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GEOMORPHOLOGICAL CHARACTERISTICS OF WESTERN GHATS

Part III: HEMAVATI BASIN UPTO SAKLESHPUR

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PREFACE

The advanced knowledge of geomorphology of a basin is of importance. The different geomorphological parameters of a watershed can be employed in synthesizing and understanding its hydrological behaviour. The geomorphological properties of channel network are generally referred to the basin composition which represents the topographical and geometrical properties of the basin. The linear, areal and relief aspects of the watershed are some of the important characteristics which are considered generally in the science of geomorphology and particularly in hydrological studies.

In this report an attempt has been made to present methodology to quantify various geomorphological parameters of Hemavati Basin upto Sakleshpur using modern measuring techniques for use in subsequent rainfall runoff modeling studies. This study has been carried out by Sri M K Jain, Scientist B, in the Mountain Hydrology Division, National Institute of Hydrology, Roorkee.

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ABSTRACT

The geomorphological characteristics of a watershed represents the attributes of the watershed and can be employed in synthesizing and understanding its hydrological behaviour. For hydrological purposes, the various geomorphological characteristics which are of importance can be broadly classified into following three groups :

(1) characteristics representing linear aspects of the basin,

(2) characteristics representing areal aspects of the basin and

(3) characteristics representing relief aspects of the basin.

In this study the above mentioned aspects of the Hemavati Basin upto Sakleshpur situated in the Western Ghats region are evaluated. The study may be useful at finding out effect of geomorphology on watershed runoff response and identifying those parameters which are more closely related to runoff in Western Ghat region.

1.0 INTRODUCTION

One of the most important tasks in theoretical as well as practical hydrology, is to find the laws of runoff processes in river basins. The difficulty of this task increases when there is a lack of hydrological data as is often the case in mountainous areas. It is a well known fact that the climate and geomorphological characteristics affect the basin response to a considerable extent. Thus the linking of geomorphological parameters with hydrological characteristics of the basin provides a simple way to understand the hydrological behaviour of different basins and particularly of the ungauged basins.

Quantitative studies of geomorphological parameters is a prerequisite for taking up hydrological simulation studies by using these parameters. The geomorphological properties which are important to the hydrological simulation studies includes the linear, areal and relief aspects of the basin. Various measures have been suggested by many investigators to represent the linear, areal and relief aspects of the basin. The quantification of these measures is cumbersome and time taking if carried out manually . But the task becomes comparatively easy by using electronic digitizers and computers.

The western ghats area is the origin of the major river systems like Godavari , Krishna and Cauvery. Since major portion of the discharge of these river systems is contributed by the overland flow of the rainfall, it becomes all the more important to have a clear idea of the land form characteristics of the catchments in these areas.

In this study various geomorphological aspects such as linear, areal and relief aspects of the Hemavati basin upto WRDO gauging site at Sakleshpur are evaluated. The toposheet maps of the scale of 1:2,50,000 covering Hemavati basin upto Sakleshpur have been digitized . The digitized information is used to quantify some of the important geomorphological properties of the basin with the help of electronic computers. Some of the derived geomorphological parameters will be used in another study for simulating rainfall runoff of the basin in conjunction with other conventional hydrological data.

1.1 Application in Hydrology:

A large number of studies (Brush 1961, Coulter 1961) have related indices of drainage basin composition rock and soil type, vegetation and land use hydrological behaviour, especially measures of water and sediment yields and their frequency distributions. Of all the indices, the basin area, drainage density, main stream length and main stream slope appears to have been utilized most frequently.

Synder (1938) employed basin area, mean stream length, and main drainage length to the centroid of the area to synthesize unit hydrograph lag, peak flow and peak time. Taylor and Schwartz (1952) used these as well as mean stream slope to synthesize the runoff hydrograph. A large number of studies (Laten et al. 1940; US Army Corps of Engineers, 1954; O'kelly, 1955; Gray, 1962; Morgan and Johnson, 1962; Mirajgaonkar and Chitambaran, 1963; Askew, 1963; Hopkins and Kachis, 1964; Schulz et al., 1971; Body et al.,1979) have since appeared on synthesis of unit hydrographs in ungauged areas. Recently, Rodriguez-Iturbe (1982); Rodriguez-Iturbe et al.(1982); Rodriguez-Iturbe and Valdes (1979); Gupta et al. (1980), Singh (1983), Pristochova (1990) employed bifurcation ratio, length ratio, area ratio, stream lengths and stream areas for synthesizing unit hydrograph. Rosso (1984) gave relation between Nash model parameters and Horton's order ratios Zelazinski (1986) applied GIUH theory to evaluate parameters of two conceptual models.

White (1975) classified 112 basins in Pennsylvania and surrounding states according to drainage density, Channel slope, shape factors, and geometric factors for the purpose of evaluating their flood potential. Clang and Body 91977) wed watershed and climate factors for estimation of low floods. Ebisemiju (1979) used drainage density, stream numbers, steam lengths, and relief for identifying morphologically and hydrologically uniform basins. A study by Patton and Baker (1976) concluded that drainage density, steam magnitude and relief ratio are practical measures of flood potential in basins smaller than 100 mi^2 in area.

Melton (1957) found a strong correlation of drainage density with the ratio of average annual precipitation to average annual evaporation. A comprehensive account of potential application of drainage density was given by George (1977, 1979) and Gurnell (1978).

1.2 Problem Definition:

The various geomorphological parameters are required to be quantified for taking up studies using these parameters. The estimation of such parameters gains further importance in case of hilly catchments because direct measurement of hydrologic data is difficult in such areas. Quantification of these parameters is cumbersome and time taking. This report is aimed at development of a suitable methodology for quantifying commonly used geomorphological characteristics. In this study, various geomorphological parameters of Hemavati Basin upto Sakleshpur will be evaluated. The parameters thus evaluated may be used to test hydrological models for these catchments.

2.0 METHODOLOGY

This section describes the different geomorphological parameters and the methodologies to quantify these parameters.

2.1 Geomorphological Characteristics:

Systematic description of the geometry of a drainage basin and its stream channel system requires the following measurements (i) linear aspect of drainage network, (ii) areal aspect of drainage basin, and (iii) relief aspect of channel network and contributing ground slopes. Here, the first two categories of measurement are planimetric (i.e. treat properties projected upon a horizontal datum plane) and the third category treats the vertical inequalities of the drainage basis forms.

2.1.1 Ordering of the Streams:

For all practical purposes, the quantitative study of channel networks used to begin with Horton's (1945) methods of ordering of channels. Later on, Strahler (1952) proposed a modification of Horton's ordering scheme. Strahler's method is now generally preferred due to its simplicity and greater freedom from subjective decisions. In this report,the Strahler's method will be employed. There are three steps in Strahler's ordering procedure.

i) Channels that originate at a source are defined to be first order streams;

ii) When two stream of order w joins, a stream of order (w+1) is created; and

iii) When two streams of different order joins, the channel segment immediately downstream has the higher order of the combining streams.

Fig. 2 shows the stream ordering for Hemavati basin upto Sakleshpur by Strahler ordering method.

2.2 Linear Aspects

The linear aspects proposed by various investigators which are of importance in hydrological studies, are described below. The methodology used to quantify them is also stated.

2.2.1 Number of streams of given order (N_w):

The quantity N_w represent total number of all streams, counted as the stream segments, having the order, w present in the watershed. Since a watershed of a given order can be modelled as a collection of elements of lower orders, the number of streams of each order is an important concept in hydrologic synthesis.

2.2.2 Bifurcation ratio (R_b):

The bifurcation ratio (R_b) for a given channel network can be obtained by determining the slope of the fitted regression of the plot of the logarithm of number of stream on ordinate versus order on abscissa. The regression coefficient, b is identical with the logarithm of R_b. The R_b is a dimensionless quantity and shows only a small variation from region to region. The value of R_b varies normally between 3 to 5 and is a useful index for hydrograph shape for watersheds similar in other respect.

The R_b computed using Horton's law of stream number which states, "The number of stream segments of each order form an inverse geometric sequence with order number" or

$$N_w = R_b^{k-w}$$

where k is the order of trunk segment

N_w is the number of segments of order w

$$\log N_w = (k-w) \log R_b$$

or $$\log N_w = a - b w$$

where

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

$$b = \log R_b$$

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

For computing R_b, a 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.

$$N = \sum_{w=1}^{k} N_w = \frac{R_b^k - 1}{R_b - 1}$$

2.2.3 Length of main channel (L):

This is the length along the longest water course from the outflow point of designated sub basin to the upper limit of the catchment boundary. For computing the length of the main channel (L), the data file was prepared by tracing the cursor of analog to digital converter along with the main channel . The coordinates of the closely spaced points were stored in a data file and distance between two points was obtained by

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

For the length of the channel, distances of all the small segments were added using a subroutine LENGTH.

2.2.4 Stream lengths (L_w):

Stream length L_w is the total length of all streams of order w in a given drainage basin.

$$L_w = \sum_{i=1}^{N_w} L_i$$

Where L_i is the length of the i th segment of order w and N_w is the number of streams of order w . Stream lengths are employed in development of simplified geometric configurations required in hydraulic modeling of watershed response. The length of all streams of each order was calculated in the same way as of main channel length using the subroutine LENGTH.

2.2.5 Stream length ratio (R_L):

This is the ratio of mean stream segment length of order w to the mean stream segment length of order (w-1),

$$R_L = \frac{\bar{L}_w}{L_{w-1}}$$

The value of R_L ranges normally between 1.5 to 3.5 in natural networks. The R_L is calculated by using Horton's law of stream lengths and stream numbers, or

$$L_w = \sum_{i=1}^{w} \sum_{j=1}^{N_i} L_{ij} = \bar{L}_1 R_b^{w-1} \frac{R_{Lb}^{w}-1}{R_{Lb}-1}$$

Here, L_w, L_1 and R_b are known. The above equation is solved for R_{Lb} by using Newton-Rapson non-linear optimization technique. The R_L is calculated by

$$R_{Lb} = \frac{R_L}{R_b}$$

2.2.6 Length of overland flow (L_o):

The length of over land flow can be defined as the length of flow of water over the ground before it becomes concentrated in defined stream channels. It can be measured as the length of flow path, projected to horizontal, of non channel flow from a point on the drainage divide to a point on the adjacent stream channel. Horton recommended using half the reciprocal of drainage density D for the average length of over land flow L_o for the entire watershed.

$$L_o = \frac{1}{2D}$$

2.2.7 Length of channel between outlet and a point near 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 to the centroid of the basin. The centre of gravity is located by procedure described below,

For computing centre of gravity (x_g, y_g) of the basin, it is divided into small triangles and x and y coordinates of small triangles (x_c, y_c) are calculating using formulae:

$$x_c = \frac{1}{3} (x_1 + x_2 + x_3)$$

$$y_c = \frac{1}{3} (y_1 + y_2 + y_3)$$

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 catchment is divided into n parts, the x coordinate of the centre of gravity of each part (x_{Gi}) is obtained by dividing sum of multiples of x_c and area of all respective triangles by the sum of areas of all the triangles. Similarly, the y - coordinates of the centre of gravity (y_{Gi}) are also obtained for each parts of the catchment. The x and y coordinates of centre of gravity of whole basin is calculated by

$$x_G = \frac{\sum_{i=1}^{n} x_{Gi} . Area_i}{\sum_{i=1}^{n} Area_i}$$

$$y_G = \frac{\sum_{i=1}^{n} y_{Gi} . Area_i}{\sum_{i=1}^{n} Area_i}$$

Where $Area_i$ represents the area of 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 perpendicular distances from the centre of gravity to the different channel segments. Subsequently the length of channel from the outlet to the nearest located point from C.G. is computed.

2.2.8 Watershed eccentricity (τ):

Watershed eccentricity is given by

$$\tau = \frac{\sqrt{|(L_c^2 - W_L^2)|}}{W_L}$$

where

τ = watershed eccentricity, a dimensionless factor

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

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

It is to be noted that if $L_c = W_L$, $\tau = 0$, and as either L_c or W_L increases, τ increases. Thus the lower the value of τ, the greater the compactness of the watershed concentrated near to the mouth and higher the peak flood. The τ is calculated using formula described earlier.

2.2.9 Basin perimeter (P):

Basin perimeter is defined as the length of the watershed divide which surrounds the basin. The perimeter P of the basin is obtained using the same procedure as for length. The sum of lengths of segments along the catchment boundary include the length between first and last digitized point provides the estimate for perimeter of the catchment. A subroutine PARAM is used to compute the perimeter P from digitized basin boundary points.

2.3 Areal Aspects:

Various areal aspects of the geomorphological characteristics which have been evaluated include:

2.3.1 Drainage area (A):

Drainage area represents the area enclosed within the boundary of the watershed divide. The drainage area A is probably the single most important characteristics for hydrologic design. It reflects the volume of water that can be generated from rainfall.

The catchment area is calculated using analog to digital converter. The data for calculating catchment area A, are obtained by tracing around the catchment boundary with the cursor of analog to digital converter. The coordinates of closely spaced points are stored in a data file along with the coordinate of a centrally located point as the last value. The centre point should be such that the lines joining each boundary point to it lie within the catchment. Some times a single centre point does not fulfill this condition. In such cases the catchment is divided in to two or more parts according to the shape of the catchment. Each part is then digitized separately and area of each part is later added to give total area. A subroutine AREA is used to calculate area using digitized data of the catchment, each digitized point along the boundary are joined with the centre point dividing the whole catchment into small triangles. Area of each triangle is computed using formula

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

where

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

and $s = \frac{a+b+c}{2}$

The areas of triangles are added for computing the drainage area of the basin . Now boundaries for different order streams are worked manually and their areas (A_i) are also calculated using the same procedure.

2.3.2 **Drainage density (D):**

Drainage density is defined as the ratio of total length of channels of all orders in the basin to the drainage area of the basin. The drainage density is calculated using formula.

$$D = \frac{\sum_{i=1}^{w} \sum_{j=1}^{N_i} L_{ij}}{A_w}$$

2.3.3 **Constant of channel maintenance, (C):**

Constant of channel maintenance is defined as the ratio between the area of a drainage basin and total lengths of all the channels expressed as square metre per metre. It is equal to the reciprocal of drainage density. This parameter indicates the number of square meters of watershed surface required to maintain one linear metre of channel. It is calculated as,

$$C = \frac{A_w}{\sum_{i=1}^{w} \sum_{j=1}^{N_i} L_{ij}}$$

2.3.4 **Stream frequency (F):**

Stream frequency is defined as the number of streams per unit area. Melton (1956) analysed in detail the relationship between drainage density and stream frequency and gave following relation,

$$F = 0.694\ D^2$$

Stream frequency, F is computed as the number of streams per unit area Or ,

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

where,

N is the total number of segments of all orders in the catchment area

A is the drainage area of basin

2.3.5 Circularity ratio (R_c):

Basin circularity ratio is defined as the ratio of the basin area to the area of a circle having circumference equal to the perimeter of the basin. As the basin shape approaches to a circle, the circularity ratio approaches to 1. It is computed as the ratio of basin area to the area of a circle having same perimeter as of the basin.

2.3.6 Elongation ratio (R_e):

It is defined as the ratio between the diameter of a circle with the same area as the basin and basin length. The value of R_e approaches to 1 as the shape of the basin approaches to circle. This ratio varies from 0.6 to 1 over a wide variety of climatic and geologic regimes. Typical values are close to 1 for areas of very low relief and are between 0.6 and 0.9 for regions of strong relief and steep ground slope.

2.3.7 Form factor (R_f):

Horton defined form factor, R_f, as the ratio of basin area A, to the square of basin length, L.The R_f is a dimensionless parameter and is computed as

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

2.3.8 Unity shape factor (R_u):

The unity shape factor was introduced by smart and Surkan (1967) and can be defined as the basin length (L_b) to the square root of the basin area.

$$R_u = \frac{L_b}{\sqrt{A_w}}$$

2.3.9 Watershed shape factor (R_s):

The watershed shape factor, R_s was defined by Wu et al (1964) as the ratio of main stream length, L_c to the diameter D_c of a circle having the same area as of watershed.

$$R_s = \frac{L_c}{D_c}$$

2.4 Basin Relief Aspects

The following aspects have been considered.

2.4.1 Total relief (H):

The basin relief or total relief is the maximum vertical distance between the lowest (outlet) and the highest (divide) points in the watershed. It has been defined in several ways. Schumm (1956) measured it along the longest dimension of the basin parallel to the principal drainage line. On the other hand, Maxwell (1960) measured relief along the basin diameter, an objectively defined axial line, whereas Strahler (1954, 1957) obtained it by determining the mean height of the entire watershed divide above the outlet. Relief is an indicative of the potential energy of a given watershed above a specified datum available to move water and sediment down slope. In this study relief is measured as the maximum vertical distance between the outlet and the highest (divide) point in the watershed.

2.4.2 Relief ratio (R_h):

The relief ratio is a dimensionless ratio and can be defined as the ratio between the relief and the distance over which the relief is measured. It measures the overall steepness of the watershed and can be related to its hydrological characteristics.

2.4.3 Relative relief (R_p):

Melton (1957) defined relative relief as the ratio of basin relief H to the length of the perimeter, P. It is an indicator of general steepness of the basin from summit to mouth. It is computed using eqn.

$$R_p = \frac{H}{P}$$

2.4.4 Ruggedness number (R_n):

Melton (1957) and Strahler (1958) defined a dimensionless number called Ruggedness number, R_n as a product of relief, H and drainage density, D. The ruggedness number combines slope and length characteristics in one expression. The areas of low relief but high drainage density are as ruggedly textured as areas of higher relief having less dissection. The ruggedness number R_n is calculated as

$$R_n = HD$$

2.4.5 Taylor and Schwartz's Slope (T_s):

Taylor and Schwartz (1938) described the slope of the main channel as parts per 10,000. Here the channel was treated as series of lengths (l) of approximately uniform slope (s), whose time of flow are considered to be proportional to ($l/\sqrt{s_i}$) . The average slope of channel is therefore computed by

$$L / \sqrt{T_s} = \sum_{i=1}^{n} (l_i / \sqrt{s_i})$$

where, T_s is the Taylor and Schwartz slope of the channel of the same length and time of flow as of actual length, n is the total number of segments of the main channel, l_i is the length of i th segment and s_i is the slope of the i th segment.

3.0 DESCRIPTION OF STUDY AREA AND DATA AVAILABILITY

3.1 The Cauvery Basin

The Cauvery is one of the major inland rivers of the peninsula flowing east and draining into the Bay of Bengal. The Cauvery basin extends over an area of 87,900 sq. km in the state of Karnataka and Tamil Nadu. The basin lies between longitudes $75^\circ29'$ and $79^\circ45'$ east and north latitudes $10^\circ05'$ and $13^\circ30'$. The basin is some what rectangular in shape, the maximum length and breadth being 360 km and 200 km respectively. The basin may be divided mainly into three physiographic division viz. the western ghats, the plateau of Karnataka and the delta. The western ghats region is mountainous and covered with thick vegetation. The plateau of Karnataka with an average elevation of 750 m slopes gently towards the east/south-east. The delta is the most fertile tract in the basin and covers the major portion of the Tiruchirapalli and Tanjavur districts of Tamil Nadu.

3.2 The Hemavati Basin

The Hemavati, also known as Yennehole, is one of the important tributaries to join the Cauvery on its northern bank. It rises in Ballalara -Yanadurga in the Mudigere taluk of Chickmaglur district in western ghats. The Hemavati, after traversing a length of 193 km in Hassan and Mandya district, joins the river Cauvery in the water spread of Krishnarajasagar reservoir near Akkihebbal. Fig.1 shows the Hemavati sub basin in Cauvery basin.

In its upper reaches, the river Hemavati originates from a very heavy rainfall region in the vicinity of Mudigere and Kotigere. Important tributaries of Hemavati are Yagachi and Alur. In addition to these major streams, a number of minor streams join the river all along its course. The river drains an area of 5, 200 sq km. The annual rainfall varies from a maximum of 5080 mm to a minimum of 762 mm with an average annual rainfall of 2972 mm.

The economy of the basin is primarily dependent on agriculture which is the chief occupation of the people. In the

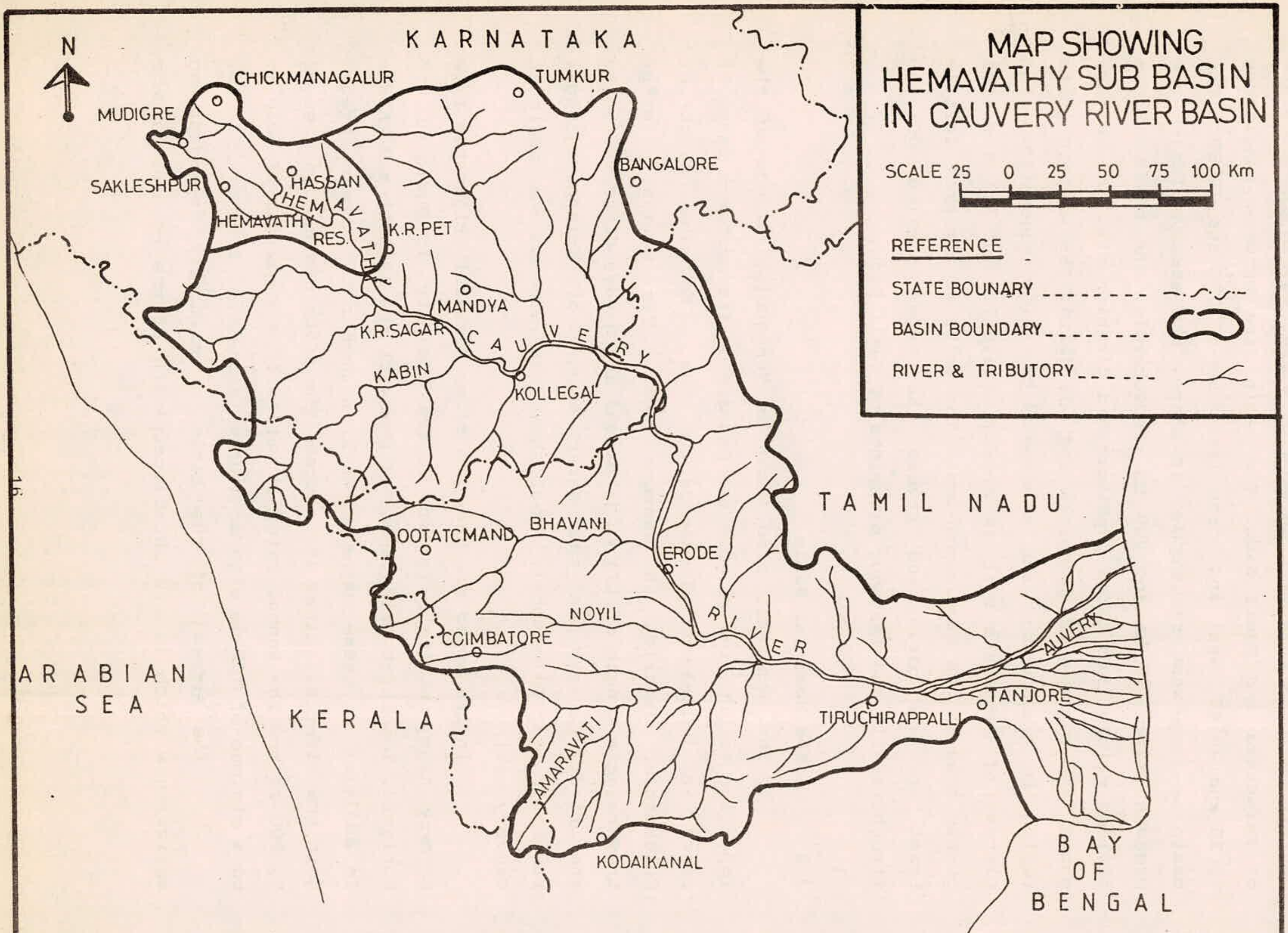

FIG.1. HEMAVATHY SUB-BASIN IN CAUVERY RIVER BASIN

hilly region there are number of check dams constructed across the river during 19th century which are still in use for irrigation. In the undulating plain, tank irrigation is common. Efforts are being made to increase irrigation potential by constructing storage structures.

3.3 The Study Area:

For the present study, the Hemavati upto WRDO gauging site at Sakleshpur is selected. The selected area lies between $12^{\circ}55'$ and $13^{\circ}11'$ north latitude and $75^{\circ}29'$ and $75^{\circ}51'$ east longitude in the south western parts of Chickmaglur and Hassan district. The area is covered in Survey of India toposheet Numbers 48 O and 48 P. Fig.2 shows the map of the study area.

3.3.1 Climate and rainfall:

The catchment area is a typical example of monsoon type of climate. The summer season extends from March to May . Rainy season extends from June to October . Heavy to very heavy rainstorms are experienced in the rainy season. November to February are winter months. Severe cold is experienced during these months.

3.3.2 Topography:

The area under study is a hilly catchment with steep to moderate slope. The slope is very high in the upper reaches and reduces gradually in the lower reaches. The general elevation of the basin ranges from 890 m to 1240 m above mean sea level. The entire basin may be classified as hilly lands, moderately sloping and low lands(valley lands). Fig. 3 shows the topographic map of the basin.

3.3.3 River network:

The basin is heavily dissected by stream network. The stream frequency is high in upper reaches of the basin compared to the lower reach.

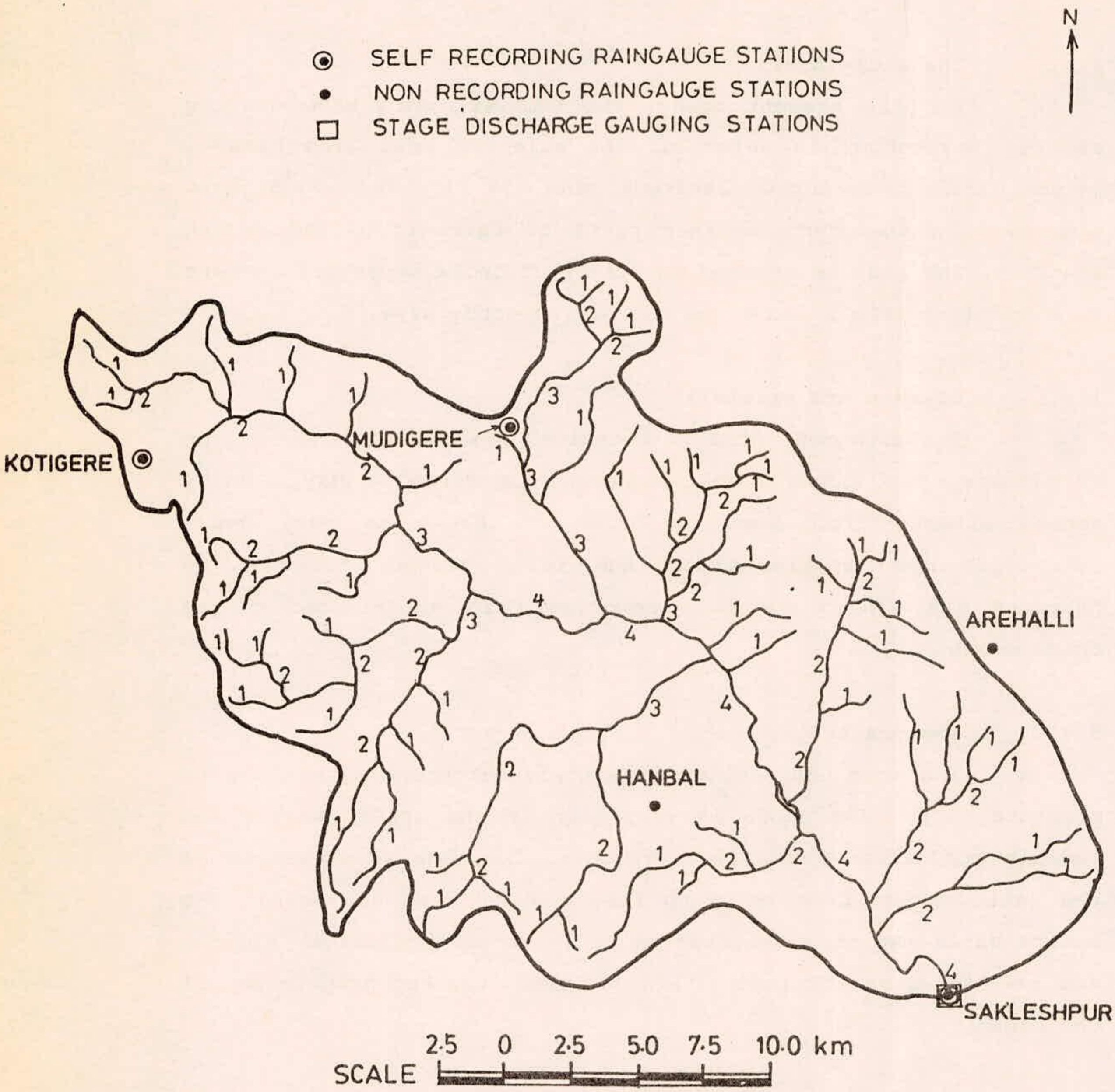

FIG.2. MAP OF HEMAVATI(UP TO SAKLESHPUR) BASIN

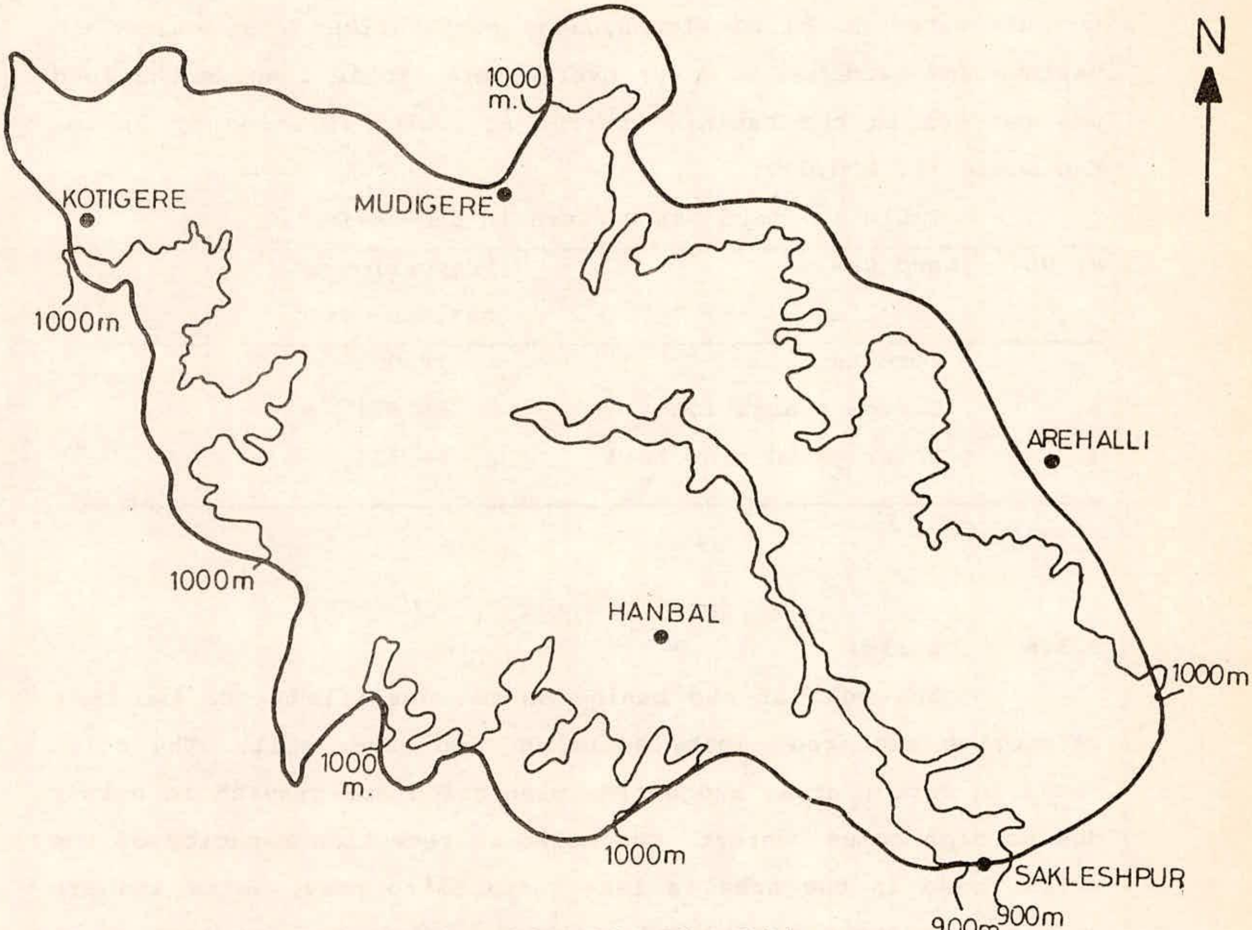

FIG. 3. CONTOUR MAP OF THE STUDY AREA

3.3.4 Geology:

The main geological formations are schists, granites and grosses all of precambrian age. Schists are found in western parts of the basin and some scattered patches are also found in eastern portion.

3.3.5 Land use:

Agriculture and plantation is the main land use in the basin. The main crops grown are coffee, paddy and Cardamom. Coffee is cultivated on hills slopes, paddy cultivation is practiced in valleys and cardamom is grown every where. Table 1 shows the land use pattern in the basin. (Source: Agricultural Atlas of India, Map Scale 1:1,000,000)

Table 1 : Land Use Pattern in the Basin

Sl No.	Land Use	Proportion of basin covered
1.	Forests	12.00%
2.	Coffee plantation	28.67%
3.	Unirrigated crop land	59.33%

3.3.6 Soils:

The soil of the basin can be classified into two main categories viz. red loamy soils and red sandy soils. The soils found in forest areas and coffee plantation are grayish in colour due to high humus content. The moisture retention capacity of the soils found in the area is less compared to heavy soils and are unable to sustain a good crop without irrigation. The texture of the soil is fine to very fine. The soils are neutral in nature and the soil pH ranges from 6.5 to 7.5. (Source: Agricultural Atlas of India)

3.3.7 Network of observation stations:

There are five rain gauge stations in the basin. Out of these five stations three stations are self recording station

(SRRG) and remaining two stations are ordinary rain gauge stations (ORG). The SRRG'S are Mudigere, Kotigere and Sakleshpur. There is only one gauging site in the study basin at Sakleshpur. The gauging site is maintained by Water Resources Development Organisation (WRDO) of Government of Karnataka. At this gauging site stage and discharge observation for 3 to 5 times a day are available . The nearest Meteorological observatory is situated at Gorur. Location map of various observatory/stations is given in Fig. 2.

4.0 ANALYSIS AND DISCUSSION OF RESULTS:

For evaluating different geomorphological parameters, the topographic map of area was drawn from the Survey of India Toposheet No.48 O and 48 P in the 1:2,50,000 scale. The river system of the basin was ordered according to Strahler ordering scheme discussed earlier. It is observed that the basin is fourth order basin. The map of the basin with Streams marked on it is shown in Fig. 2. The contour map of the basin in shown in fig. 3.

The contributing areas of each stream was marked and the boundaries and river network was digitized on VAX-11/780 system using Calcomp 9100 electronic digitizer available at the Institute. The digitized data were stored in files on VAX-11/780 system in the required format to give input to the computer program developed for calculating various geomorphological parameter.

After successful execution of the program, various linear, areal and relief parameters of the basin were obtained.

Table 2 shows the linear measures of the basin. It can be seen from the table that the mean lengths, which were calculated as the ratio of total length of specific order stream to number of stream segment are 3.024, 6.473, 3.732 and 29.395 km for order 1,2,3 and 4 respectively. The number of streams for different orders are 55, 14, 5 and 1 for order 1,2,3 and 4 respectively. Since a watershed of a given order can be modelled as a collection of sub elements, the number of streams of each order is an important concept in hydrology. It can be seen from table 2 that the number of streams of a given order decreases with the increase in order w. The length ratio and bifurcation ratio ratio for the Hemavati sub basin are 2.017 and 3.6882 respectively. These dimensionless parameters are very useful in synthesizing hydrograph characteristics.

Table 2 :Linear Measures of Hemavati Basin upto Sakleshpur

Sl. No.	Name of parameter	Symbol	Value
1.	Basin perimeter	P	132.570 km
2.	Length of main channel	L	50.157 km
3.	Centre of gravity	X_G	19.487 km
		Y_G	33.500 km
4.	Length of channel between outlet and a point near C.G.	L_c	21.750 km
5.	Bifurcation ratio	R_b	3.688
6.	Stream length ratio	R_L	2.017
7.	Total lengths of channels		
		L_1	166.348 km
		L_2	90.633 km
		L_3	24.873 km
		L_4	29.395 km
8.	Total length of all orders	L_u	311.240 km
9.	Mean length of channels		
		$\bar{L}_1$	3.024 km
		$\bar{L}_2$	6.473 km
		$\bar{L}_3$	4.972 km
		$\bar{L}_4$	29.395 km
10.	No. of segments of various orders		
		N_1	55
		N_2	14
		N_3	5
		N_4	1
11.	Total no. of segments of all orders	N_u	75
12.	Watershed eccentricity	τ	0.561

The length of channel between outlet and a point near to centre of gravity is 21.75 km. The other linear measures which have been computed for Hemavati sub basin include perimeter of basin, length of main streams, watershed eccentricity etc and are given in table 2. Fig. 4 shows the variation of number of streams of different order with their order number on semilog plot. Fig. 5 shows the plot of average stream length with their order number on semilog paper. The plot shows the increasing trend in average length of the streams and it follows Horton's law of stream length. Fig. 6 shows the tree structure representing the Hemavati basin upto Sakleshpur.

Various areal measures evaluated for Hemavati basin upto Sakleshpur are listed in table 3. The total drainage area of the basin at WRDO Gauging site at Sakleshpur is 632.10 sq.km. The drainage area of a basin is a very important geomorphological parameter and has been used widely in various hydrological simulation studies. The area drained by first, second, third and fourth order streams is 309.90, 460.80, 381.90 and 630.10 sq.km. respectively. The mean drainage area of 1st, 2nd, 3rd and 4th order streams is 5.634, 32.914, 76.380 and 632.10 sq.km. respectively. The other areal measures which have been computed for this basin are, elongation ratio, circularity ratio, drainage density, area ratio, form factor, constant of channel maintenance and stream frequency and are listed in table 3. Fig. 7 shows the variation of average area with stream number. It can be seen from the plot that the drainage area follows the Horton's law of stream areas.

Table 3 :Areal Measures of Hemavati Basin upto Sakleshpur

(Areas are in sq. km.)

Sl. No.	Name of parameter	Symbol	Value
1.	Total drainage area	A	632.100
2.	Drainage density	D	0.4825
3.	Constant of channel maintenance	C	2.072
4.	stream frequency	F	0.1186
5.	Circularity ratio	R_c	0.4521
6.	Elongation ratio	R_e	0.5655
7.	Form factor	R_f	0.2512

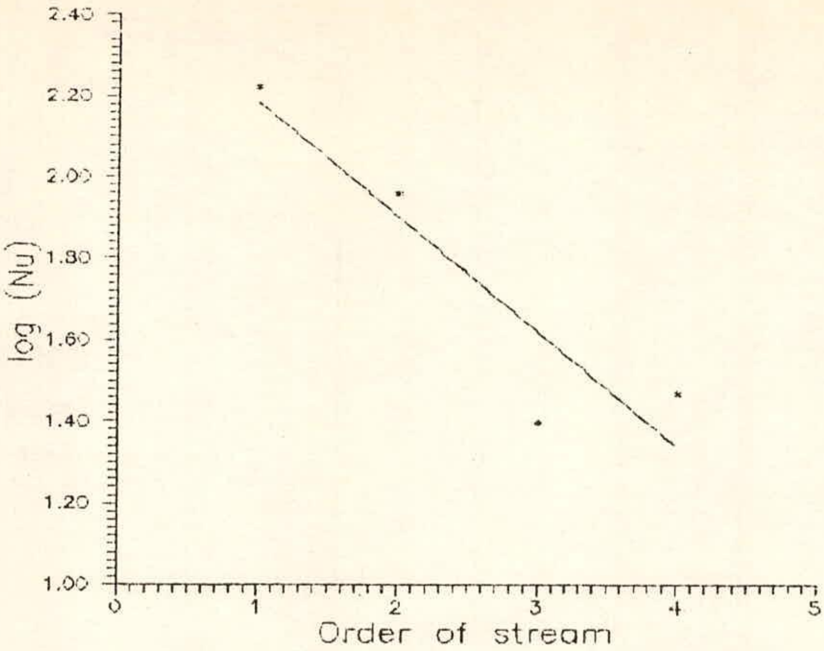

Fig. 4 Plot of stream order vs log of number of streams

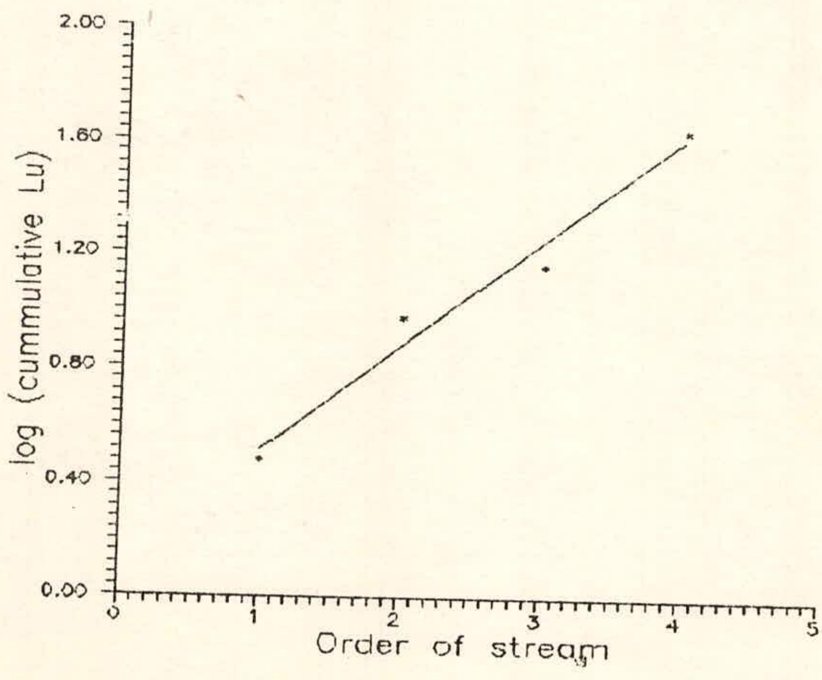

Fig. 5 Plot of stream order vs log of cummulative mean stream length

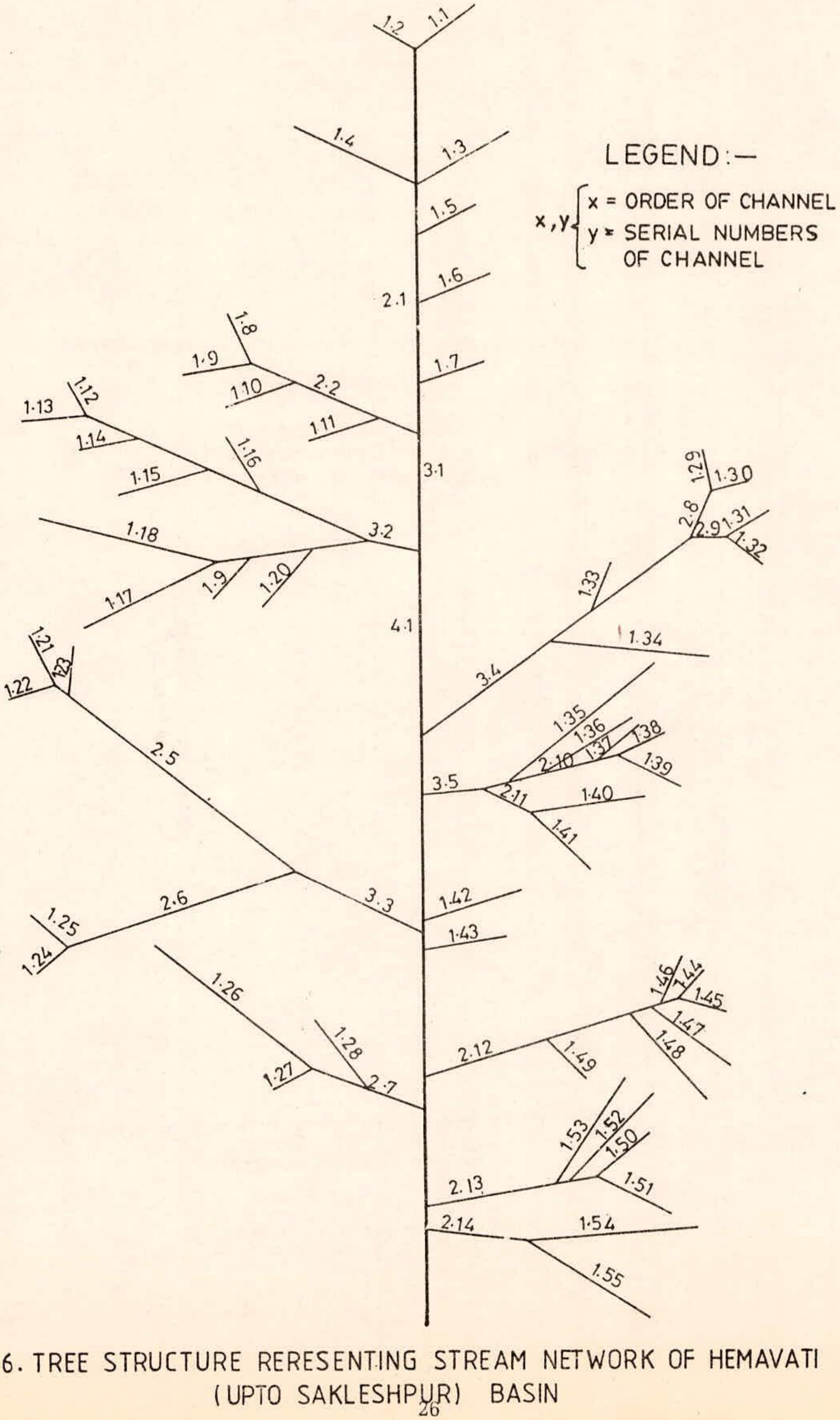

FIG. 6. TREE STRUCTURE RERESENTING STREAM NETWORK OF HEMAVATI (UPTO SAKLESHPUR) BASIN

8.	Drainage area of various order		
		A_1	309.900
		A_2	460.800
		A_3	381.900
		A_4	632.100
9.	Mean drainage area of various orders		
		$\bar{A}_1$	5.634
		$\bar{A}_2$	32.994
		$\bar{A}_3$	76.380
		$\bar{A}_4$	632.100

Some of the important relief measure evaluated for the basin are listed in table 4. These measures include slope of main stream, basin relief, relief ratio, relative relief, Ruggedness number, Taylor and schawrtz slope. Fig. 8 shows the profile of the main drainage channel of the basin. The relief parameters govern the overland and stream flow processes of a basin. These parameters are of profound importance in hydrological studies in mountainous areas, and are often used in modeling hydrological responses of these areas.

Table 4 :Relief Measures of Hemavati Basin upto Sakleshpur

Sl. No.	Name of parameter	Symbol	Value
1.	Basin relief	H	350 m
2.	Relief ratio	R_h	0.0251
3.	Relative relief	R_p	0.0026
4.	Ruggedness number	R_n	0.1609
5.	Taylor & Schwartz slope	T_s	0.000976

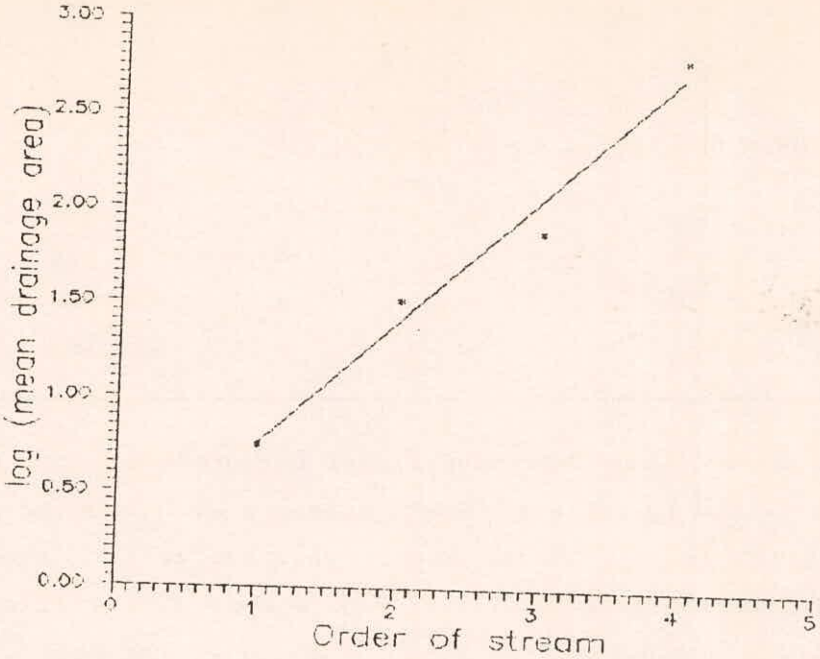

Fig. 7 Plot of stream order vs log of mean drainage area

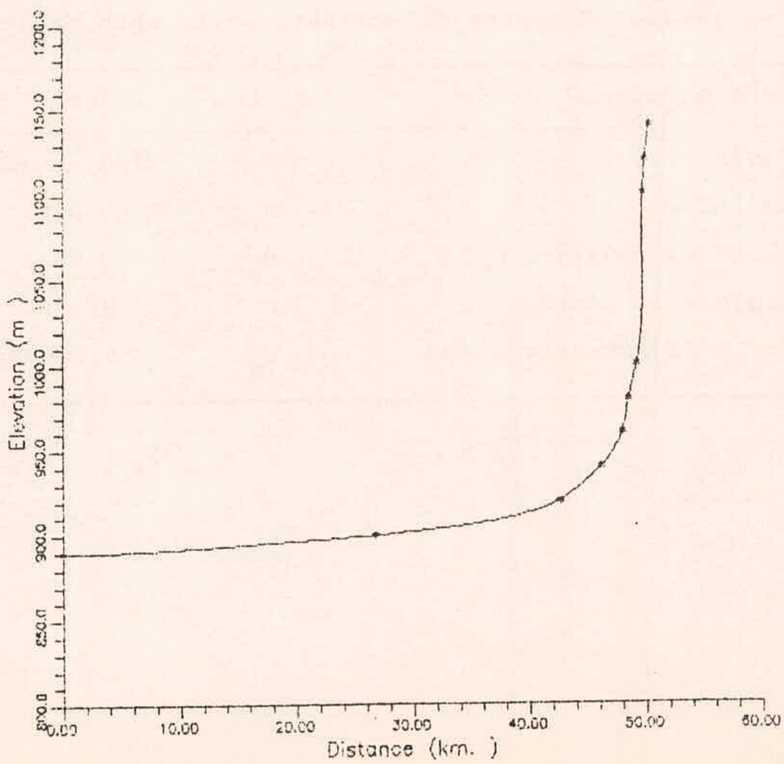

Fig 8. Main channel profile of Hemavati upto Sakleshpur

5.0 SUMMARY AND CONCLUDING REMARKS

In this report various geomorphological parameters covering linear, areal and relief aspects of the Hemavati basin upto Sakleshpur situated in western ghats region have been evaluated using modern measuring aids. The basin under study is a fourth order basin with steep to moderate slopes. The slope is very high in its upper reaches and reduces gradually in its lower reaches. The basin has low value of watershed eccentricity which indicates greater compactness of the basin. The other important parameters evaluated include area of watershed, length of channels, bifurcation ratio, circularity ratio, elongation ratio etc. The geomorphological parameters, thus estimated, may be utilized for developing the hydrological models to simulate hydrological response of the basin. Such models are very useful and are being widely used for simulating hydrological response of ungauged basin or basin with limited data.

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