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Geomorphology of Kolar Sub-Basin

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ABSTRACT

The hydrologic response of a watershed usually depends upon the climatological and watershed characteristics. The geomorphological characteristics of a watershed represent the attributes of the watershed that can be employed in synthesizing, and perhaps understanding its hydrologic behaviour. For the purpose of hydrological studies,geomorphological characteristics can generally be classified in three groups;(i) the characteristics representing the linear aspects of the watershed, (ii) the characteristics which represent the areal aspects of the watershed, and (iii) the characteristics represent- ing the relief aspects of the watershed.

In this paper procedures for the estimation of some of the important geomorphological parameters covering the linear, areal and relief aspects of the watershed are described. Based on that computer softwares have been developed in FORTRAN-77 language. For running the programmes the digitized data of the drainage network are needed as input. The developed computer softwares have been implemented and tested on VAX 11/780 computer system available at NIH. The different geomorphological characteristics of Kolar subbasin of Narmada basin are derived using the developed softwares.

1.0 INTRODUCTION

Streamflow synthesis from ungauged basins has long been recognised as a subject of scientific investigations. The simple and most popular approach, in this regard, comprises the empirical relations for determining the parameters of conceptual models or some key characteristics of streamflow hydrographs, such as lag time, peak discharge, time to peak, or hydrograph duration. These relationships are developed by standard curve fitting methods based on data from gauged basins and are then applied to ungauged basins hoping for desired results. Although such relations can be useful in particular cases, they do not seem to be scientifically sound. On the other hand, geomorphologic techniques have recently been advanced for hydrograph synthesis. These techniques have added a new dimension to application of geomorphology to the hydrologic simulations particularly to the effective rainf a ll- direct runoff relationship. However, they remain to be tested on wide variety of gauged basins and have yet to be applied to ungauged basins.

Geomorphology is a science which deals with the basin composition with respect to the topographical and geometric configurations of the basin. It is well known fact that the climatic as well as geomorphologic characteristics affect the basin response to a considerable extent. Thus the liking of the geomorphological parameters with the hydrological characteristics of the basin provides a simple way to understand the hydrologic behaviour of the different basins particularly of the ungauged basins. Before taking up the studies related with hydrologic simulations using the geomorphologic characteristics, the important geomorphological properties have to be quantified from the available topographical map of the basin. The geomorphological properties which are important from the hydrological studies point of view include the linear, areal and relief aspects of the watersheds. Various measures have been suggested by many investigators to represent the linear, areal and relief aspects of the watersheds. The quantification of those measures is quite cumbersome and time consuming, if it is carried out manually. With the help of digital computers, considerable computational time can be saved once the topographical maps are accurately digitized using electronic digitizer connected with the computer. The digitized data points are automatically stored in a file opened by the user on the computer at the time of digitizing the maps.

Drainage basins are the fundamental units of the fluvial landscape and, accordingly, a great amount of research has focused on their geometric characteristics including the topology of the stream networks, and the quantitative description of drainage texture, pattern, shape and relief(Abrahams, 1984).

Horton, who made the first modern quantitative studies of drainage basins (Horton, 1932, 1945), provided the theoretical base for the hydrogeomorphic approach by suggesting that there were certain unvarying or intransient drainage basin characteristics that correlate to the hydrologic response of a basin. Horton's important contribution was his description of the laws of drainage network composition (Horton, 1945).

The quantitative analysis of drainage networks is a subject of interest to both geomorphologists and hydrologists. Although the two groups naturally have somewhat different objectives, both find it convenient to choose as a basic unit for study the set of all channels above a given point in a network, i.e. all channels that contribute to the discharge at that point. If the channels are idealized as single lines, the resulting diagram is known in the geomorphological literature as a channel network. Horton (1945) introduced the term composition of the drainage network (or basin) as: 'Composition implies the numbers and lengths of streams and tributaries of different sizes and orders, regardless of their pattern'.

The intent of this quote can be expressed by saying that the basin composition refers to the geomorphologic(topographic and geometric) properties of channel networks.

Under the impetus supplied by Horton, the description of drainage basins and channel networks was transformed from a purely qualitative and deductive study to a rigorous quantitative science capable of providing hydrologists with numerical data of practical value. Horton's work was supplemented by Langbein (1947), then developed in detail by Strahler and his Columbia University

Associates. Subsequently, a significant amount of research works have been done by many investigators regarding the geomorphological characteristics. Discussions on many of these characteristics are given by Horton (1945); Strahler (1964); Markovic (1966), Eagleson (1970); Bunik and Turner (1972); Smart (1972); Abrahams (1984); Edgar and Melhorn (1974), Warntz (1975); James and Padmini (1983) and others.

2.0 Hydrological studies using geomorphological characteristics

In many hydrological studies such as design flood estimation, water availability studies and runoff estimation, geomorphological characteristics have been frequently used, particularly in the regional studies, in order to make the required estimates for ungauged catchments. Some of the hydrological studies, wherein the different aspects of the geomorphological characteristics are utilized include:

(i) Development of Empirical formula using gemorphological parameters

(ii) Regional unit hydrograph studies using geomorphological and physical characteristics of watershed.

(iii) Regional Flood Frequency Analysis using Geomorphological Characteristics

(iv) Development of Geomorphological Instantaneous Unit Hydrograph (GIUH).

(v) Application of geomorphological parameters and physiographic characteristics in other hydrological studies including hydrologic modeling studies.

3.0 DESCRIPTION OF THE STUDY AREA

The Kolar subbasin is situated in two districts of Madhya Pradesh, Sehore and Raisen in the latitude range of 22°40′ to 23°08′ and longitude 77°01′ to 77°29′. The Kolar river originates in the Vindhyachal mountain range at an elevation of 550 m above mean sea level (msl) in the district Sehore of Madhya

Pradesh State. The river length from its origin to the point where it joins the river Narmada near a place Neelkanth is 100 **km**. During its 100 km course river first flows towards east and then towards south. The index map of the subbasin is given as fig.2.

4.0 METHODOLOGY

This section describes the methodology used for the quantification of some of the important geomorphological characteristics.

(a) Stream Length (L)

For the preparation of data files to runthe programme topographic map of desired basin was prepared. The basic data for computing the length (L) of the main channel obtained by tracing along the main channel with the cursor of the analog to digital converter. Analog to digital converter is used to record x and y coordinates of closely spaced points. Coordinates of the main channel points are stored on computer which are utilised for computing the length of a small segment between first two points using:

$$\text{Distance} = [(\Delta x)^2 + (\Delta y)^2]^{1/2} \qquad (1)$$

For the length of the channel, distances of all small segments of the channel are to be added. For this purpose a subroutine, LENGTH is developed. Length of all streams of each order (L_i) have also been computed using the same procedure.

(b) Catchment Area(A)

The data for computing the area (A) of the catchment are obtained by tracing around the catchment boundry with the cursor of the analog to digital converter. The coordinates of closely spaced boundry points are stored in a data file. After digitizing the boundry, a centre point in the catchment is digitized whose x and y co-ordinates are stored inthe same file as the last point. Center point should be such that the lines joining each boundry point to it lie within the catchment. Some times the catchment

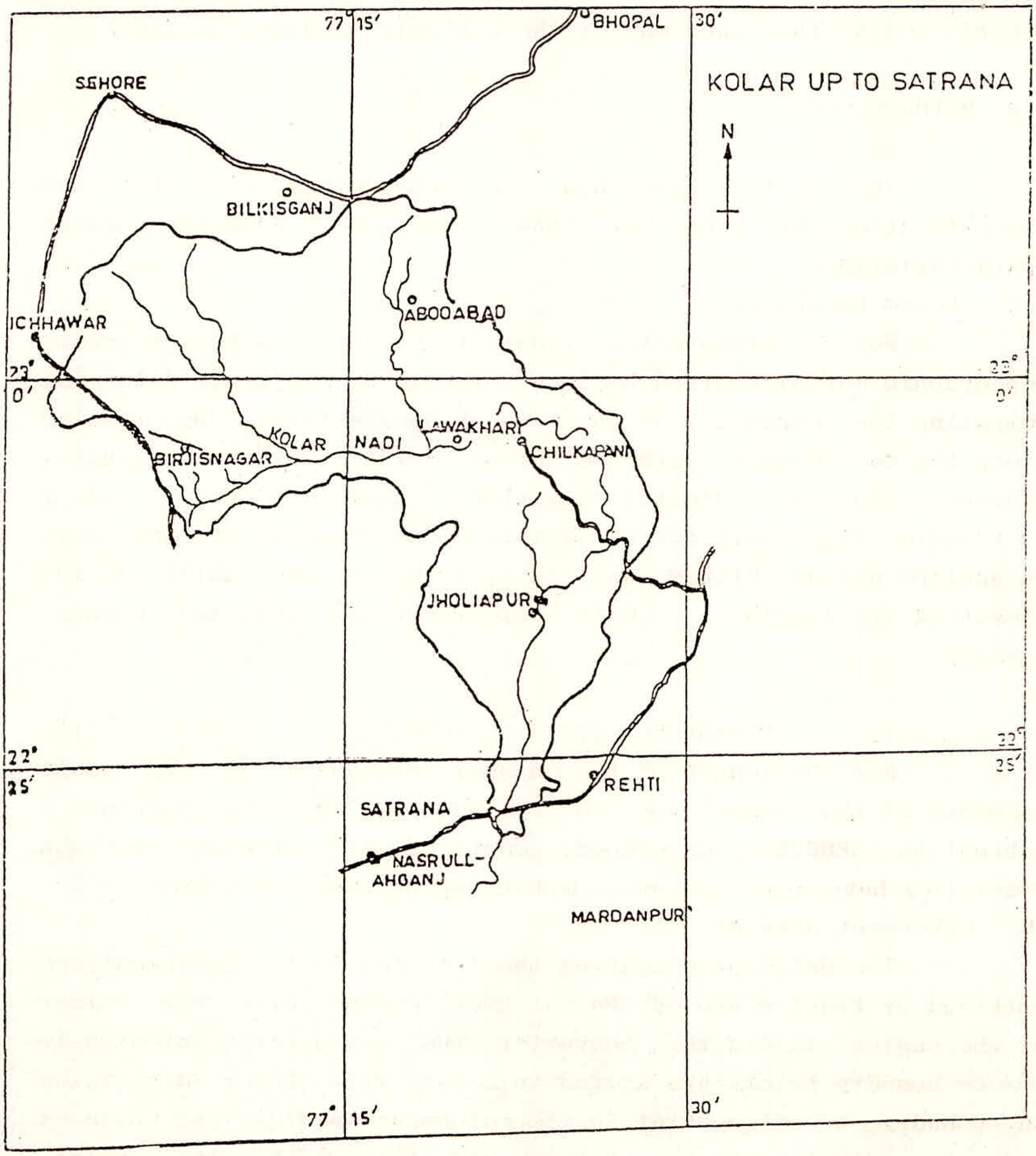

Fig. 1 : The Kolar basin upto Satrana gauging site. Also shown are the locations of hydrometeorological sites and important towns.

shape is such that a single centre point within the catchment does noc fulfil this condition. In such cases the catchment should be divided into two or more parts according to the shape. Then each part of the catchment should be digitized and seperate data files should be prepared. While running the main program GEO.FOR, the user will be prompted for (i) for how many parts do you want to divide the catchment ? and (ii) the filename corresponding toeach part of the catchment having digitized data.A subroutine AREA is developed for computing the area using the digitized data of the catchment boundary or for a part of the catchment.For computing the area of the catchment, each digitized points along the boundary are joined with the centre point dividing the whole catchment into smaller triangles. Area of each triangle was computed using formula :

$$A = \sqrt{s(s-a)(s-b)(s-c)} \qquad (2)$$

where

a,b & c are the lengths of sides of triangle

and $S = (a + b + c)/2$

The areas of all triangles lying within each part of the catchment are added in order to have the areas for different parts of the catchment. Subsequently, the areas of each part of the catchment are added to obtain the total catchment area. Now boundries for different order streams are drawn manually and their areas(A_i) are also obtained using the subroutine AREA.

(c) Perimeter of the Catchment(P)

Perimeter (P) of the catchment is obtained using the same procedure as for length. The sum of the lengths of different segments along the catchment boundary including the length between first and last digitized point provides the estimate for perimeter of the catchment.For this the data file is prepared by digitizing the boundry of the catchment. A subroutine PARAM is developed for computing the perimeter.

(d) Length of the Channel between the outlet and a point nearest to C.G. (L_c)

It is the length of the channel measured from the outlet of the catchment to a point on the stream nearest the centroid of the basin. Thus, the first step involved in the computation is to locate the centre of gravity of the basin.

For computing the center of gravity (x_G,y_G) of the basin, it is divided into small triangles as discussed in section 4.0 part (b). x and y co-ordinates for the centres of small triangles (x_c,y_c) are calculated using:

$$x_c = (x_1 + x_2 + x_3)/3 \qquad (3)$$

$$y_c = (y_1 + y_2 + y_3)/3 \qquad (4)$$

where (x_1,y_1),(x_2, y_2) and (x_3, y_3) are the coordinates of the three nodes of any triangle. If the catchment is divided into n parts, as discussed in section 4.0 part (b), for computing the catchment area, the x coordinate for the centre of gravity of each part(x_{Gi}) is obtained by dividing the sum of the multiples of x_c and area of all respective trinagles by the sum of area of all trainagles. Similarly, the y-coordinates of the centre of the gravity (y_{Gi}) are also obtained for each parts of the catchment. The x and y coordinates for centre of gravity of the whole catchment is computed by:

$$x_G = \frac{\sum_{i=1}^{n} x_{Gi}\ \text{Area}_i}{\sum_{i=1}^{n} \text{Area}_i} \qquad (5)$$

$$y_G = \frac{\sum_{i=1}^{n} y_{Gi}\ \text{Area}_i}{\sum_{=1}^{n} \text{Area}_i} \qquad (6)$$

where Area represents the area of the i^{th} part of the catchment. Now a point nearest to the centre of gravity can be located on a channel segment taking the minimum of the perpendicular distances from the centre of gravity to the different channel segments.

Subsquently the length of the channel from the outlet to the nearest located point from C.G., is computed using the Subroutine LENGTH. The computer software is developed based on the above stated procedure in order tc compute the length of the channel between the outlet and a point nearest to C.G. (L_c).

(e) Elongation ratio (R_e)

It is computed as the ratio of diameter of a circle of the same area as the basin to the maximum basin length.

(f) Circularity ratio (R_c)

It is computed as the ratio of basin area to the area of a circle having the same perimeter as the basin.

(g) Bifurcation ratio (R_b)

It is computed using the Horton's law of stream numbers which states that the numbers of stream segments of each order form an inverse geometric sequence with order number or

$$N_u = R_b^{k-u} \tag{7}$$

where k is the order of the trunk segment

and N_u is the number of segments of order u.

$$\log N_u = (k-u) \log R_b \tag{8}$$

$$\text{or } \log N_u = a - bu \tag{9}$$

where

$$a = k \log R_b \text{ and}$$

$$b = \log R_b$$

$$\text{or } R_b = \log^{-1}(b)$$

For computing $\log R_b$, subroutine for linear regression REG based on least square approach is used. This value of R_b is used to compute the total number of streams of all order (N) in a given network :

$$N = \sum_{u=1}^{k} N_u = \frac{R_b^k - 1}{R_b - 1} \tag{10}$$

(h) Mean length of the channels

To obtain the mean length of channel $\bar{L}_u$ of order u, the total length is divided by the number of segments N_u of that order,

$$\bar{L}_u = \frac{\sum_{u=1}^{N} L_u}{N_u} \qquad (11)$$

Total length of channels of all orders for a catchment is computed as the sum of the lengths of all order streams.

(i) Length Ratio (R_L)

For computing the length ratio (R_L), R_{Lb} is computed using the formula

$$\sum_{u=1}^{k} \sum_{u=1}^{N} L_u = \bar{L}_1 R_b^{k-1} \frac{R_{Lb}^{k} - 1}{R_{Lb} - 1} \qquad (12)$$

here L_u, $\bar{L}_1$ & R_b are known.

Since the form of the above equation is a non-linear, therefore, a separate subroutine, NEWTON is developed based on the Newton-Raphson nonlinear optimisation technique in order to provide the solution for R_{Lb}. The R_{Lb} is defined as:

$$R_{Lb} = \frac{R_L}{R_b} \qquad (13)$$

Substituting the values of R_{Lb} and R_b in eq.(13) the value of R_L is computed.

(j) Watershed Eccentricity(τ)

The watershed eccentricity is evaluated using the expression :

$$\tau = \frac{\sqrt{|(L_C^2 - W_L^2)|}}{W_L} \qquad (14)$$

where,

τ = watershed eccentricity , a dimesionless factor,

L_C = length from the watershed mouth to the centre of mass of the watershed

W_L = the width of the watershed at the centre of mass and perpendicular to L_C

(k) Form Factor

Form factor (R_f) is dimensionless ratio of basin area A to the square of basin length L, thus it is computed as

$$R_f = A/L^2 \tag{15}$$

(l) Drainage Density

Drainage density (D) is computed as the ratio of total channel segment lengths cumulated for all orders within a basin to the basin area, i.e.

$$D = \frac{\sum_{i=1}^{k} \sum_{i=1}^{N} L_u}{A} \tag{16}$$

(m) Constant of channel maintenance

Constant of channel maintenance (C) is computed as the inverse of drainage density.

(n) Stream Frequency (F)

Stream frequency (F) is computed as the number of stream segments per unit area, or

$$F = \frac{N}{A} \tag{17}$$

where N is the total no. of segments of all order within the given basin.

(o) Slope

Slope (S_i) is simply the gradient, or vertical distance between two points, whose elevations are known, divided by the horizontal distance between them.

(p) Basin relief

Basin relief (H) of a basin has been computed as the maximum vertical distance from the stream mouth to the highest point on the divide.

(q) Relief Ratio

Relief ratio(R_h) was obtained as the ratio between the basin relief and the basin length. In normally shaped basins the relief ratio is a dimensionless height length ratio.

(r) Relative Relief

Relative relief (R_p) is computed as the ratio of the basin relief to the length of the perimeter.

(s) Ruggedness number

Ruggedness number (R_n) is computed by the product of drainage density and relief, both in the same unit.

(t) Taylor and Scharwtz slope of the channel

To obtain the average slope of the river, it is divided into several parts through the points where the elevation of the river change. The slopes for each part is obtained using the definition of slope given in section 4.0 part (o).

Now the channel is treated as series of lengths(l) of approximately uniform slope (s), whose times of flow are considered to be proportional to ($1/\sqrt{s}$). The average slope of the channel is, therefore, computed by

$$L/\sqrt{T_s} = \Sigma \left(1/\sqrt{s} \right) \qquad (18)$$

where T_s is the Taylor and Scharwtz slope of the channel of the same length and time of flow as the actual length.

5.0 ANALYSIS AND DISCUSSION OF RESULTS

The topographic map of the Kolar subbasin of river Narmada was prepared using the Survey of India toposheets No.55E & 55F of scale 1:250,000. Fig. 2 illustrates the river network for the Kolar subbasin The river network has been ordered using Strahler's ordering scheme. It is observed that the Kolar river is a fifth order stream. The rivers of various orders have been digitized using electronic digitizer. The digitized data were stored on VAX-11/780 computer system. The points over the subbasin boundry were also digitized along with the boundry of the areas covered by the different order streams. The computer program GEO.FOR was run taking the digitized data as input. The lengths of different order streams for Kolar sub-basin werecomputed using eq.(12) and these are given in table 1 along with the number of streams of different orders and other linear measures. It is

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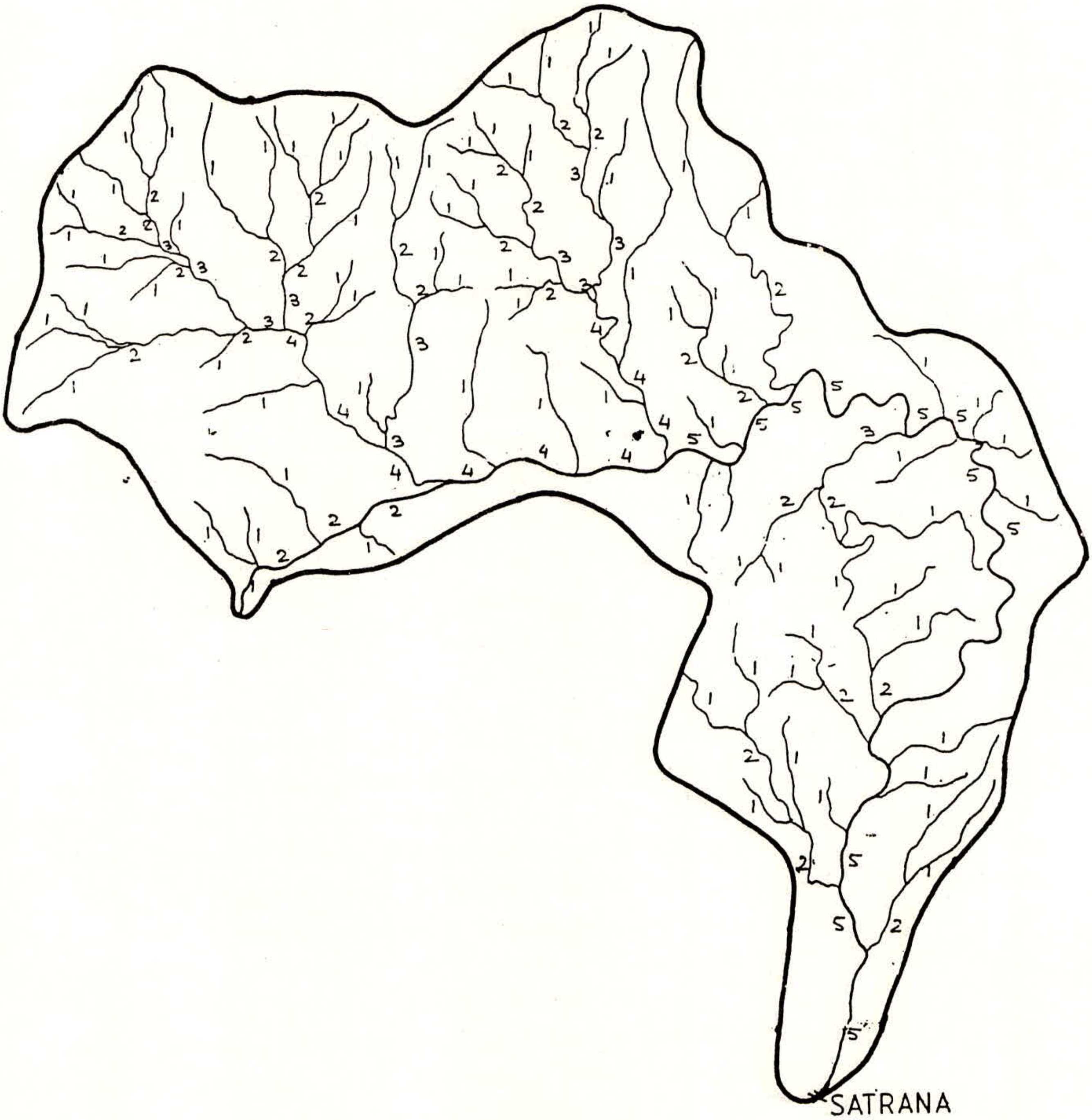

FIG.2 - RIVER CHANNEL NETWORK OF KOLAR SUB-BASIN UP TO SATRANA GAUGING SITE

Table 1 :Geomorphological Characteristics of Kolar Sub-basin -Linear Measures

P	160.46 Km
L	75.34 Km
X_G	32.26 Km
Y_G	40.50 Km
L_c	18.27 Km
R_b	2.92733
R_L	1.51959
L_1	301.43 Km
L_2	156.47 Km
L_3	81.23 Km
L_4	42.16 Km
L_5	21.89 Km
L_u	603.18 Km
$\bar{L}_1$	3.97 Km
$\bar{L}_2$	6.52 Km
$\bar{L}_3$	11.60 Km
$\bar{L}_4$	14.05 Km
$\bar{L}_5$	21.89 Km
N_1	76
N_2	24
N_3	7
N_4	3
N_5	1
N_u	111
r	0.4166

observed from the table that the mean lengths, which have been computed as the ratio of the total length of specific order streams and the total number of streams of that order, are 3.97, 6.52, 11.6, 14.05 and 21.89 km for order one, two, three, four and five respectively. The number of streams for different orders are 76, 24, 7 ,3 and 1 respectively. It indicates the increasing trend in the mean length with the higher order of streams and number of streams of different order shows decreasing trend from lower to higher order streams. The bifurcation ratio and the length ratio for Kolar subbasin are 2.92733 and 1.51959 respectively. These non dimensional parameters reflects the hydrological characteristics of the Kolar subbasin and may be considered for the purpose of hydrological modelling. The length of C.G. of the catchment along the main stream upto the outlet of the catchment is 18.27 km. This characteristic alongwith other measures has been frequently used in hydrological modeling particularly for regional unit hydrograph analysis. The other linear measures which have been computed for Kolar subbasin are perimeter of the subbasin, length of the main stream and watershed eccentricity and their values are given in table 1. Fig.3 shows the variation of No. of streams of different orders with their order no. on semi-log plot. The slope of the straight line is negative showing the reduction in number of streams with increase in order. It follows the law of stream numbers. Fig.4 shows the variation in average stream length with different orders of the stream. The plot shows increasing trend in average length of different orders and it follows the Horton's law of stream length.

The various areal measures described in section 4.0 are given in table 2 for Kolar subbasin. In this table the total area covered by different order streams have been reported along with the mean areas. The table 2 indicate the mean areas as 11.28, 29.07, 87.85, 117.96 and 881.36 respectively for different order streams. It shows that there is an increasing trend in the mean areas of different order streams with the increase in the stream order. Computed subbasin area is 903.88 Sq.km. The subbasin area is

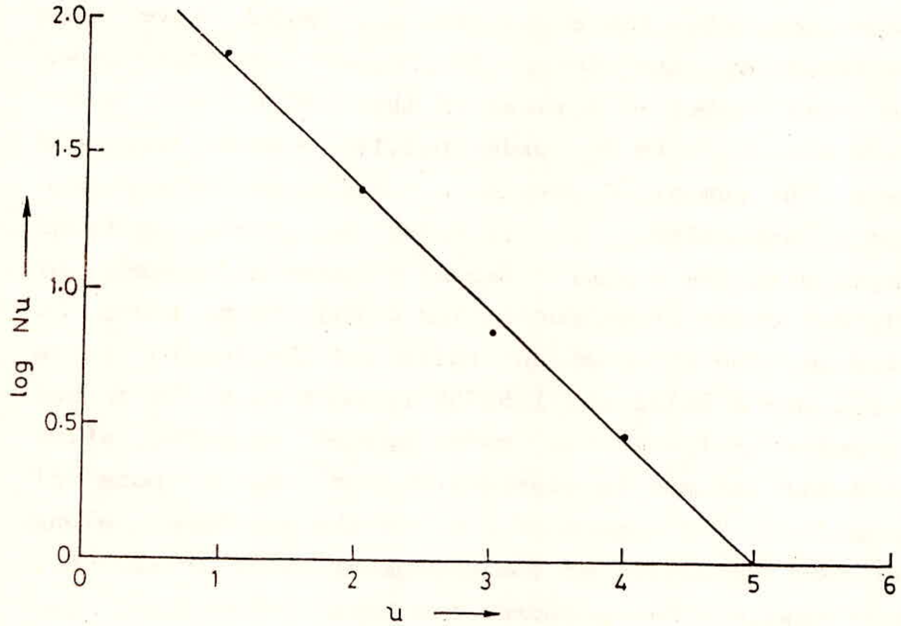

FIG.3 -VARIATION OF NO. OF STREAMS WITH THEIR ORDER NO.

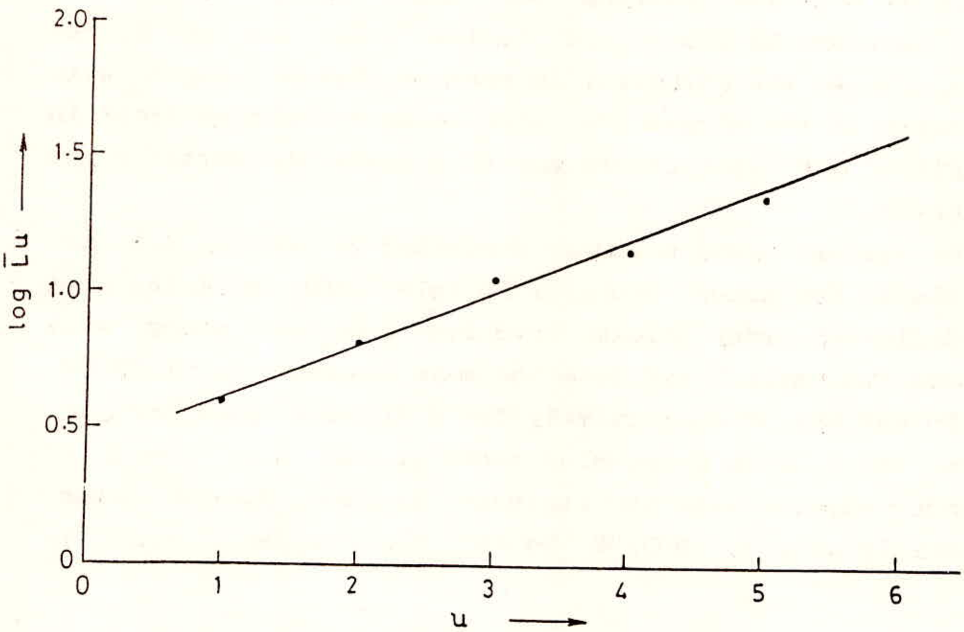

FIG. 4 - VARIATION OF AVERAGE STREAM LENGTHS WITH THEIR ORDER NO.

Table 2 :Geomorphological Characteristics of Kolar Sub-basin -Areal Measures

A	903.88 Sq. Km
R_e	0.4502
R_c	0.4414
R_α	2.7506
A_1	445.40 Sq.Km
A_2	609.31 Sq. Km
A_3	668.29 Sq. Km
A_4	750.93 Sq. Km
A_5	901.47 Sq, Km
$\bar{A}_1$	11.28 Sq. Km
$\bar{A}_2$	29.07 Sq. Km
$\bar{A}_3$	87.85 Sq. Km
$\bar{A}_4$	117.96 Sq. Km.
$\bar{A}_5$	881.36 Sq.Km
D	0.6673 Km/Sq. Km
C	1.4985 Km
R_f	0.1592
F	0.1228/Sq.Km

Table 3 :Geomorphological Characteristics of Kolar Sub-basin -Relief Measures

H	300 metre
R_h	0.0040
R_p	0.0019
R_n	0.2002
T_s	0.0026

consideredto be one of the important geomorphological characteristic and has been used frequently in various hydrological studies. The other areal measures which have been computed for this subbasin are elongation ratio, circularity ratio, Area ratio, drainage density, constant of channel maintenance, form factor and stream frequency,and their values are given in table 2. Such areal measures may be used in the modelling of hydrological response using geomorphological features for the watershed having no flow records or inadequate flow records. The variation of average area for different order streams with their order no. is shown in Fig.5. It can be seen from the plot that the drainage network follows the Horton's law of stream areas.

The third important measures which represent the geomorphological characteristics of the subbasin are relief measures.In literature various relief measures have been described and used in many hydrological studies. However in this study some of the important relief measures have been evaluated using the procedure described in section 4.0. The various relief measures computed for Kolar subbasin are given in table 3. These measures include slope of the main stream, Basin relief, Relief ratio, Relative relief, Ruggedness number and Taylor & Scharwtz slope.The relief measures have significant importance specially in the modelling of mountainous catchment where velocity of flow are considerably high. The relief parameters govern the overland flow and stream flow processes of a subbasin. Therefore these measures may be used to model the flow processes of the subbasin.

6.0 REMARKS

The manual estimation of geomorphological parameters from the toposheets is atedius and time consuming job which may lead tosometime lead erroneous estimates. In order to provide an ease in the computations the software for computing some of important geomorphological parameters from hydrological studies

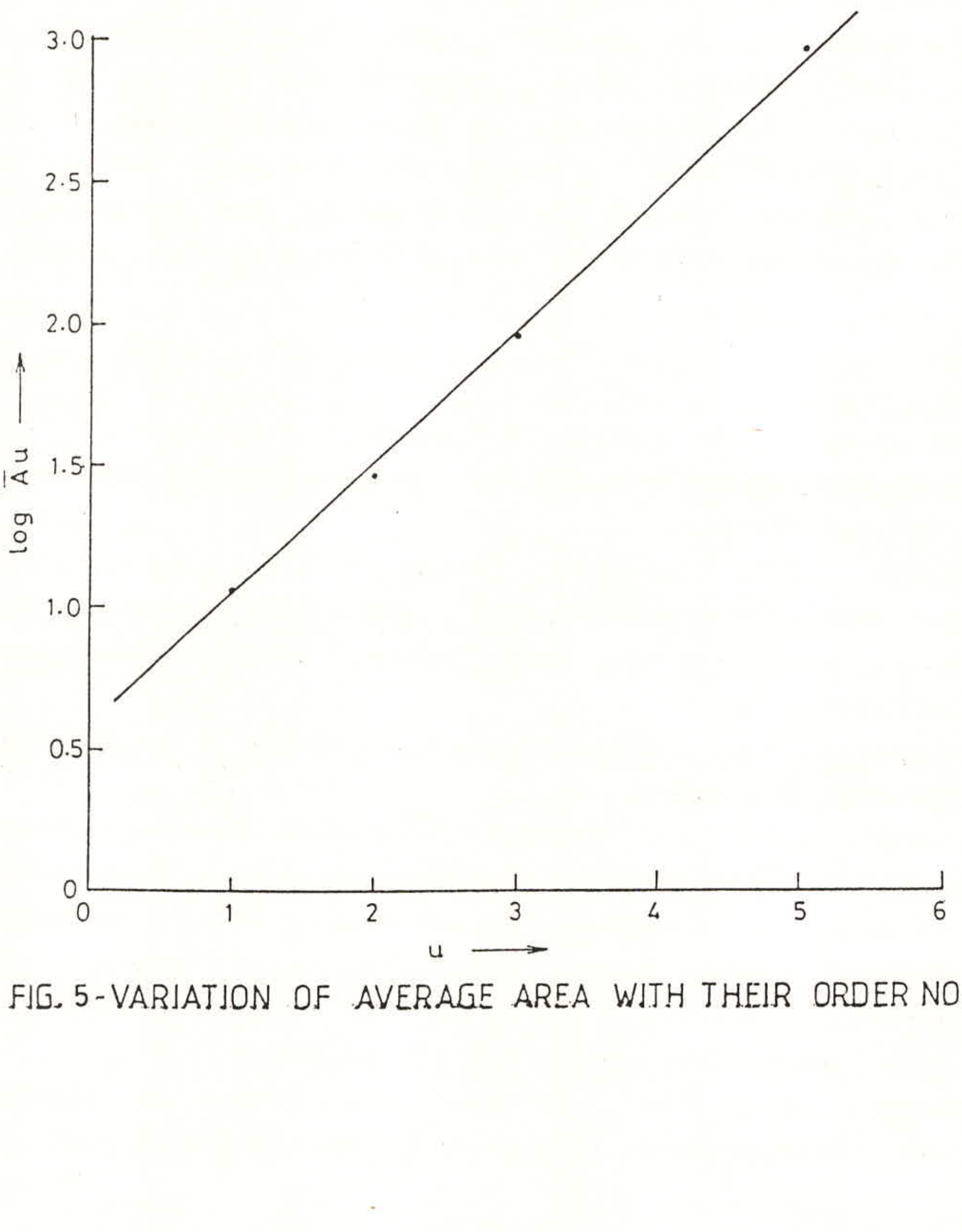

FIG. 5 - VARIATION OF AVERAGE AREA WITH THEIR ORDER NO.

point of view have been developed in FORTRAN-77 language .The softwares have been implemented and tested on VAX-11/780 ComputerSystem. The softwares have been used for quantifying the geomorphological characteristics of Kolar-Sub-basin of River Narmada.

The limited number of geomorphological parameters covering the linear,areal and relief aspects of the subbasin have been estimated for Kolar basin. However,the softwares may be suitably modified for estimating the other parameters which have not been included in the present study. The geomorphological parameters ,thus estimated, may be utilised for developing the hydrological models for simulating the hydrologic response of the subbasin. Such type of modeling studies are very much useful and being widely used particularly for simulating the response of ungauged catchments or catchments having inadequate flow records.

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