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FUNCTIONAL ANALYSIS OF BASIN AREA DEVELOPMENT IN A GREATER HIMALAYAN REGION (DHAULI GANGA BASIN)

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ABSTRACT : The present paper is an attempt to understand the drainage basin genesis in relation to the other topographic, hydrologic and lithological factors. The functional relationship between basin area and other variables of basin morphometry has been established by bivariate regression analysis. The step-wise regression analysis has been attempted to identify the dominant factors contributing to the growth of basin area. Ultimately total stream length and constant of channel maintenance have emerged as the main determinants of drainage basin size.

INTRODUCTION

The area of the basin is a resultant of multi-functional interaction of various environmental activities. The horizontal expansion of drainage basin is the expression of intensity of different causative factors viz. relief conditions, drainage texture, climate, geology – tectonics operating in the area and vegetal canopy etc. Thus, the study of drainage basin area is an important aspect of drainage morphometry, leading the diagnosis of basin genesis which ultimately seems to be inevitable in understanding the nature of existing landscape and to work-out the intensity of processes operating in the region. It is particularly so in Himalaya where endogenetic forces are still in operation.

GEO-IDENTITY OF THE STUDY BASIN

The Dhauli Ganga basin lying in greater range of the Central Himalaya is a 6th order basin in Strahler's fashion. The area extends between 79^{o} 30'E to 80^{o} 15'E longitude and 30^{o} 15'N to 30^{o} 45'N latitude, encompassing an area of 1992 km^2. Politically, the basin covers an area of Chamoli and Pithoragarh districts of Garhwal and Kumaon regions respectively, in the extreme north of Uttar Pradesh. The basin has two distinct lithoformations i.e., metamorphic formations of central crystalline (dominated by gneiss and schists) are separated from sedimentary rocks (mainly limestone) of Tethys zone by NNW striking Dhar-Martoli fault that traverses through Malari village (Heim and Gansser, 1939, Gairola, 1975) (Fig. 1).

METHODOLOGY

For this exercise all third order basins lying within the entire Dhauli-ganga basin have been taken into account, because of the more orderly development on either sides of the trunk stream and provide more scope for the choice of the basins with the varying area, lithology and topographic conditions for more intensive study. Different dimensions of the drainage network for

each basin have been measured and a correlation matrix of 21 variables has been prepared to make a choice of appropriate indicators. The significance of relationship of the parameters has been established by 't' and 'F' tests. The exponential functions of the relationships of the indicators are assessed by the bi-variate regression analysis. A step-wise regression analysis has been applied to obtain the best set of the explanatory variables in order to their intensity of influence.

Following variables, which have significant relationship with drainage basin area, on the basis of correlation matrix, have been taken into account for detail study:

Dependent variable:

X_{18} = Drainage basin area (A)

Independent variables:

X_5 =Total number of stream segments (Σ N)

X_6 =Total stream length (Σ L)

X_7 =Mean length of segments (L)

X_8 =Mean bifurcation ratio (R_b)

X_{11} =Drainage density (D_d)

X_{12} =Stream frequency (D_f)

X_{13} =Dissection index (D_i)

X_{16} =Relief ratio (R_r)

X_{19} =Constant of channel maintenance (C_{cm})

X_{20} =Length of overland flow (L_g)

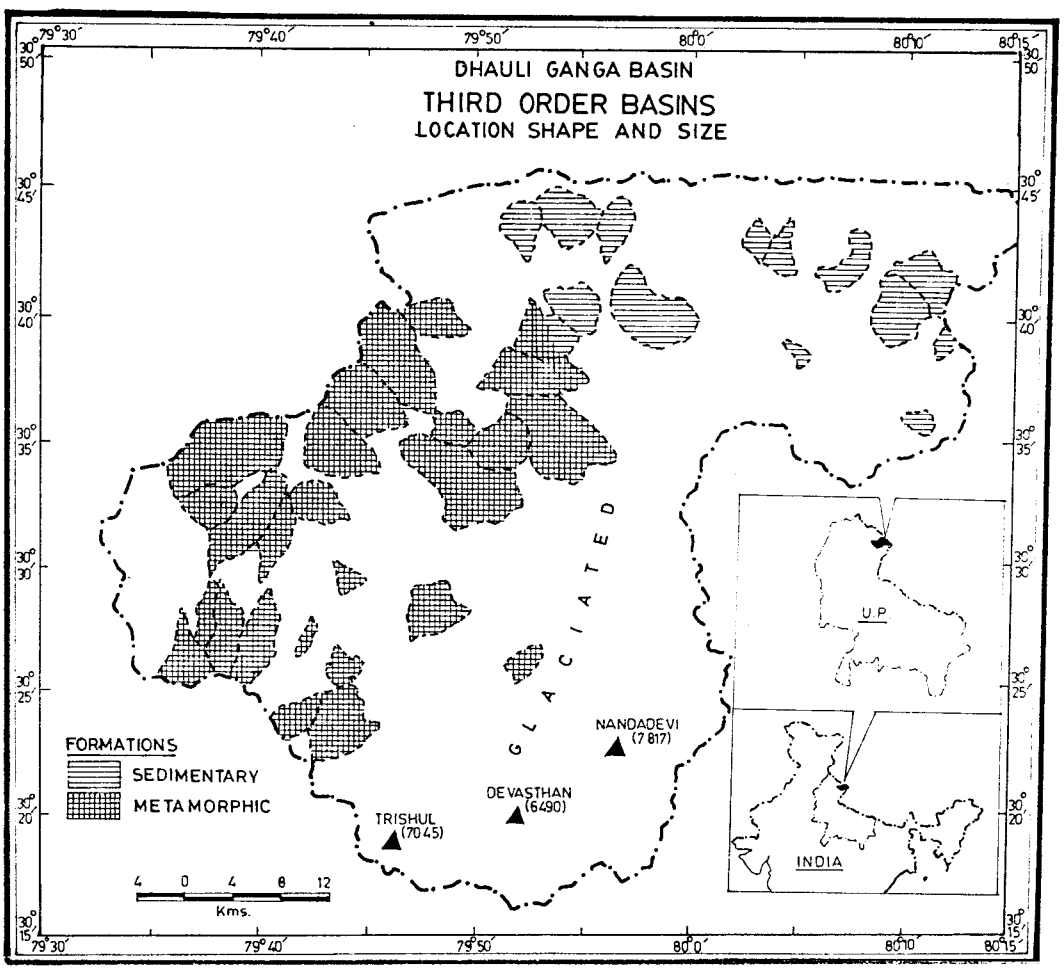
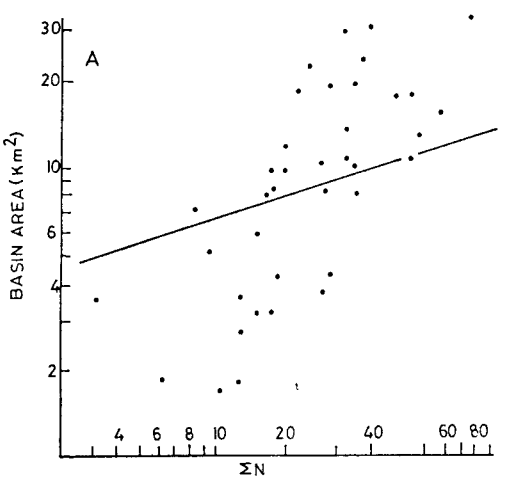


Fig. 1

RESULTS AND DISCUSSIONS

The results of the correlation matrix indicate that the basin area has a strong and positive correlation with ΣN (0.628), ΣL (0.863), $\bar{L}$ (0.571), $\bar{R}_b$ (0.596), D_i (0.491), R_r (0.497), C_{cm} (0.607) and L_g (0.607), all are significant at 0.01 level of significance. The positive relationship between basin area and ΣN has a direct contradiction with the results of S. E. Chhota Nagpur region's study by Singh et. al (1981), i.e., 'the stream number is independent of basin area'. The probable reason is that the plateau region has flattish surface in relation to high mountain, thus higher value of C_{cm}, so that a few streams drain larger area, while in higher altitudinal basin more number of streams are required to drain a smaller area (because of very low value of C_{cm}, 0.475 km^2 in this case). With the development of basin, number of streams increase by headward erosion which retreat the basin parimeter, and ultimately area of the basin. This relationship between two variables is portrayed by the scattered diagram (Fig. 2–A) and well explained by the equation as below:



$$\text{Log } X_{18} = 3.190 + 0.326 \log X_5$$
$$(4.969)^*$$

R^2 = 0.394

F = 24.693*

where, X_{18} = basin area

X_5 = ΣN

The above equation implies that ΣN has explained 39.4% of variations in the basin area development. The increasing number of stream segments in turn increases the length of streams and this is because of fluvial process of headward erosion, which increase the stream length and retreat the basin boundry and ultimately basin area. This said relationship between basin area and ΣL is exhibited by the graph (Fig. 2-B) and fully supported by the bivariate regression equation as below:

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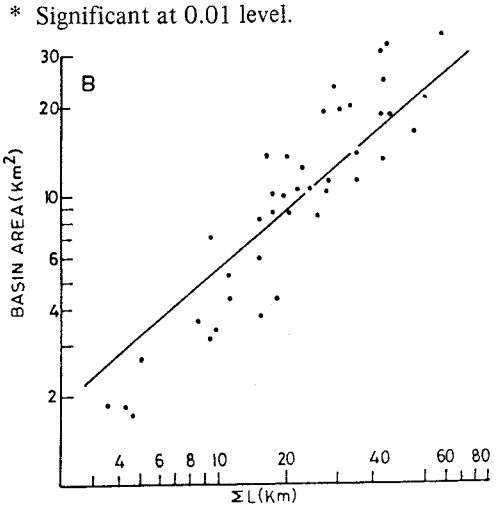
* Significant at 0.01 level.



$$\text{Log } X_{18} = 0.363 + 0.586 \log X_6$$
$$(0.516)^*$$

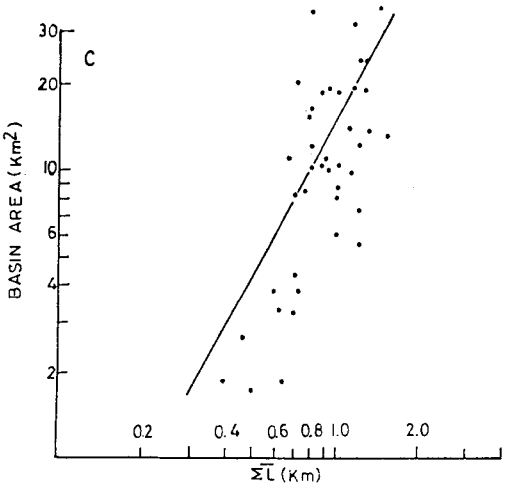
X_6 = ΣL

R^2 = 0.745

F = 110.581*

The above equation implies that ΣL explains 74.5% of variations of the basin area expansion.

The same logic of headward extension of streams is applicable in case of L also. Obviously, the $\bar{L}$ of stream will increase as the stream segments increase their length, which ultimately related o the horizontal expansion of the drainage basin. This positive and linear relationship between basin area and $\bar{L}$ of stream is represented by the scattered diagram (Fig. 2-C) and well supported by the regression equation as below:



$$\text{Log } X_{18} = -4.662 + 18.062 \log X_7$$
$$(4.288)^*$$

$X_7 = L$

$R^2 = 0.33$

$F = 18.391^*$

The said equation implies that 33% variations of basin area development are explained by mean stream length.

Bifurcation ratio reflects the branching phenomena of the drainage network, the significant correlation between $\bar{R}_b$ and basin area, indicates that higher values of $\bar{R}_b$ are associated with the bigger areas of the basin. The simple logic behind this postulation is that in a mountainous region, more finger streams are required to drain the bigger area (because of low C_{cm}), which enhance the value of $\bar{R}_b$. This trend of relationship is well portrayed by the scattered diagram (Fig. 2-D), maximum points lie along the best fit line. The equation of the fitted line is as follows:

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* Significant at 0.01 level.

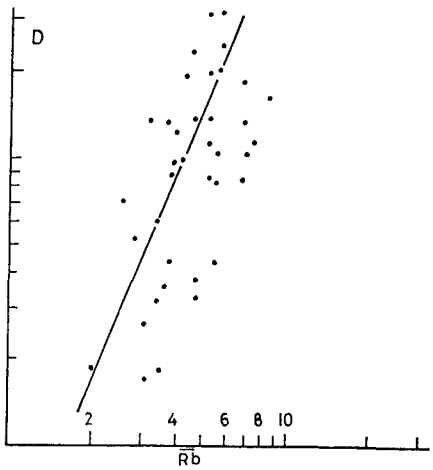
$$\text{Log } X_{18} = 3.03 + 3.21 \log X_8$$
$$(4.576)^*$$

$X_8 = \bar{R}_b$

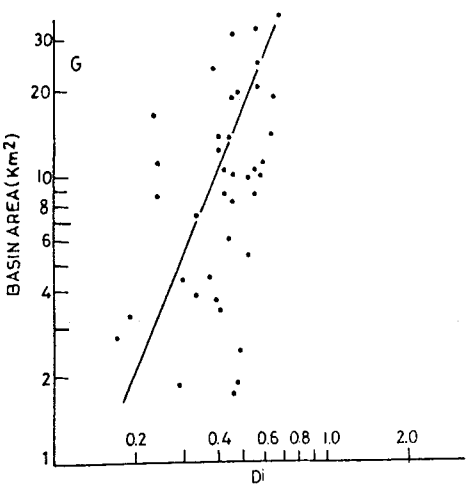
$R^2 = 0.36$

$F = 20.935^*$

The value of R^2 explains 36% variations of basin area development.



The higher value of dissection index enhance the velocity of running water and stimulate the erosional capacity of rivers. Thus, a combined effect of gradient and sediment yields brings a change in water divide by shifting it headward and ultimately enlarges the basin area. This linear positive relationship is well portrayed by the scattered diagram (Fig. 2-G), where points tend to be scattered along the best fitted regression line. The equation is as below:



$$\text{Log } X_{18} = -2.407 + 33.134 \log X_{13}$$
$$(3.477)^*$$

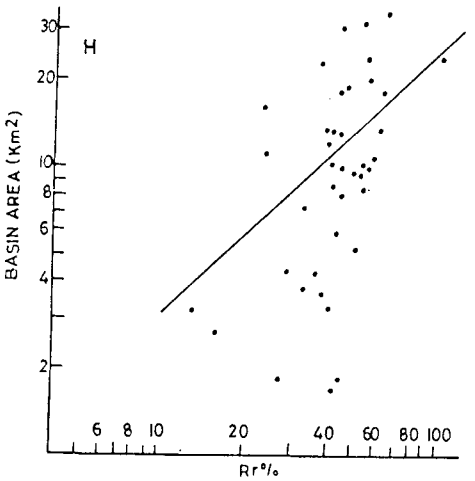
$\text{Log } X_{13} = D_i$

$R^2 = 0.241$

$F = 12.093^*$

D_i above explains 24.1% variations of basin development.

The higher R_r provides the favourable conditions for the maximum sediment yield by enhancing the stream velocity to shift the water divide headward. This headward erosion extends the length stream segments, which ultimately largens the basin size. This positive relationship is well supported by the scattered diagram (Fig. 2-H). The regression equation is as below:



$$\text{Log } X_{18} = -2.494 + 0.334 \log X_{16}$$
$$(3.526)^*$$

$X_{16} = R_r$

$R^2 = 0.247$
$F = 12.434^*$

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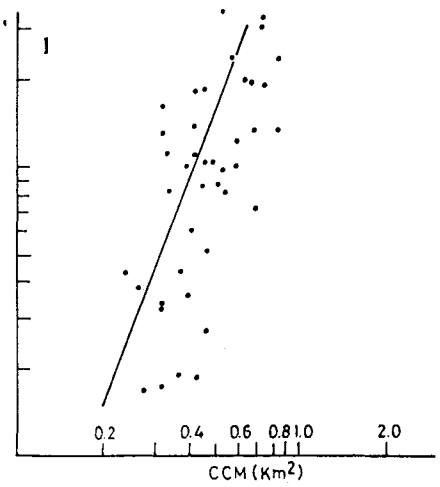
* Significant at 0.01 level.

The value of R^2 shows that 24.7% variations of the basin area are explained by the R_r.

To drain a larger area a higher value of C_{cm} is required (discussed earlier). Further, C_{cm} has a positive and significant correlation (0.798) with $\bar{L}$ of streams. This indicates that the longer length of stream segments is a function of bigger area of C_{cm}, where, longer length of stream segments plays a vital role in retreating the basin boundry and thereby largening the basin size. This said relationship between basin area and C_{cm} is well depicted on the graph (Fig. 2-I), the equation of the fitted line is as follows:



$$\text{Log } X_{18} = -3.797 + 33.078 \log X_{19}$$
$$3.710)^*$$

$X_{19} = C_{cm}$

$R^2 = 0.368$
$F = 22.186^*$

The above equation implies that 36.8% of variations of basin area development are explained by C_{cm}.

Similar to C_{cm}, L_g also has a positive and significant correlation (0.80) with the $\bar{L}$ of stream segments. Thus, it may be concluded that the higher value of L_g is a function of longer stream segments, which is the important property of bigger basin development. The positive function of L_g with basin area is proved by the scattered diagram (Fig. 2-J) and bivariate regression equation as below:

$$\text{Log } X_{18} = -3.551 + 65.851 \log X_{20}$$
$$(4.712)$$

$X_{20} = L_g$

$R^2 = 0.363$
$F = 22.202^*$

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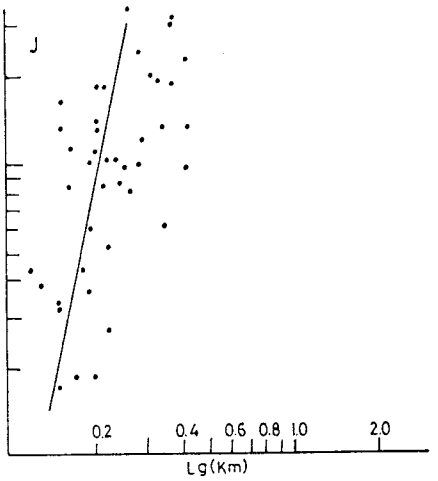
* Significant at 0.01 level.



The said equation reveals that 36.3% of variations in the basin area development are explained by L_g.

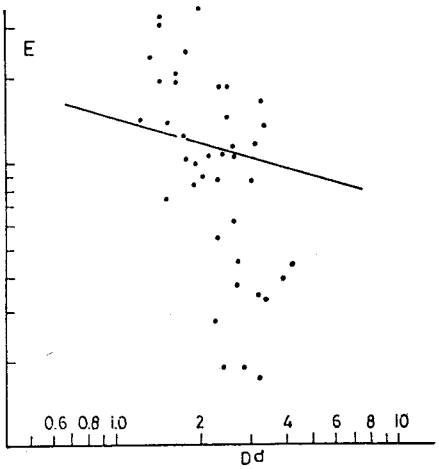
In contrary to the above discussed factors, drainage density (–0.574) and stream frequency (–0.612) are inversely correlated to the basin area, both significant at 0.01 level of significance. The location of basins and underlying rock formation seems to be important factor to decide the negative relationship between D_d and basin area, because basins of higher D_d and smaller area lie over the sedimentary formation, in upper parts of the Dhauliganga basin, while bigger basins with smaller D_d are located southward over the metamorphic formation. This tally, with the earlier studies that the zones of erosion shift headward (Schumm, 1977), Kumar, 1983). The negative correlation (–0.903) between length of stream segments and D_d is a characteristic of early stage of basin development. This is again supported by the significant correlation (0.435, significant at 0.10 level) between D_d and hypsometric integral. This explains that the chronological development of the basin area is a negative function of D_d. This relationship between the said two is exhibited by the graph (Fig. 2-E) and statistically proved by the regression equation as below:

$$\text{Log } X_{18} = 27.308 - 6.599 \text{ Log } X_{11}$$
$$(-4.324)^*$$

$X_{11} = D_d$

$R^2 = 0.33$
$F = 18.693^*$

The equation implies that 33% variations of basin area development are explained by drainage density.



Similar to D_d, D_f also high over the soft rocks formation of Tethys zone and lower over the hard rocks of metamorphic characteristics. This is portrayed by the graph (Fig. 2-F) and regression equation of the fitted line as below:

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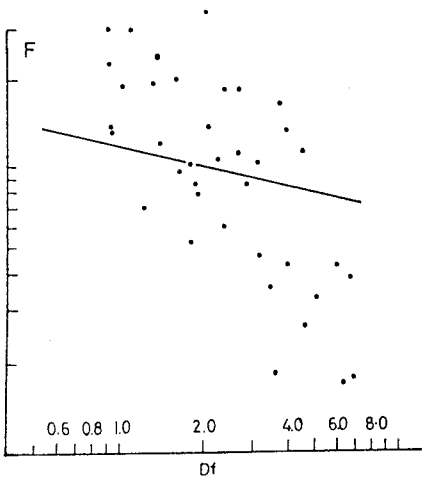
* Significant at 0.01 level.



$$\text{Log } X_{18} = 20.826 - 2.99 \log X_{12}$$
$$(-4.774)$$

$X_{12} = D_f$

$R^2 = 0.374$
$F = 22.790^*$

Equation implies that D_f explains 37.4% variations of basin area development.

On the basis of the above discussions following equation of the explanatory variables of the basin area has been obtained:

$$X_{18} = f(X_5, X_6, X_7, X_8, X_{11}, X_{12}, X_{13}, X_{16}, X_{19}, X_{20})$$

To obtain the best set of explanatory variables a set-wise regression analysis has been applied.

STEP-WISE REGRESSION ANALYSIS

On the basis of the significance test viz. 't' and 'F', following equation of explanatory variables has been obtained:

$$X_{18} = 16.969 + 0.788\ X_6 + 27.628\ X_{19} + 1.325\ X_{12} - 0.273\ X_5$$
$$(9.702)^* \quad (8.969)^* \quad (4.312)^* \quad (-3.975)^*$$

$\bar{R}^2 = 0.968$
$F = 290.119^*$

The results of the step-wise regression analysis (Table 1) reveal that ΣL entered as the first explanatory variable in the equation and alone explains 74.3% variations of basin area. In the second step C_{cm} is entered as the second explanation variable and both explain 95.26% variations. D_f emerges as the third explanatory variable and all three explain 95.45% variations of basin area.

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* Significant at 0.01 level.

TABLE 1 : FACTORS AFFECTING THE DRAINAGE BASIN AREA – A STEP-WISE REGRESSION ANALYSIS RESULTS

Step-wise Regression Equations	Intercepts	Regression Coefficient of				R	R^2	$\bar{R}$	$\bar{R}^2$
		X_6	X_{19}	X_{12}	X_5				
I	– 0.363	0.506 (10.516)*				0.863	0.745	0.863	0.745
II	–11.123	0.455 (20.991)*	25.217 (12.509)*			0.975	0.950	0.975	0.950
III	–16.961	0.473 (21.613)**	31.874 (9. 287)*	0.751 (0.332)**		0.979	0.958	0.977	0.954
IV	–16.969	0.788 (9.702)*	27.628 (8.969)	1.325 (4.312)**	–0.273 (–3.975)*	0.985	0.970	0.984	0.968

* Significant at 0.001 level.
** Significant at 0.10 level.

In the final equation ΣN emerges as the fourth explanatory variable and all four together explains 96.82% of variations in the basin area development.

CONCLUSION

On the basis of the whole discussion, it can be concluded that the basin area is dependant of multi-function of topographic, hydrologic and lithological characteristics of the region. The ΣL, C_{cm}, D_f and ΣN emerge as the main governing factors respectively. Lithoformation has its impact only in relationship with the location and stages of the basin development. The basins of bigger size have developed near the mouth of the trunk stream and become smaller sourceward and prove the headward extension of the zones of erosion.

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