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STREAM NUMBERS AND BIFURCATION RATIOS

S. R. Jog, Pune

ABSTRACT : The present paper attempts to use the chi-square technique to analyse the stream number distribution. The bifurcation ratio has been used as an estimator for expected frequency. It is suggested that for estimating stream numbers the geometric mean of ratios should be used instead of arithmatic mean. The analysis was carried out for 107 basins of fifth order stream from Upper Bhima basin. The use of ratio-values of IInd order basins and the stream junction angle has been suggested to differentiate between initial and integration stages of network development as in both the cases value of Rb tends to be close to the lower limit of 2.

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INTRODUCTION

The network analysis forms an inseparable part of drainage basin studies. The channels are the containers and the most dynamic aspect of the basin and hence these are the first to respond to the changes in the competence of the erosive agent. Hence the analysis of the stream network and its development has, since long, attracted the attention of the geomorphologists. However, the network analysis received the treatment it deserved only after Horton (1945) published his system of ordering and laws of drainage composition.

A large number of papers have since been published particularly in the fifties and the sixties by scholars like Strahler (1952, 1964), Schumm (1966), Shreve (1966, 1967 and 1964) and Scheidegger (1966, 1967 and 1968). Various aspects of drainage composition, network development and other related factors have been discussed using statistical techniques and comibational analysis. The present paper concentrates only on one of the parameters of drainage composition 'the number of streams' and the law related to them. For this purpose, a sample of 107 fifth order streams from the Upper Bhima basin was chosen. These 107 basins, located in different morphoclimatic zones, have relatively homogeneous lithological characteristics as all of them are underlain by Deccan basalt.

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The first law of Hortonian analysis of drainage composition relates to stream numbers which reads as follows: "The number of streams of different order 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 ...." (Horton 1945 P. 291). This law has got wider acceptance and it holds good even in case of Strahler's system of stream ordering. The bifurcation ratio is defined as an average of ratios of stream numbers of successive orders and can be computed as

$$\sum Rb = n_1/n_2 + n_2/n_3 + ... n_{k-1}/nk] \;/K-1$$

where n_1, n_2 are number of streams of different orders and K is order of the basin.

The lower limit of bifurcation ratio is 2, whereas theoretical upper limit can be equal to the number of streams of first order. However, it is too improbable for a natural drainage system to have Rb equal to the number of the first order streams.

The number of streams of a given order within a basin can be computed using the average bifurcation ratio. It is given by the equation

$$nw = Rb^{k-w} \text{ ------------------ } (2)$$

where K is order of the basin and,

w = 1, 2, -------------------- K−1.

Thus the value of RB can be employed as an estimator of stream numbers. However, if the bifurcation ratio is to be used as an estimator and to be considered as rate of change of numbers of streams, the values computed as arithmetic mean (Equation 1) show a marked deviation from the observed values. The distribution of the numbers follows a geometric series and hence it is appropriate to calculate Rb as a geometric mean of individual ratios.

$$Rbg = \sqrt[K-1]{(n_1/n_2)(n_2/n_3) .... (n\,k-1/nk)} \; ... (3)$$

The Rb values calculated as arithmetic means of ratios and geometric means for 107 basins of fifth order did not differ significantly, but the estimated values of the stream numbers do vary considerably. In case Herton's system of ordering is used the variation between observed and expected number is much more. But, if Strahler's ordering is followed, the geometric mean can be directly computed as

$$Rbg = \sqrt[k-1]{-N_1} \quad .... (4)$$

where N_1 is number of first order streams.

The Rb values obtained as arithmetic average and geometric means have been classified and given in the following table (1).

TABLE 1

Rb Value Classes

Classes	2.01 to 2.51	2.51 to 3.01	3.01 to 3.51	3.51 to 4.01	4.01 to 4.51	4.51 to 5.01	5.01 to 5.51	5.51 to 6.01	6.01 to 6.51
Rb (a)	-	6	27	36	27	3	4	1	3
Rb (g)	5	27	50	31	3	1	-	-	-

It may be noted that the values of Rbg range from 2.01 to 5.01 which is the normal limit for Rb. The arithmetic values, however, appear slightly exaggerated and therefore cause higher expectancy of streams in a given order. As a matter of fact, it should be noted that Rbg is invariably less than Rb (a)

CHI–SQUARE ANALYSIS OF STREAM NUMBER DISTRIBUTION

Using the Rbg as an estimator, expected number of streams of each order were obtained for all the 107 catchments. The X^2 technique was employed to analyse the expected and the observed distributions of streams. The chi-square values computed were well within the critical limits in case of 85 basins. In case of remaining 22 basins, the null-hypothesis of zero difference was rejected in favour of alternate hypothesis.

The very fact that the computed square values exceed the critical limits at 2.01 level suggests that the bifurcation ratio for the given basin is not a good estimator of number of streams. This situation arises particularly in case of lower order streams. The expected number in some cases is higher than observed, whereas in others it is far less than the existing streams. The higher expectancy clearly indicates a condition under which the value of bifurcation ratio is rather exaggerated. The lower expectancy of streams indicates lower value of bifurcation ratio. Both these conditions are uncommon and are observed in only 22 basins. It is obvious that the number of streams of a given order 'nw' is far more than the number required of the streams of W + 1 order. The excess streams can be obtained as

$$Pw = nw - 2\ nw + 1 \ ...... (5)$$

Where Pw is number of excess stream.

STAGES OF NETWORK DEVELOPMENT AND BIFURCATION RATIO

The stages of network development have been identified by Glock (1931) such as initiation, elongation, elaboration and integration. The values of bifurcation ratio which normally range between 3 and 5, can best be employed in the identification of atleast two extemes. In both the stages, initiation and integration, the number of the streams is too low and hence the Rb values tend to be closer to the lower limits. The values of Rb increase with addition of excess streams. These Pw streams are found to influence the Rb values. The lower the number of excess streams, the greater the deviation of the basin from the condition which Scheidegger (1970) calls 'Structurally Hortonian and the lower is the value of Rb. The number of streams increases only after the existing streams perform some work.

THE CASE OF FIRST AND SECOND ORDER CATCHMENTS

The first and second order streams are usually the gullies actively eroding the landmass whereas the higher order streams are mostly engaged in transporting the debris supplied. As far as the parameter number of streams is concerned it is observed that the first and second order streams are exceedingly higher than those required for developing streams of higher order.

The bifurcation ratios of second order streams from 22 basins were computed. The values of Rb in case of second order streams is equal to n_1 in case of Strahler system and $n_1 - 1$ in case of Horton's system However, this value varies between 2 and 4 in case of basins developed in inter-basin areas and also in initiation and integration stages. The values are also higher in the areas of high relative relief.

THE STREAM ORDER AND THE ANGLE OF CONFLUENCE

The angle of confluence of the first order streams forming the basin of second order and the excess first order streams differ considerably. The stream junction angle depends on the slope of the main channel and the tributary, and as the valley. side slopes of first or second order basins in areas of high relief are steep, the junction angles in many cases are as high as 90^{o}.

The stream junction angle decreases with the slope of the tributary. This fact can be employed in interpreting the basin development. The distribution of junction angles of first order with the second or higher order give some interesting results. It is observed that the stream junction angles and the number of first order streams, both are on higher side in the elongation and elaboration stages of drainage development. In initiation as well as integration stage though the number is on the lower side, the junction angles differ considerably. In initiation stage (or early elongation), the tributary streams in second order are almost perpendicular, at the stage of integration when the relief is greatly reduced, the junction angle also decreases considerably.

CONCLUSION

In brief it may be summerized that the stream number can be used as a parameter of drainage development which is expressed by the bifurcation ratio. The chi-square analysis employed to test the goodness of fit for observed and expected stream numbers helps in locating the catchments which show unusual development of drainage network. The Rb values of individual second order basins and the stream junction angles can be used in differentiating the initiation and integration stages.

REFERENCES

Horton, R. E. (1945). "Erosional Development of Streams and their Drainage Basins; Hydrophysical Approach to Quantitative Morphology". *Bull. Geol. Soc. 56*. 275–370, also in Jarvis and Woldenberg (1984) : 'River Network', Hutchinson Ross Publishing Company, Stroudsburg, Pennsylvania.

Glock, W. E. (1931). 'The Development of Drainage Systems – A Synoptic View', *Geog. Rev. 21*, pp. 475–482.

Scheidegger (1970). 'Theoretical Geomorphology', Springer Varlay, Berlin.

Schumm, S. A. (1956). 'Evolution of Drainage System and Slopes in Badlands at Perth Amboy'. *Bull. Geol. Soc. Am. 67*, pp. 597–646.

Shreve, R. L. (1966). 'Statistical Law of Stream Numbers, *Jour. Geol. 74*, pp. 17–37.

. (1967). 'Infinite Topological Random Channel Networks'. *Jour. Geol. 75* pp. 179–86.

Strahler (1952). 'Hyprometric (Area–Altitude) Analysis of Erosional Topography', *Bull. Geol. Soc. Am. V*, **63**, pp. 1117–1142.

(1964). Quantative Geomorphology of Drainage Basins and Channel Forms in Chow (ed.), Hand-book of Applied Hydrology, McGraw Hill, New Delhi.

ADDRESS OF THE AUTHOR

Dr. S. R. Jog
Lecturer
Department of Geography
University of Poona
Pune