Validation of Horton's Law of Linear Aspects of Drainage Basin: A Case Study of Western Doon of Dehra, Uttrakhand (India)

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ABSTRACT

The advancement of quantitative techniques has changed the traditional ways of geomorphologic studies. The study of landforms has increasing trend of measurement, analysis and drawing inferences. The quantitative description in landform studies have helped in getting the role of variables like structure of Rock lithology and precipitation in the evolution of landscape and drainage systems. Present study is an attempt to draw some inferences from the review of linear features of the drainage basin in the western Doon of Dehra, while validating Horton's laws relating to linear aspects of drainage. Topographical sheets are the data base of study. Rotameter has been used to measure the length of the drainage system. Drainage network is ordered according to Strahler's modifications over the Horton (1945) system of drainage ordering. Accordingly, Asan is the 6th order stream in Western Doon of Dehra. There are 7 fifth order streams. Investigation reveals a close relationship between orders and numbers of stream, orders and mean length of streams, orders and mean cumulative length streams. The plotting of steam order on the abscissa on an arithmetic scale against the stream - numbers or different types of stream - lengths on the ordinate on logarithmic scale shows a linear relationship for different orders in the basins. Regression equations have also been drawn for Asan and its fifth order tributaries. Coefficient of determination R^2, which is the measure of nearness of independent variable to dependent variable has also been calculated for Asan and all the fifth order streams. $R^2 = 0.996$ for Asan river indicates that 99.6% of total variation in stream numbers is explained by stream order alone. While studying, stream -orders and mean stream- lengths; It has been found out that the value of coefficient of determination is quite high in Asan and all the fifth order streams, except Bin and Upper Asan, where it is respectively 0.855 and 0.863. Low percentage of unexplained variables indicates the validation of the second law of Horton regarding stream orders and mean stream lengths. Unexplained variables indicate the structural control incidences of river capture or tectonic disturbances in this geomorphic unit.

Keywords: Asan, Bin, Bifurcation, Horton, Regression, Ratio

INTRODUCTION

The study area is extended between 30° 14' 10'' to 30° 31' 32'' North latitude and 77° 34' 15'' to 78° 05' 39'' East longitudes (figure). The area under study is 834.28 square kilometers. Song water divides in east; Mussoorie hills in north, Yamuna in north-west and west, Siwaliks in south constitute the boundaries of study area. This landform unit falls in Dehradun district of Uttarakhand (India)

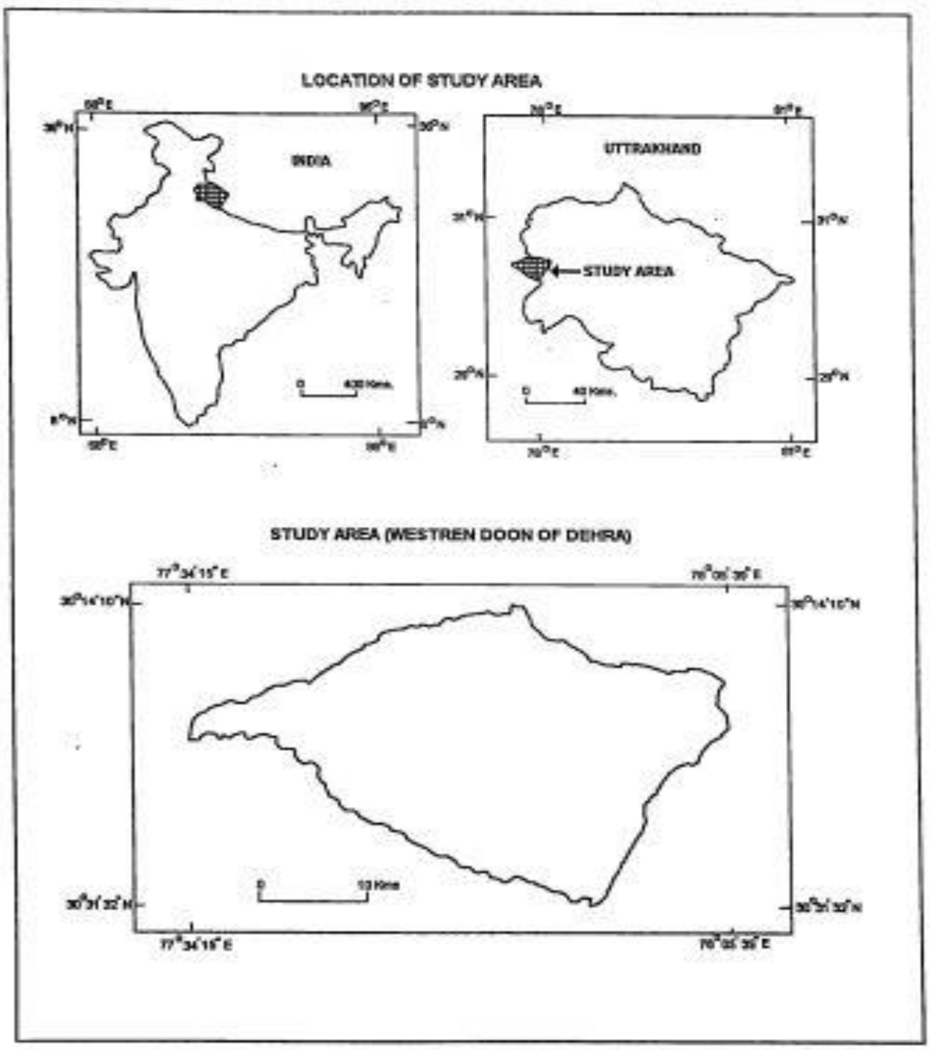

Figure1. Study Area

Taking drainage basin as a unit of study and quantitative analysis of its landforms and drainage system was pioneered by Horton (1945) which has further been extended by different scholars all over the world during the last seven decades. Among early scholar, Strahler (1950, 1952, 1956, 1958, 1964, 1971) and his associates published a number of research papers establishing the base of drainage analysis. Following these ideas an attempt is made towards the quantitative analysis of western Doon of the 'Dehra'

Drainage basin can be analyzed from two main points of view. The first is topographical, which considers the interconnection of the drainage system and yields some scheme of ordering. The second is geometrical, which has to do with the number, length, shape and orientation of the constituent part of the network etc.

The present study is an attempt to validate Horton's laws relating to linear aspects of Doon of Dehra which is also a basin. The drainage net has been ordered according to Strahler, modification over Horton (1945) system of stream ordering for this purpose. This scheme is adopted due to its simplicity and wide use.

Database and Methodology

The topographical sheets on the scale of 1:50000, of published by the Survey Department of India is the database of study. The topographical sheets bearing sheet numbers 53F/10, 53F/11, 53F/15, 53F/14, 53J/3 covers the Western Doon of Dehra. Method of drainage ordering in the present study is according to Strahler's modification over the Horton (1945) system of stream ordering. Accordingly the fingertip stream having no tributary is labeled as stream of first order. The confluence point of two order-I streams defines the head of an order-II stream, and the confluence point of two order-II streams defines the head of an order III stream and so on. An increase in the stream orders occurs only when two same order streams join each other. Convergence of different order stream does not impact the order of stream.

In this system of stream ordering, Asan River is the 6th order stream but the Yamuna which borders the area has an order of more than six. There are six fifth order sub-basins in the Asan watershed. These are upper Asan, Nun, Darer, Surna, Sitla Rao, and Tons. Bin is also a fifth order stream in this geomorphic unit but it directly drains to Yamuna river. All these fifth order tributaries except Upper Asan originate from Mussorrie hills and have the confluence with Asan on the right side. All the streams which originate from Siwaliks and joins Asan from the left side have the order of less than five (figure -2, 3)

Rotameter and thread has been used to measure the lengths in the drainage system. To plot the line of relationship, the logarithmic scale (y - axis) has been taken for stream numbers and arithmetic scale (x-axis) for orders. The coefficient of determination R^2, which is the measure of nearness of independent variable to dependent variable, has also been calculated to evaluate goodness of fit and explanatory power of regression equation.

RESULTS AND DISCUSSION

Horton's Law of Stream Numbers:

This law is related to the relationship between two variables of drainage. These variables are - order stream and number of streams. This law is called Horton's (1945) law stream number. Accordingly, "The number of stream segments of successively lower orders in a given basin tends to form a geometric series, beginning with the single segment of highest order and increases according to constant bifurcation ratio."

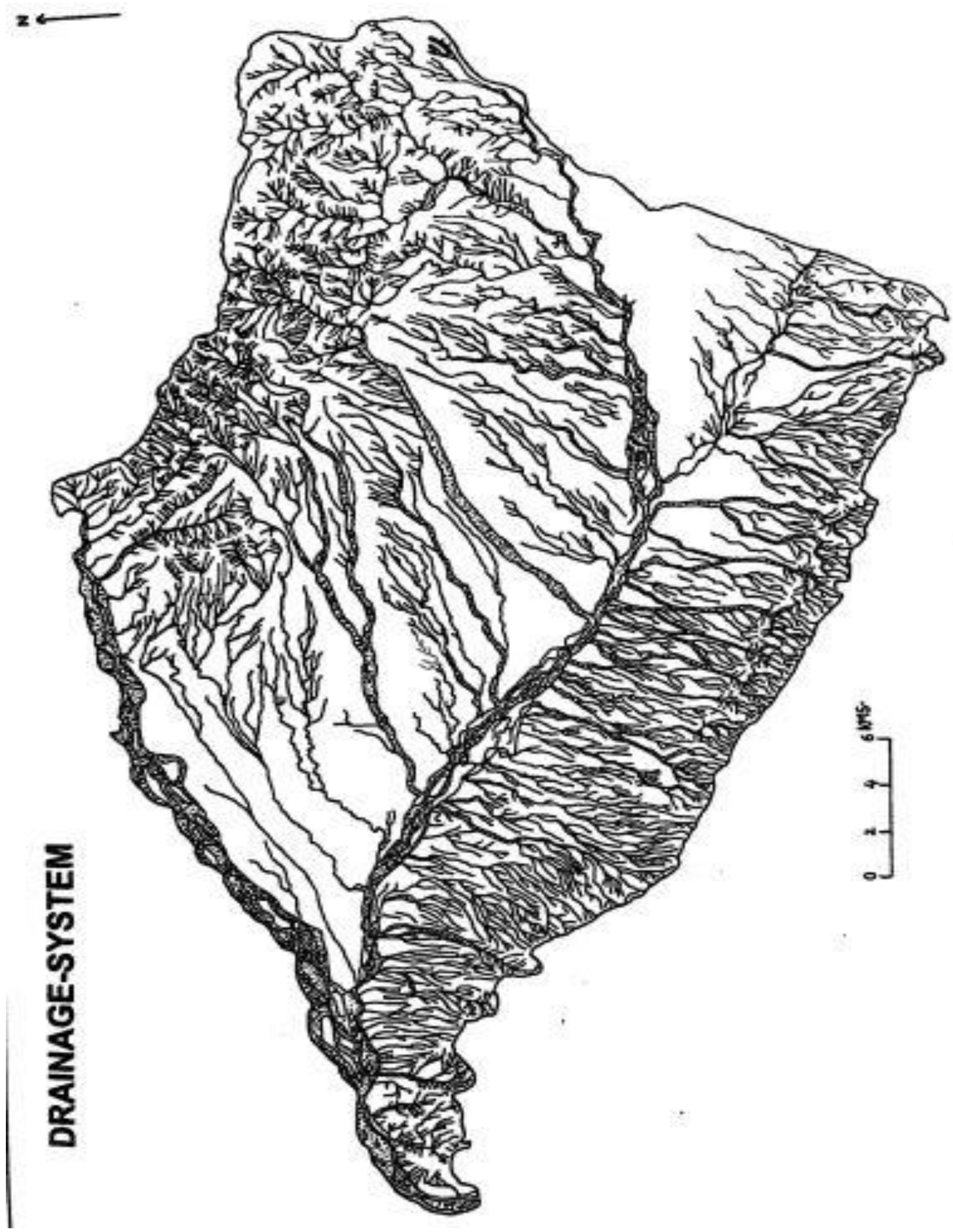

Figure2.DrainageSystem

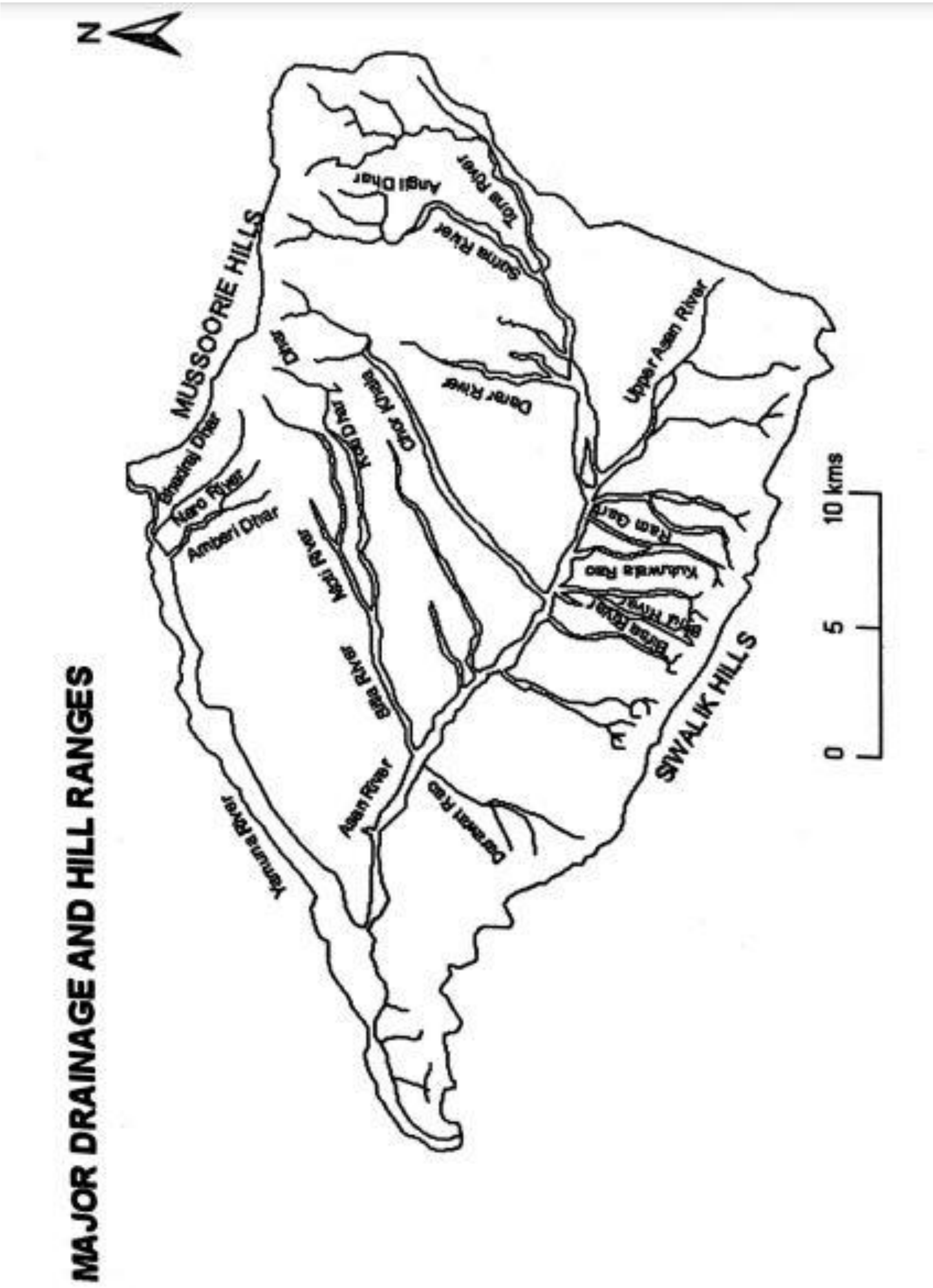

Figure 3. Major Drainage and Hill Ranges

All the fifth and sixth order watersheds of this geomorphic unit reveal the similar relationship. The numerical analysis indicates an inverse relationship between the two variables of drainage (orders and number of streams). The number of streams is decreasing with increase in the order of streams (Table).

Plotting number segments on a logarithmic scale against order segment of stream on an arithmetic scale demonstrates nearly a geometrical progression. The scatter plot between stream number and orders of the basin of different orders are given in Fig (4). The regression equations of relationship have also been worked out. To work out these equations, order is taken as independent variable numbers of stream (logarithmic form) is taken as dependent variable. These equations are tabulated as table (2). These equations are the best fit line between stream number (N) and the stream order (U). The least square regression equation of Asan, a sixth order stream, covering more than 85% of the area under study, following through central part of Doon is

$\text{Log } N_U = 3.9156 - 0.6355\ U$

Where Nu - Number of streams in given order and U is the order

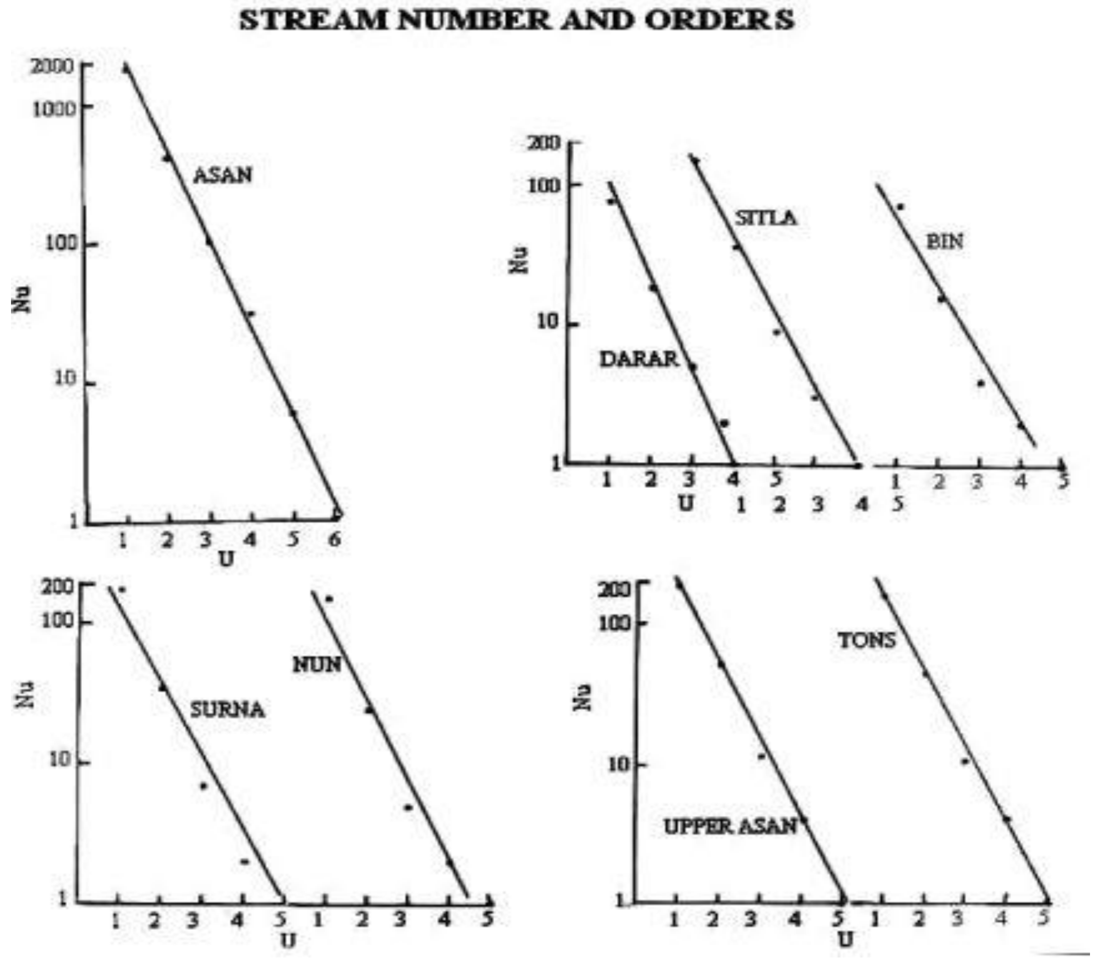

Figure 4. Stream Number and Orders

In the above given regression equation, the value of intercept on the ordinate is 3.9156 and the gradient of this line with the X-axis is –0.6355. The negative sign reveals an inverse relationship between order and number of streams in the watershed of Asan. The coefficient of determination (R^2) is a measure of nearness of independent variable to dependent variable. Infact, it evaluates goodness of fit. The R^2 value for Asan River is 0.996. The R^2 (coefficient of determination) indicates the explanatory power of the regression equation. Here, the value of $R^2 = 0.996$ indicates that 99.6% of the total variation in the stream number is explained by stream order alone and 0.4% is left to be explained. The relationship between two parameters is significant at 5% and 1% level of significance for basin of Asan River.

The regression equations for seven, other fifth order watersheds have also been worked out which are given below. In each watershed the stream-orders and stream numbers are significantly correlated related even at 0.1% level of significance; except two watershed-Darar and Bin, which are correlated at 0.5% level of significance. The value of R2 for each basin shows high linear closeness of two variables as is evident below:

Table 2: Regression Equations and Related Parameters

Basin	Regression equation of the basin	Coeff. of Determination	No. of Streams (Variables)	
			Explained (%)	Unexplained (%)
Tons	Log N_u = 2.7244-0.5428 U	0.998	99.8	0.2
Nun	Log N_u = 2.2223-0.4409 U	0.978	97.8	3.2
Upper Asan	Log N_u = 2.8181-0.5627 U	0.998	99.8	0.2
Surna	Log N_u = 2.5578-0.5475 U	0.96	96	4
Sitla Rao	Log N_u = 2.6756-0.5465U	0.996	99.6	0.4
Bin	Log N_u = 2.2409-0.4768 U	0.918	90.8	9.2
Darar	Log N_u = 2.2583-0.47514	0.916	91.6	8.4

From the above table (2), it is evident that in each case the value of coefficient determination (R^2) is quite high. It is more than 0.908 in all the basins. This means that more than 90.8% of total variation is stream number alone in all the drainage basins is accounted for by stream orders. Thus only 9.2% is left to be accounted for irrespective of the order and lithology of drainage basin. The value of unexplained variables is even 4% or less except two basins i.e. Bin and Darar. The increase in number of streams with decrease of stream order is almost in geometric progression, verifying the law of stream number postulated by Horton (1945).

Table (1): Some linear parameters of major drainage basins

Asan

U	N_u	R_b	L_u Kms	$\bar{L}_u$ Kms	R_L	C.$\bar{L}_u$ Kms	R_{cl}
1	1744	-	1095.25	0.628	-	0.628	-
2	409	4.26	382.00	0.934	1.487	1.562	2.487

3	106	3.86	216.50	2.042	2.186	3.604	2.307
4	31	3.42	134.37	4.345	2.128	18.324	2.206
5	6	5.16	62.25	10.375	2.387	54.324	2.305
6	1	6.00	36.00	36.00	3.47	54.324	2.965
Average		4.32	-		2.40		2.240

Sitla Rao

1	156	-	62.75	0.402	-	0.402	-
2	36	4.3	15.75	1.089	2.709	1.491	3.709
3	9	4.3	15.25	3.868	3.552	5.359	3.595
4	3	3.0	22.50	4.427	1.145	9.786	1.826
5	1	3.0	10.00	10.00	2.259	19.786	2.022
Average		3.52	-	4	2.78		2.530

Tons

1	156	-	78.00	0.50		0.50	-
2	44	3.54	3025	0.688	1.376	1.088	2.176
3	11	4.00	14.00	1.272	1.849	2.360	2.169
4	4	2.75	4.50	1.125	0.884	3.485	1.477
5	1	4.00	17.00	17.0	14.33	20.485	5.878
Average		3.49	-		2.35		2.130

Darar

1	77	-	45.5	0.257	-	0.257	-
2	19	4.05	17.5	0.921	3.584	1.178	4.572
3	5	3.80	5.5	1.10	1.194	2.278	1.934
4	2	2.50	7.5	3.75	3.409	6.028	2.646
5	1	2.00	4.5	4.50	1.200	10.528	1.747
Average		2.99	-	-	2.47	-	2.04

Surna

1	158	-	75.5	0.478	-	0.478	-
2	25	6.32	19.5	0.78	1.631	1.258	2.632
3	5	5.0	5.0	1.00	1.282	2.258	1.795
4	2	2.5	2.0	1.00	1.00	3.258	1.443
5	1	2.0	17.0	17.00	17.00	20.258	6.218
		3.53	-	-	2.33		2.19

Bin

1	115	-	47.75	0.415	-	0.415	-
2	23	5.0	11.00	0.478	1.152	0.893	2.152
3	6	3.5	10.00	0.458	0.958	1.351	1.513
4	2	3.0	2.75	1.375	3.002	2.726	2.018
5	1	2.0	4.50	4.5	3.270	7.226	2.651
Average		2.99		-	1.980		1.6

Nun

1	181	-	86.0	0.475	-	0.475	-
2	35	5.2	22.0	0.629	1.324	1.104	2.324
3	7	5.0	12.25	1.75	2.782	2.854	2.585
4	2	3.5	4.50	2.25	1.286	5.104	1.788
5	1	2.0	9.50	9.50	4.222	14.604	2.861
Average		2.76			2.30	-	2.070

Upper Asan

1	182	-	112.25	0.617	-	0.617	-
2	51	3.57	41.75	0.818	1.326	1.435	2.326
3	12	4.30	25.50	2.125	2.598	3.560	2.647
4	4	4.00	13.45	3.362	1.582	6.922	1.944
5	1	3.00	4.25	4.250	1.264	11.172	1.690

6		3.65	-	-	2.090		

Bifurcations Ration (R_b):

Bifurcation ratio, a widely used topographical property of the stream network and is expressed as the ratio of the stream numbers of consecutive orders i.e N_{U1}/N_{U2}, N_{U2}/N_{U3} and do on (Horton, 1945). It is an indicator of basin shape. Generally, higher the R_b, the more elongated the basin will be. The R_b value ranges between 3to5 in natural drainage systems. (Strahler, 1960) and the number varies slightly between different orders in a watershed. The average R_b calculated for the various basins is given in table (1). The average R_b ratio is the antilog of the regression coefficient (Log^{-1} b). The average R_b for streams – Asan, Tons, Upper-Asan, Surna and Sitla varies between 3 and 5, while it is little below 3 for Nun, Darar and Bin basins. Table (1) indicates that there are also high variation of bifurcation ratio between successive orders in the basin of river Asan, Nun, Darar Surna, Bin and medium variation of Rb value in Sitla, Upper Asan and Tons. Plot of number of streams versus orders (Fig-4) also indicates deviation of point from the best fitted regression. Almost all the basins indicate increase in order-I and order-II streams. High to medium variation of Rb value between successive orders of each basin; average bifurcations ratio below 3 and deviation of points from best fitted regression of order versus number; all these three results indicate that area may be structurally or tectonically controlled. Existence of higher number of lower order streams in Surna basin indicates towards the more run off, so can cause flood during heavy rain. But this also indicates that this basin is also suitable for water harvesting and conservation.

Horton's Law of Stream Length:

The following relationships normally occur between orders (U) and length of streams:

1. Inverse correlation between stream orders and order wise total length of streams.
2. Positive correlation between orders (U) and order wise cumulative mean lengths ($C\bar{L}$) of streams in the basin.
3. Horton's law (1945) of stream length states:

"mean length of stream segments of successive higher orders increase in a geometrical progression, starting with constant length ratio."

The exponential function of stream length in this regard is given below.

$$\bar{L}u = \bar{L}_1 R_L^{u-1}$$

Where $\bar{L}_1$ is average length of order-I streams and R_L stands for constant length ratio.

The regression lines (Fig-5), involving mean length of streams (L-) and basin orders (U) of Asan and its fifth order tributaries, drawn on semi logarithmic graph, again virtually validates Horton's law of stream lengths. The coefficient of correlation varies between 0.941 to 0.988 and the percentage of variance explained varies between 85.5 and 99.6. for Asan and its tributaries again confirm this law of relationship. Here, line of regression equation will be as under:

$$\text{Log } \bar{L}u = a + b_u$$

Where $\bar{L}u$ = Mean lengths of stream order, a = constant value

b = coefficient of regression, U = order of basin

The regression equation of sixth order basin of river Asan is

$$\text{Log } \bar{L}u = 2.3965 + 0.3804 \text{ U}$$

The constant value 2.3965 represents the intercept on vertical axis i.e. value of stream length when independent variable is zero. The slope of regression line with horizontal axis is 0.3804. The positive sign represents the increase in stream mean length with increase of stream orders.

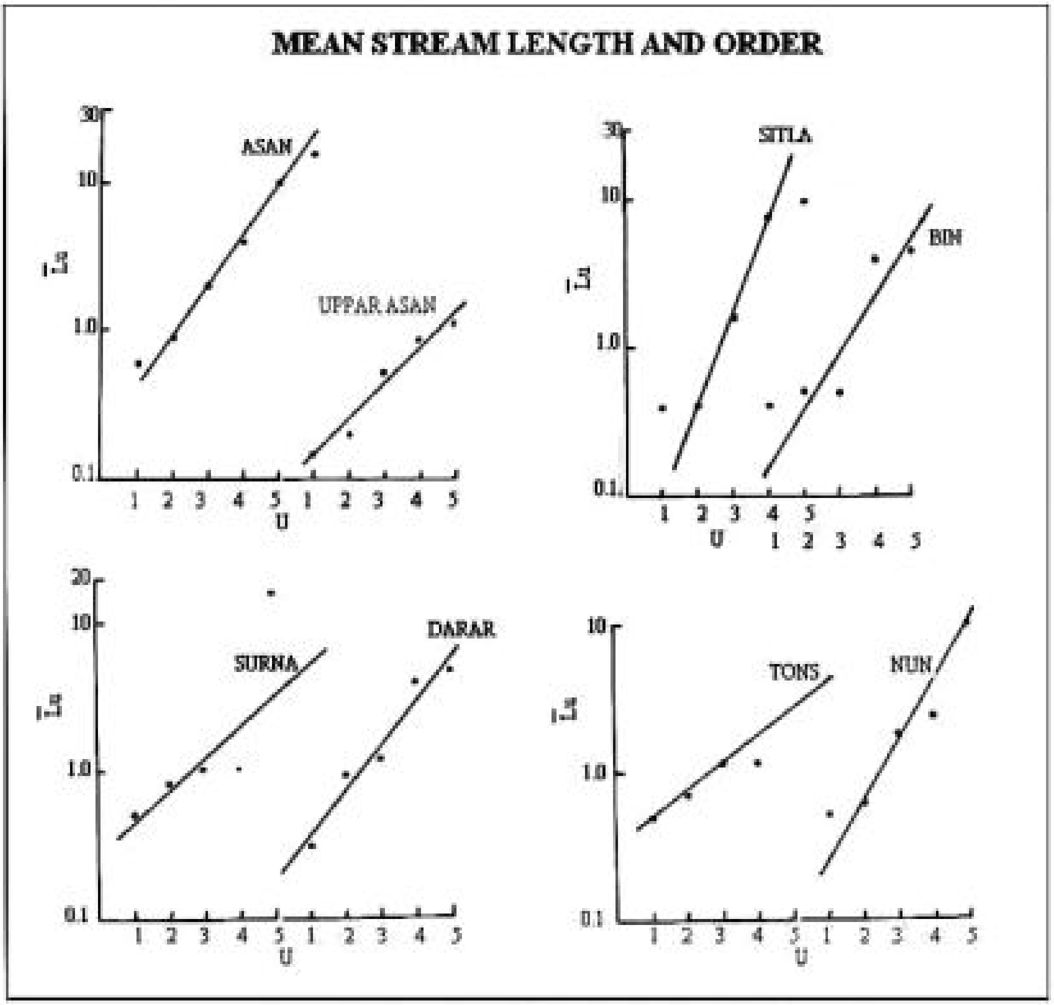

Figure 5. Mean Stream Length and Orders

The value of coefficient of determination, R^2 = 0.996; which means that 99.6% of the total variation in the value of mean 'L-' is explained by 'U' (stream order) leaving only 0.04% to be explained by other factors. Here variables (stream length and orders) are co-related at 5% as well as 1% level of significance; indicating a significant relationship between 'L' (mean stream length) 'U' and order.

Table 3 : Regression Equ. of Mean Stream Length & Order (U)

Basin	Regression equation of the basin	Coeff. of Determination	No. of Streams (Variables)	
			Explained (%)	Unexplained (%)
Tons	Log $\overline{\text{L}}$u = 2.2937+0.3709 U	0.945	94.5	5.5
Nun	Log $\overline{\text{L}}$u = 2.3182+0.3626 U	0.996	99.6	0.4

Upper Asan	Log $\overline{L}$u = 2.5168 + 0.3208 U	0.863	86.3	13.7
Surna	Log $\overline{L}$u = 2.2901 + 0.3668 U	0.931	93.1	6.9
Darar	Log $\overline{L}$u = 2.3090 + 0.2966 U	0.982	98.2	1.8
Bin	Log $\overline{L}$u = 2.1480 + 0.3934 U	0.855	85.5	14.5
Sitla Rao	Log $\overline{L}$u = 2.1058 + 0.4471 U	0.988	98.8	1.2

The regression equations between mean stream lengths and stream orders for other seven watersheds of the fifth order of doon are given below (table 3). The relationship between the two parameters is significant at level of 5% as well as 1% level of significance for all the basins; except two basins namely Darar and Upper Asan. In these two basins the parameters are co-related at 5% level of significance.

Table (3) given above indicates that unexplained variables are high in the basin of Darar, Upper Asan and Surna rivers as compared to other basins, yet there exist high correlation between mean stream length and orders. About 15% unexplained variables in Darar basin may be attributed to more structural control of the basin.

Table 4: Regression Equ. of Mean Cumulative Length and Order

Basin	Regression equation of the basin	Coeff. of Determination	No. of Streams (Variables)	
			Explained (%)	Unexplained (%)
Asan	Log C$\overline{L}$u = 2.3224 + 0.3502 U	0.878	87.8	12.4
Tons	Log C$\overline{L}$u = 2.1953+0.3289 U	0.947	94.7	5.3
Surna	Log C$\overline{L}$u = 2.1174+0.3410 U	0.832	83.2	6.8
Darar	Log C$\overline{L}$u = 2.1998+0.3096 U	0.935	93.5	6.5
Sitla Rao	Log C$\overline{L}$u = 2.0624+0.4025 U	0.931	93.1	6.9
Nun	Log C$\overline{L}$u = 2.2619+0.3158 U	0.933	93.3	6.7
Bin	Log C$\overline{L}$u = 2.3413 + 0.2029 U	0.803	80.3	19.7
Upper Asan	Log C$\overline{L}$u = 2.55 + 0.229 U	0.982	96.4	3.6

The relationship between cumulative stream lengths of different orders with the stream orders although not drawn originally by Horton, has also been experimented. Although there are deviations (fig-6), yet there seems to be the define geometric relationship between the two. The relationship between two parameters i.e. cumulative mean stream lengths and orders varies between 0.896 and 0.982 and values of coefficient of determination ranges between 0.803 and 0.964. The variables are correlated at 5% as well as 1% level of significance for each basin, except Surna and Bin basin. The Surna and Bin have a significance level of 5% in respect of correlation. The best fitted regression equations of these variables for 8 basins have been given above.

Stream Length Ratio: it is the ratio of mean length of streams of an order (Un) to the mean length of streams of preceding order (U_n). The mathematical expression of stream length ratio is as under:

$$R_L = \frac{\overline{L}_u}{L_{u-1}}$$

Where $\overline{L}_u$ = Mean length of stream in an order.

R_L = Length ratio of stream

Generally, length ratio varies between 2 and 3 in a normally developed basin, Horton (1945). The study of stream length is important in perspective of surface flow, and peak discharge. More the length, slower will be the appearance of floods and larger the surface flow. This observation leads to calculating the length ratio. The length ratio of the basins has been calculated and presented (table). The average ratio of all the 5th and 6th order drainage basin varies between 1.98 and 2.78. This value is between 2 and 3 except basin of Bin drainage. In Bin-basin this value is 1.98. The entire basins except Bin validate the Horton's range between 2 and 3 in respect of average length ratio of basin. Here, average length ratio is obtained by taking anti log of regression coefficients.

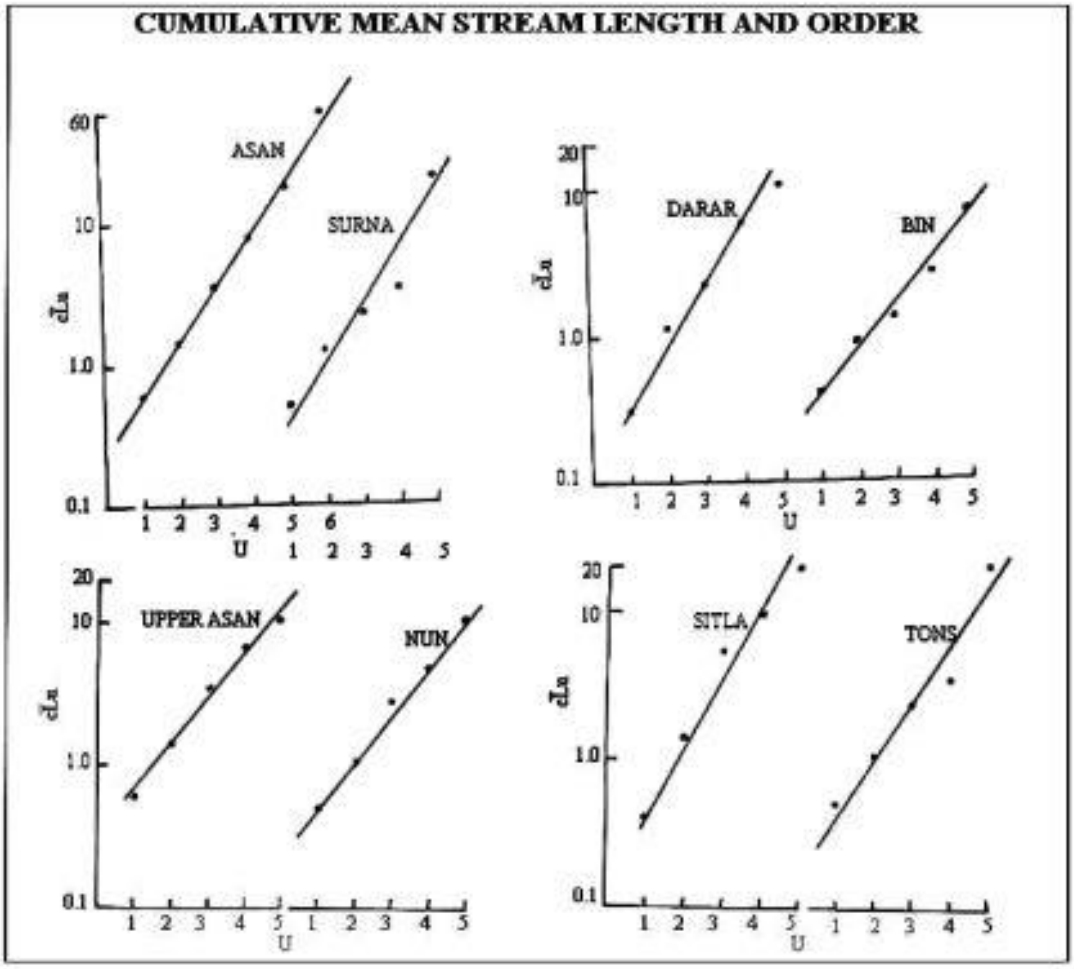

Figure6. Cumulative Mean Stream Length and Orders

There are a lot of differences in the values length ratio among different orders of streams and among different watersheds also (table)). In Asan-basin (6th order) it varies from 1.487 to 3.470. The variations in these values in other basins are – from 1.089 to 4.427 (Sitla Rao), from 1.264 to 2.598 (Upper Asan), from 1.286 to 4.222 (Nun), from 1.2 to 3.584 (Darar), from 1.0 to 17.0 (Surna), from 0.884 to 14.33 (Tons), and from 0.958 to 3.27 (Bin). Horton states that these values should vary between 2 and 3. There must not be large difference in length ratio between different orders of basin. So these variations indicate abnormalities in development of the basins and indicate the incidences of river capture or tectonic disturbances in the area. There may also be structural control in the development of basin.

If we correlate the behaviour of first and second order streams (fig. 5 and table) it may be concluded that the streams of first and second order in general are more in number but shorter in length. This behaviour indicates a change of base level. In case of abnormal or tectonic change of base level first order tributaries develop to smoothen the change. The fifth order streams in the study area are straight, lengthier and join almost at the right angle to the main stream - Asan. Such behaviour is possibly due to the upliftment along the fault plain.

Micro observations of drainage pattern, stream number in different orders (table 5.3) indicate the incidences of river capture, neo-tectonic activities and structural control in the sequential evolution of doon of Dehra

CONCLUSION

While studying stream orders and stream numbers it has been found out that in Asan stream and all its 5th order tributaries the value of coefficient of determination is quite high. Its range is from 0.998 to 0.908. This means that more than 90.8% of total variation is stream number alone in all the drainage basins is accounted for by stream orders. Thus only 9.2% is left to be accounted for irrespective of the order and lithology of doon of Dehra. The increase of stream numbers with decrease of stream orders almost in geometric progression is verifying the law of stream number, postulated by Horton (1945)

Almost all the basins indicate the increase in order-I & order-II streams. High to medium variation of Rb value between successive orders of each basin; average bifurcations ratio below 3 and deviation of points from best fitted regression of order versus number; all these More lower order streams in numbers in three results indicate that area may be structurally or tectonically controlled. The Surna watershed indicates more runoff, so can cause floods during heavy rain. But this also indicates that this basin is also suitable for water harvesting and conservation.

While studying, stream -orders and mean stream- lengths. it has been found out that in Asan stream and all its 5th order tributaries the value of coefficient of determination is quite high, except Bin and Upper Asan, where it is respectively 0.855 and 0.863. These values indicate more structural control in these fifth order catchments. Low percentage of unexplained variables indicates the validation of the second law of Horton regarding stream orders and mean stream lengths.

The variations in the values of length ratios indicate abnormalities in development of the basins and also indicate the incidences of river capture or tectonic disturbances in the area. There may also be structural control in the development of the basin.

In nutshell, it can be concluded that doon of Dehra is validating Horton's laws of linear aspects of drainage basin Unexplained values of variables regarding relationship between order and numbers of streams or order and mean lengths of respect of Horton's laws is below 15%. While validating Horton's laws, some influences have also been drawn regarding doon of Dehra. These are:

- More lower order streams in numbers in the Surna basin indicates more runoff, so can cause floods during heavy rain. But this also indicates that this basin is also suitable for water harvesting and conservation.
- The unexplained variables indicate the incidences of river capture or tectonic disturbances in the area. There may also be structural
- The fifth order streams in the study area are straight, lengthier and join almost at the right angle to the mainstream - Asan. Such behaviour is possibly due to the upliftment along the fault plain.
- Drainage pattern and stream number in different orders indicate the incidences of river capture, neo-tectonic activities and control of structure in the evolution of drainage basin.

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