drainage as opposed to their qualitative depiction. It could be defined as the measurement and mathematical analysis of the configuration of the earth's surface and of the shape and dimensions of its landforms (Upendran, et al. 1998; Singh and Singh; 1997 and Agrawal, 1972).The area, altitude, volume, slope, profile, and texture are the main aspects examined in the study of morphometry. The technique is used to understand varied characteristics of drainage basins such as erosion surfaces, nature of erosion, formation of slopes etc. It has also been used for explaining the direct and indirect evidence related to the genesis and evolution of certain landforms (Kharkwal, 1968).

The quantitative analysis of the morphometric characteristics of a drainage basin has been useful in many applied studies which include estimation of runoff, flood discharge, groundwater recharge, sediment yield, soil and water conservation, environmental analysis and so on (Gopalakrishnan, 1997). There are several published studies which deal with quantitative analysis of drainage basin (Strahler, 1952). Most of them are dependent on the degree of accuracy of depiction of drainage networks obtained from maps (Morisawa, 1957, quoted in Astaras, 1985). Only a few studies in the last 30-35 years have specifically put into practice the application of remote sensing and geographic information system (GIS) techniques as effective tools in determining the quantitative description of watershed morphometry.

Objectives and Research Questions

The present study seeks to realize the following two fold objectives and investigate research questions related to them:

1. To describe and discuss quantitatively the linear and areal properties of Solani watershed.
2. To study the relationship among the morphometric characteristics of Solani watershed. In other words, it tries to examine that how the linear and areal parameters of drainage basin are associated with each other.

Data Base and Methodology

The present study is based on ASTER MSS data (14 bands) acquired on March 17, 2003 namely FCC of the bands 1, 2 and 3N of 15 m spatial resolution for visual analysis of the landforms. The details of the remote sensing data used are given in table 1.

Table 1

Characteristics of Terra Satellite, ASTER Sensor

1 Sensor – Aster (17th March, 2003)
2 Band – 14

	Bands	VNIR	SWIR	TIR
	Spectral Range	Band 1: 0.52 – 0.60 Nadir Looking	Band4: 1.60 – 1.70	Band 10: 8.125 – 8.475
		Band 2: 0.63 – 0.69 Nadir Looking	Band 5: 2.145 – 2.185	Band 11: 8.475 – 8.825
		Band 3N: 0.76 – 0.86 Nadir Looking	Band 6: 2.185 – 2.225	Band 12: 8.925 – 9.275
		Band 3B: 0.76 – 0.86 Backward Looking	Band 7: 2.235 – 2.285	Band 13: 10.25 – 10.95
			Band 8: 2.295 – 2.365	Band 14: 10.95 – 11.65
			Band 9: 2.360 – 2.430	
3	Ground Resolution	15m	30m	90m
4	Date Rate (Mbits/Sec)	62	23	4.2
5	Cross-track Pointing (degree)	+-24	+-8.55	+-8.55
6	Cross-track Pointing(km)	+-318	+-116	+-116
7	Swath Width (km)	60	60	60
8	Detector Type	Si	PtSi-Si	HgCdTe
9	Quantization (bits)	8	8	12
10	System Response Function	VNIR Chart VNIR Date	SWIR Chart SWIR Date	TIR Chart TIR Date

Source: *ASTER Image Provided by Department of Water Resources, IIRS, Dehradun*

The Survey of India topo-sheets Nos.53 F/15; 53F/16; 53G/13; 53J/3; 53J/4 of scale 1:50,000 and 53/F; 53/G; 53/J of 1:2,50,000 as collateral data have also employed in the present study. An epipolar stereopair using 3N channel as left image and 3B as right image was created in ILWIS software. Subsequently, to delineate the watershed boundary, anaglyphic visualization (3-D, seen stereoscopically through anaglyph spectacles) has been employed in the present study. The drainage layer has been generated from linearly stretched standard false colour composite (FCC) of Terra ASTER satellite data. The drainage network has been digitized using ERDAS 8.7and ARC/ INFO tools.

Linear Aspects

Linear aspects have been examined in terms of stream number, stream order, bifurcation ratios, stream length, mean stream length, stream length ratio and sinuosity index. In the present study, Strahler (1952) method of stream ordering has been used.

Areal Aspects

Areal aspects like drainage density, drainage area, basin length, basin perimeter, shape parameters viz., form factor, circulatory ratio and elongation ratio have also been investigated.

Regional Setting

The Solani watershed covering an area of about 532.40 sq km is located between 29⁰52'45.53"N to 30⁰16'16.72"N latitude and 77⁰43"58.45"E to 78⁰00"05.93"E longitude (Fig.1.).The Solani river originates from the northeastern part (Siwalik hill, 787 meter) of Saharanpur district near the Kaluwala pass (30⁰15'59.36"N latitude and 78⁰53'16.83"E longitude). The river flows essentially south-west to south-east for

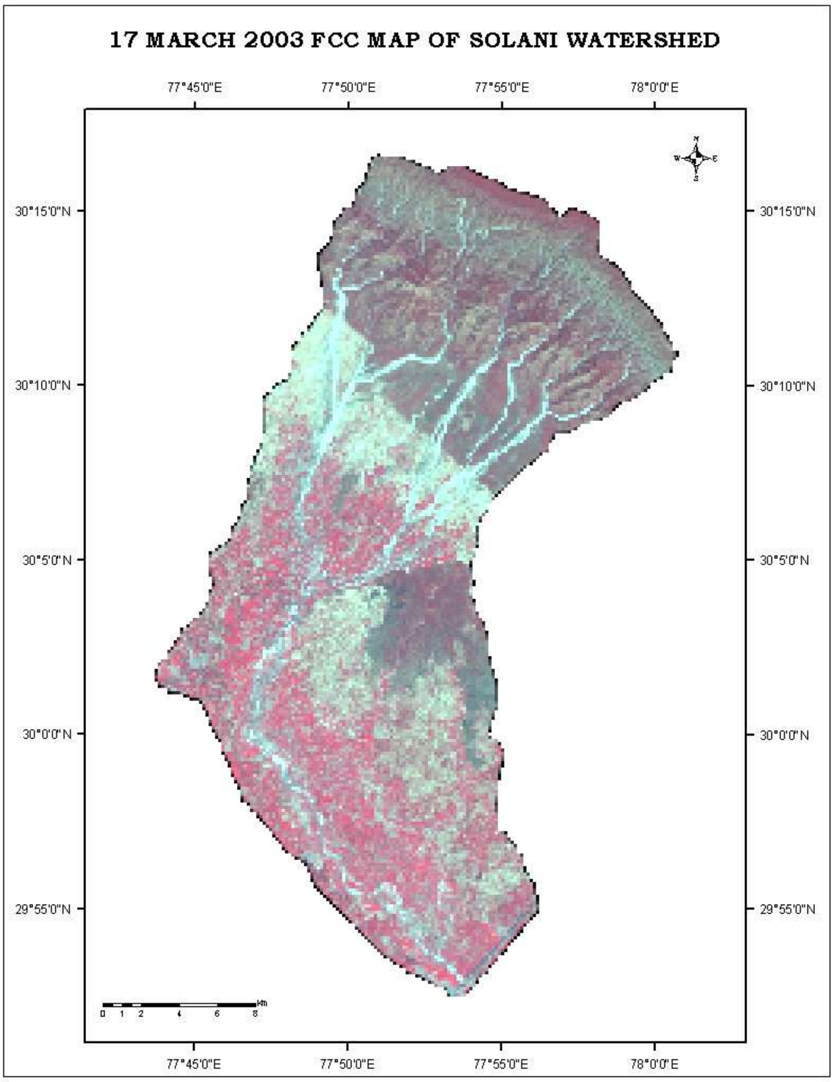

Fig. 1

60.17 km to join the Ganga river near Jansath in Muzaffarnagar district (U.P.).

Results and Discussion

Linear Aspects

(i) Stream order

The stream order is a measure of the position of a stream in the hierarchy of the tributaries (Horton, 1945). Fig.2. shows the stream order map of the Solani watershed.

(ii) Stream number

The count of stream channels in each order is known as stream number. It is evident from the table 2 that the number of streams decreased with increasing order of the stream in Solani watershed. The Solani watershed as a whole has 1171 first order streams, 259 second order streams, 54 third order streams, 16 fourth order streams, 5 fifth order streams, 2 sixth order streams and one seventh order stream. Table 2 and fig 2 indicate that Solani river basin is a seventh order stream. Thus, the study reveals that Solani watershed is dominated by first order streams which constitute about more than three- fourth of total streams.

Table 2

Solani Watershed: Order-wise Distribution of Stream Segments

Sr. No.	Stream Order	Number of Segments	Per cent to Total Streams Segments
1	1	1171	77.65
2	2	259	17.18
3	3	54	3.58
4	4	16	1.06
5	5	5	0.33
6	6	2	0.13
7	7	1	0.07
8	**Total**	**1508**	**100.00**

Source: Standard FCC ASTER Image

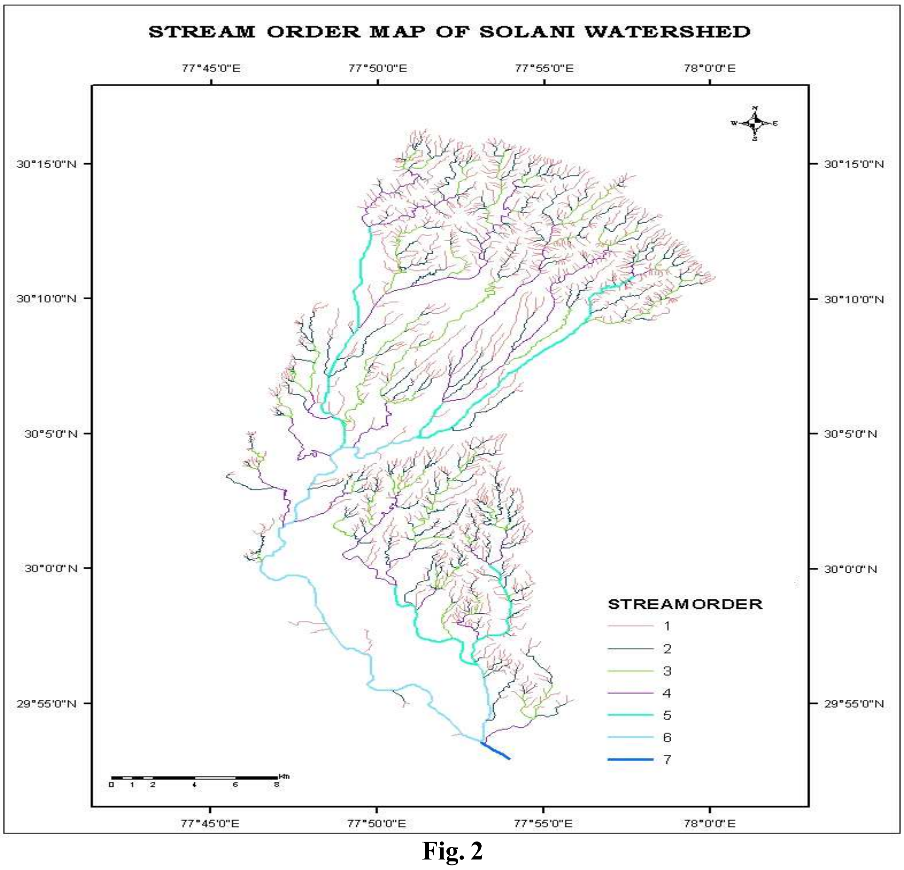

Fig. 2

Fig 3 shows a straight-line correlation between stream order and stream number as per Horton's law. It signifies that the number of streams generally decreases in geometric progression as the stream order increases. It is noted that high proportion of first order streams could be attributed to structural weaknesses present across the study area.

(iii) Bifurcation ratio (R_b)

The term bifurcation ratio refers to the ratio between the total number of streams of one order to that of the next higher order (Schumm, 1956). The under mentioned formula is applied to calculate the bifurcation ratio:

$$R_b = \frac{Nu}{Nu+1}$$

where, Rb = bifurcation ratio

N_u = number of segments of a given order 'u'

N_{u+1} = number of segments of the next higher order

It is evident from table 3 that bifurcation ratio values range from 2 to 4.8 in the Solani watershed. The study indicates that bifurcation ratio values are higher being 4.52 and 4.80 for first and second order streams respectively. The high bifurcation ratio is the result of large variation in stream frequency between successive orders. It also indicates their origin from higher level. The bifurcation ratio also reflects indirectly the impact of lithology of the watersheds. In upper Shiwaliks, there is more dominance of first and second order streams (Fig 2.). Hence, there seems to be possibility of higher R_b than alluvium tract of the study area where number of streams is less. The average bifurcation ratio as a whole in the Solani watershed is 3.4 which is an indication of normal range. Hence, it can be inferred that the geological structures have not distorted the drainage pattern to a considerable extent. The average value of R_b indicates that the Solani watershed has nearly elongated basin configuration.

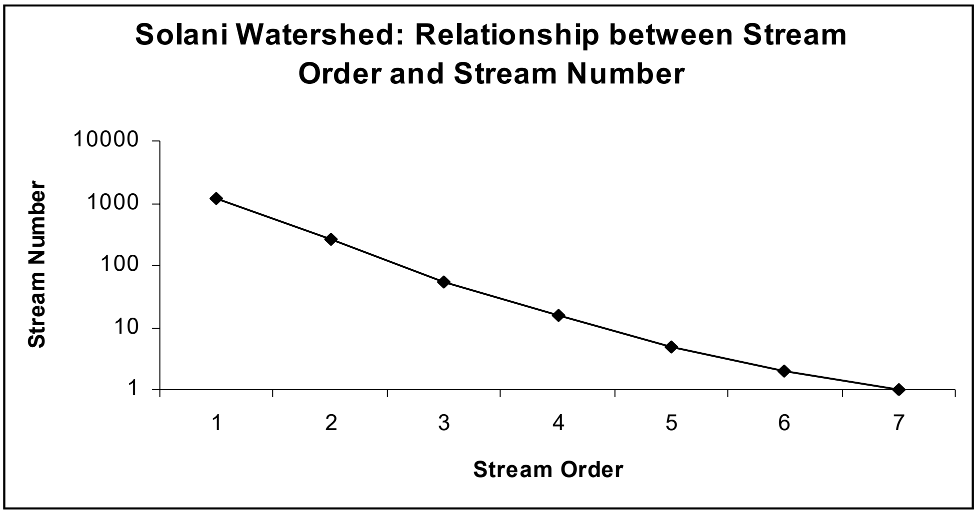

Fig. 3

Table 3

Solani Watershed: Relationship between Stream Order and Bifurcation Ratio

Sr. No.	Stream Order	Number of Segments	Bifurcation Ratio
1	1	1171	4.521
2	2	259	4.796
3	3	54	3.375
4	4	16	3.200
5	5	5	2.500
6	6	2	2.000
7	7	1	
Total		**1508**	
Average	-	-	**3.40**
Weighted mean Bifurcation Ratio	-	-	**4.50**

In general, there is inequity in bifurcation ratios between successive pairs of stream orders within the same basin. Hence, to arrive at a more representative and revealing bifurcation number, Strahler (1953) used a weighted mean bifurcation ratio. It is obtained by under mentioned formula:

$$Rbw = \frac{Rb1 \times n1 + Rb2 \times n2 + ---}{n1 + n2 + n3 ---}$$

where, Rbw = weighted mean bifurcation ratio.

Rb1 = bifurcation ratio between first and second order streams.

n1 = total number of stream segments involved

Rb2 = bifurcation ratio between second and third order streams

n2 = total number of stream segments involved, and so on.

The weighted mean bifurcation ratio is 4.50 for the entire watershed.

(iv) Sinuosity index (SI)

Sinuosity deals with the pattern of channel of a drainage basin. It has been defined as 'the ratio of channel length to down valley distance'. In general, its value varies from 1 to 4 or more. Rivers having a sinuosity index less than 1.5 are called sinuous, and above 1.5 are called meandering. Mueller (1968) also defines two main types i.e., topographic and hydraulic sinuosity index concerned with the flow of natural stream courses and with the development of flood plains respectively. Here, calculations of various types of sinuosity indices are made on the basis of the following formula advanced by Mueller, 1968.

$$\text{Channel Index (CI)} = \frac{CL}{Air}$$ (Hydraulic and Topographic Sinuosity)

$$\text{Valley Index (VI)} = \frac{VL}{Air}$$ (Topographic Sinuosity)

Cl= Length of channel in the stream under study

Air = Shortest air distance between the source and mouth of the stream.

VL= Valley length along a stream, the length of a line which is everywhere midway between the base of the valley-walls.

$$\text{Hydraulic Sinuosity Index (HSI)} = \frac{CI-VI}{CI-1} \times 100$$

$$\text{Topographic Sinuosity Index (TSI)} = \frac{VI-1}{CI-1} \times 100$$

$$\text{Standard Sinuosity Index (SSI)} = \frac{CI}{VI}$$

Table 4

Solani Watershed: Sinuosity Parameters

Sr. No.	Parameter	Sinuosity Parameters
1	Channel Length(km)	60.18
2	Valley Length (km)	56.35
3	Minimum Aerial Distance (km)	49.81
4	Channel Index (CI)	1.21
5	Valley Index (VI)	1.13
6	Hydraulic Sinuosity Index (HSI)	38.10
7	Topographic Sinuosity Index (TSI)	61.91
8	Standard Sinuosity Index (SSI)	1.07

Table 4 presents the distribution of different parameters employed for computing the sinuosity index of Solani watershed. It is evident from the table that standard sinuosity Index (SSI) of Solani watershed and its tributaries is 1.07. Hence, it can be inferred that drainage network of Solani watershed is sinuous.

(v) Stream length

The stream length has an important relationship with the surface flow discharge. Table 5 reveals that the total length of stream segments is maximum in case of first order streams. It decreases as the order increases. It is observed that the total length of stream segments is comparatively lesser in case of higher order streams i.e. 41.20 km (3.46 per cent) and 1.90 km (0.16 per cent) in sixth and seventh order streams respectively in the study area (Table 5). The Fig. 4 indicates that curves are not forming linear relationship according to the Horton's law but are irregular, revealing convexities and concavities in some parts. It signifies that the lengths of higher orders do not decrease sharply in a geometric progression. It might be attributed to stream courses traversing in areas of high altitude, moderately steep slopes and varying lithological conditions.

Table 5
Solani Watershed: Order-wise Distribution of Stream Length

Stream Order	Number of Stream Segments	Stream Length (Km)	Per Cent to Stream Length
1	1171	599.55	50.37
2	259	254.69	21.40
3	54	153.30	12.88
4	16	97.62	8.20
5	5	42.13	3.54
6	2	41.20	3.46
7	1	1.90	0.16
Total	1508	1190.38	100.00

(vi) Mean stream length

Given the laws of stream numbers and of the summed lengths of streams of successive orders in a given drainage basin, the law of average lengths can easily be deduced (Zavoianu, 1985). The mean stream length of a stream- channel segment of order (u) is a dimensionless property, which indicates the characteristic size of components of a drainage network and its associated surfaces (Nag and Chakraborty, 2003). It is obtained by dividing the total length of stream of a order by the total number of segments in that order, i.e.

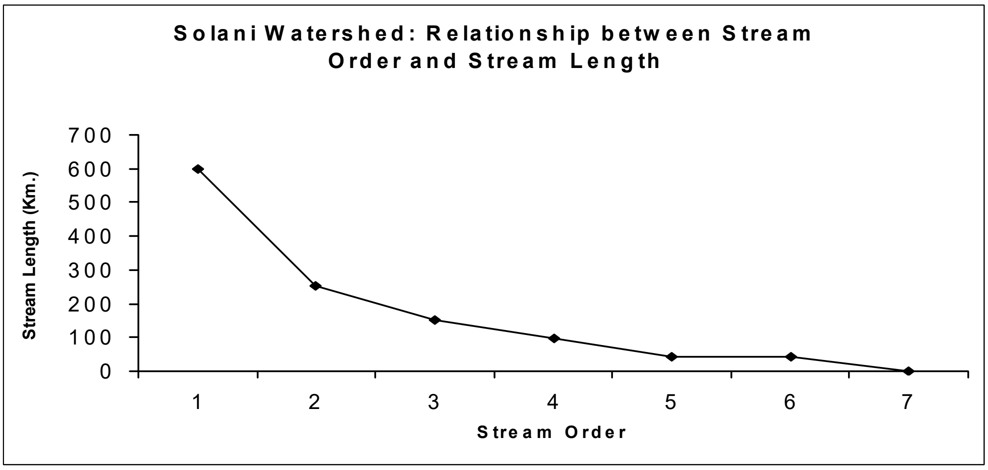

Fig.4

$$L_u = \frac{\sum Lu}{Nu}$$

Where, L_u = mean stream length of order 'u'

ΣL_u = total stream length of order 'u'

and

N_u = number of stream segments of order 'u'

In general, the mean stream length increases as the order of segment increases. It is also evident from table 6 where the mean length of first order and second order streams segments is 0.51 km and 0.98 km respectively. Likewise, the mean stream length of all orders up to fifth order increases from 2.84 km to 8.43 km. The study reveals that highest stream length (20.60 km), which constitutes about half of the total stream length is found in sixth order stream system in the Solani watershed.

The study therefore, reveals that mean stream length increases as the stream order increases in the study area. The mean stream length for the entire Solani watershed is 5.91 km. This relationship holds true in case of Solani watershed up to sixth order.

(vii) Stream length ratio

It is the ratio between the mean lengths of streams of any two consecutive orders. Horton (1945) defined stream length ratio (RL) as the ratio of the average length of stream of any order to the average length of streams of the next lower order. He postulated that the length ratio tends to be constant throughout the successive orders of stream (quoted in Singh, 2000, Upendran, et al. 1998 and Singh and Singh, 1997).

Stream length ratio has been computed with under mentioned formula**:**

$$RL = \frac{Lu}{Lu\text{-}1}$$

Where, RL = stream length ratio, Lu = the mean stream length of all stream segments of the order u., Lu – 1 is the mean length of all stream segments of the next lower order.

Table 7 presents the stream length ratio among streams of various orders in the study area. It is evident from the table that there are noted spatial variations in the distribution of stream length ratios across different orders. It ranges from 1.92 to 2.89 in first and second order stream segments respectively. The increasing trend in the length ratio from lower order to higher order could be attributed to early mature geomorphic stage of the watershed.

Table 6

Solani Watershed: Order-wise Distribution of Mean Stream Length

Sr. No.	Stream Order	Number of Stream Segments	Stream Length (km)	Mean Stream Length (km)	Per cent to Total Mean Stream Length
1	1	1171	599.55	0.51	1.24
2	2	259	254.69	0.98	2.38
3	3	54	153.30	2.84	6.86
4	4	16	97.62	6.10	14.75
5	5	5	42.13	8.43	20.37
6	6	2	41.20	20.60	49.80
7	7	1	1.90	1.90	4.58
	Total	**1508**	**1190.38**	**5.91**	**100.000**

Table 7
Solani Watershed: Order- wise Stream Length Ratio

Sr. No.	Stream Order	Stream Length Ratio
1	I – II	1.92
2	II – III	2.89
3	III – IV	2.15
4	IV – V	1.38
5	V – VI	2.44
6	VI – VII	0.09
7	Average	1.81

Areal Aspects

Drainage density (D_d)

Drainage density introduced by Horton (1945) is an important factor of linear scale landform elements in stream eroded topography. It is the ratio of total channel length, cumulated for all orders within a basin to the total area of the basin (Nag and Chakraborty, 2003 and Gopalakrishnan *et al* 1997). The drainage density is defined as the ratio of the total length of all streams of all orders within a watershed to the total area of the watershed. A high value of the drainage density indicates a relatively high density of streams and thus a rapid stream response (Singh, 2000).

It is observed that low drainage density is found in regions of highly resistant or permeable soil material under vegetative cover and low relief. In contrast, high drainage density is found in the regions of weak and impermeable sub-surface material, sparse vegetation and mountainous relief (Nag, 1998).

In order to calculate the drainage density watershed was divided into grids of one sq km and total length of all stream segments has been measured in each grid and the calculated values (total stream length / sq km area) have been classified into the under mentioned drainage density groups.

Table 8
Solani Watershed: Drainage Density

Sr. No.	Range of Drainage Density	Explanation
1	0.00	Nil
2	0.000020-0.001824	Moderate
3	0.001824 – 0.003390	High
4	0.003390 - 0.006096	Very High
5	0.002286	Average

It is evident from the Table 8 that the average drainage density in Solani watershed is 0.002286 km /km^2. However it ranges between minimum (0.000020 km/km^2) to 0.006096 km/km^2. The highest drainage density is observed in northern part, covering Shiwalik ranges, of the study area (Fig.5). Besides, some southern part which includes largely the Sakrauda forested area and its surrounding portions of the watershed also shows high drainage density. It is largely attributed to the dominance of first and second order streams found in these parts of the study area (Fig.2).

Shape Parameters

Basin configuration

The basin configuration is the shape of the projected surface on the horizontal plane of basin map. It has been observed that a series of morphometric parameters and even the formation and movement of floods depend on the shape of the basin. Thus, the basin shape has a significant effect on stream discharge characteristics. The quantitative expression of basin shape can be characterized by (i) form factor, (ii) circularity ratio and (iii) elongation ratio. In order to assess the impact of basin configuration on hydrological responses and associated activities the following shape indices have been computed in GIS environment (Table 9).

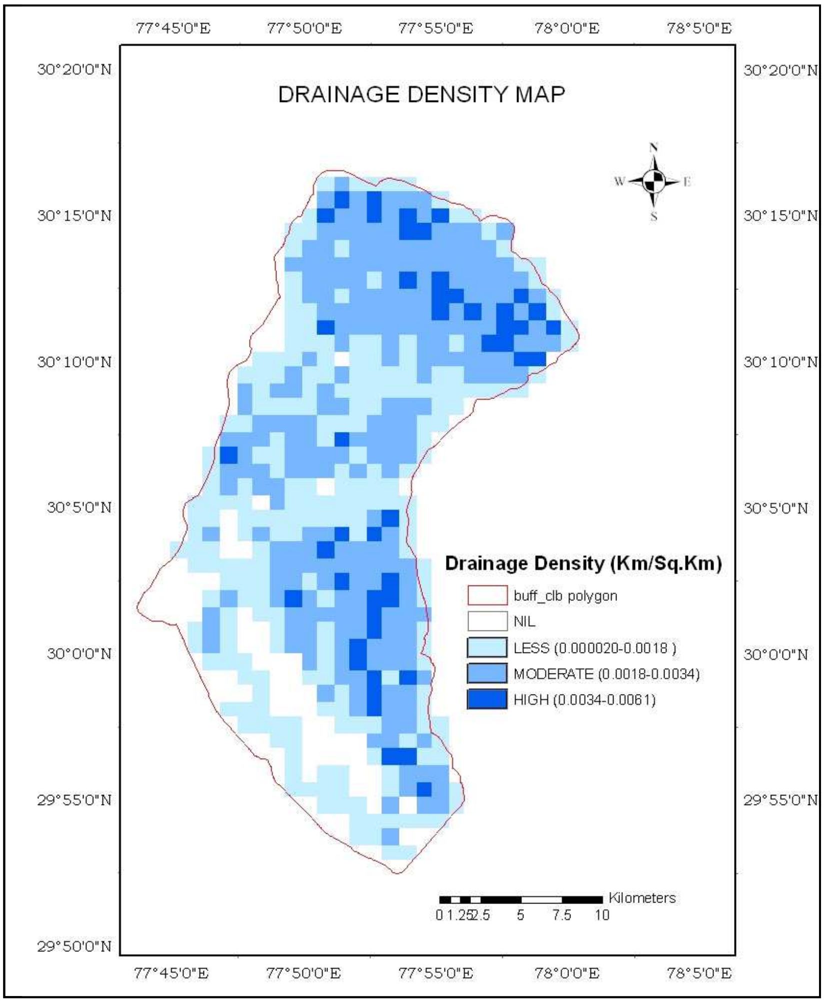

Fig. 5

(i) Form factor

The ratio of basin area to the square of basin length is called the form factor. It is computed by using the under mentioned formula:

$$R_f = \frac{A}{L_b^2}$$

Where, R_f = Form factor, A = Area of the basin, L_b = Length of the basin.

Form factor is a dimensionless property and is used as a quantitative expression of the outline of basin form. The study shows that Solani watershed with the form factor value of 8.85 seems to be more elongated in shape.

Table 9
Solani Watershed: Shape Parameter

Sr. No.	Shape Parameter	Value
1	Basin Area (A) sq km	532.40
2	Basin Length (Lb) km	60.18
3	Basin Perimeter (P) km	119.51
4	Form Factor (Ff)	8.85
5	Circularity Ratio (Rc)	0.47
6	Elongation Ratio (Re)	0.43

Source: Calculated from Attribute table.

(ii)Circularity ratio

Miller (1953) introduced the circularity ratio to quantify the shape of the basin. The ratio is equal to unity when the basin shape is a perfect circle, decreasing to 0.785 in case of square shape and continues to decrease to the extent to which the basin becomes elongated (Zavoianu, 1985). The circularity ratio is influenced by the length and frequency of streams, geological structure, vegetation cover, climate, relief and slope of the basin. It is computed by using the under mentioned formula:

$$R_c = \frac{\text{Area of Basin}}{\text{Area of the Circle with same Perimeter}} = \frac{4*Pi*A}{P^2}$$

Where R_c = Basin circularity, A = Area of Basin, P = Basin Perimeter and Pi = 22/7

It is evident from the table 9 that circularity ratio for entire Solani watershed is 0.47. Thus, on the basis of circularity ratio, it can be concluded that the configuration of Solani watershed is elongated.

(iii) Elongation ratio (Re)

Schumm (1956) proposed an "elongation ratio" to characterize basin shape. It is the ratio of diameter of a circle having the same area as the basin and the maximum basin length. The values of elongation ratio generally range from 0.6 to 1.0 over a wide variety of climatic and geologic types (Schumm, 1956). The values close to 1.0 are typical of regions of very lower relief, whereas values in the range from 0.6 to 0.8 are generally associated with high relief and steep ground slope (Strahler (1964), quoted in Singh, 2000; Upendran, *et al.*, 1998 and Zavoianu, 1985). It is observed that the smaller the fraction the more elongated is the shape of the basin, and higher the elongation ratio, the more circular is the shape of the basin (Singh, 1979 and Agrawal, 1998). The elongation ratio is a very significant index in the analysis of basin shape which provides an idea about the hydrological character of a drainage basin. This information is very significant, particularly in the flood forecasting. To obtain the elongation ratio the under mentioned formula is employed:

$$R_e = \frac{D}{Lb} \quad \text{or} \quad R_e = \frac{2\sqrt{A/Pi}}{L}$$

Where: Re = Elongation ratio.

D = Diameter of the circle having same area as the basin.

Lb = Maximum basin length parallel to the principal drainage line

A = Area

L = Maximum basin length.

Pi = 22/7

Table 9 indicates that overall elongation value is 0.43 which signifies the elongated shape of the watershed.

Hence, the quantitative symbolization of basin configuration based on form factor, circularity ratio and elongation ratio together, clearly indicates that Solani watershed has almost an elongated shape. It reveals that basin shape of Solani watershed doesn't support strong and high velocity floods and more discharge of runoff. As such, there is less possibility of erosion and transport capacities. Consequently, the suspended load is lesser therefore, the evolution of such watersheds, occurs at a slow rate.

Conclusion

The study shows that the use of remote sensing and GIS techniques has made the geographical analysis very easy and feasible. The study reveals that the Solani river is a seventh order stream. Solani Watershed as a whole has 1508 streams. However, more than three-fourth of total streams are of first order in the watershed. It could be attributed to structural weaknesses and varying topographic conditions. The relationship between number of streams and stream orders signifies that the number of streams generally decreases in geometric progression as the stream number increases. The average bifurcation ratio of the watershed is 3.40. The study indicates that bifurcation ratio values are higher for first and second order streams due to large variation in stream frequency between successive orders. The influence of lithology and vegetation on bifurcation ratio is clearly reflected in this watershed as the dominance of lower order streams is much in hilly and forested areas i.e. the Shiwalik ranges than the alluvial tract. Hence, it supports the higher bifurcation ratio in the former region than the later one. The weighted mean bifurcation ratio is 4.50 for the entire watershed. It means the geological structures have not distorted the drainage pattern to a considerable extent. The standard sinuosity index computed for Solani watershed and its tributaries is 1.07. Hence, it is inferred that drainage network of the study area is sinuous.

The study brings out that the total length of the stream segments of all orders is 1190.38 km in Solani watershed. It is observed that the total length of stream segments is maximum in case of first order streams. The length decreases as the order increases. The stream segment of various orders does not make geometric series due to stream courses traversing areas are of high altitude, moderately steep slopes and varying lithological conditions. The study indicates that mean stream length for the entire watershed is 5.91 km. It is noted that mean stream length increases as the stream order increases except for seventh order. The study shows that there are noted spatial variations in the distribution of stream length ratios across different orders. The stream length ratio is seen varying between 0.09 in higher orders to 2.89 in lower orders particularly, second and third. The study outlines that highest drainage density is observed in northern part covering the hilly areas and certain pockets in the south-eastern part of the study area. It is largely due to the dominance of first and second order streams in these parts of the watershed. In contrast, low drainage density is a phenomenon of high stream order and low relief areas. On the basis of quantitative symbolization of shape indices viz., form factor, circularity ratio and elongation ratio combined together it is inferred that basin configuration of Solani watershed is elongated. Hence, it does not support strong and high velocity floods and more discharge of run- off. As such, there is less possibility of erosion and transport capacities. Consequently, the suspended load is lesser therefore, the evolution of such watersheds occurs at a slow rate.

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