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A GEOMORPHIC STUDY OF THE CHIKKAHAGARI BASIN IN KARNATAKA, INDIA

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ABSTRACT : A descriptive and a quantitative geomorphic study of the Chikkahagari basin undertaken by the authors shows that the two distinct rock units of this region have interacted with the geomorphic agents in a different manner to produce various geomorphic features like Domes, Whalebacks, Inselbergs and Koppies and Tors with typical dendritic drainage.

The basin, a seventh order basin covering an area of 3047 Km^2 in the semi arid climatic zone of Thornthwaite's P–E index, has a drainage density of 2.72. The average ground slope is 12. 3m/Km (64.91 feet per mile) and the the average main channel slope is 5.6 m/Km (29.79 feet per mile). The hypsometric analysis and the bifurcation ratios indicate that the basin has reached a mature stage.

The climatic data of the region when interpreted according to Wilson and classified, suggest that the region oscillates between semi arid and arid climates. With this climatic condition, the morphogeny shows a dominant action of the running water followed by a moderate action of mechanical-chemical weathering and mass wasting, with minimum of wind action.

Introduction

The Chikkahagari river is a tributary to the Tungabhadra river, which in turn is a tributary to the Krishna river. This river basin covering an area of 3047 Km^2 lies in the northern *maidan* region of Karnataka which occupies northern half of the state which is a broad undulating country with relatively lower elevations generally ranging 350–650 m.

Among the various parameters which control the geohydrological conditions of a basin, geommorphology is undoubtedly the most dominant. In this paper an attempt is made to give a brief account of both descriptive and quatitative geomorphology of the Chikkahagari basin.

The Chikkahagari basin is composed of granitoids of the Peninsular Gneissic complex and schists of the Dharwar Super group. A few post Dharwar dolerite dykes are the intrusives into the granitoids and the schists. The schists cover only an area of 90 Km^2 of the basin. A detailed geological account is given by Chandrashekhar (1978).

Descriptive Morphology

Both schists and granitoids form the hillocks in the basin, The interesting and contrasting feature of schistose hillocks is that they present a smooth and rolling topography as opposed to the granite hills which exhibit a rugged topography. All the schistose hill ranges are aligned in NW–SE, directions, whereas those of granites do not follow any particular trend. The ancient rocks which were subjected to selective denudation and uplift have given rise to geomorphic features which are described below:

a) Dome

The term dome has been used in a simple topographic (relief) sense for rounded mountain tops following Fairbridge (1968). The most conspicuous domes in the basin are Narasimhadevaragudda (76° 2′40″ : 14°51′ 0″) west of Arsikere and Varandurga (76°23′30″ : 14°51′0″) 4 miles south of Kudligi. In both the cases the rock is a highly jointed granitic gneiss. Both the domes stand out very prominently, surrounded by a flat terrain and present a very rugged topography with steep slopes.

b) Whalebacks and flat domes

Longitudinal, oval shaped hillocks with narrow crests are called Whalebacks. The famous Uchangidurg (76°3′25″ : 14°33′30″) hill range is an example of this category with a peak of 2652′. The hill range trends in NW–SE direction, and the western water divide runs over the peak of this Whaleback. At the end of this huge hillock or chain of hills, sometimes small flat domal rocks are found. The relief of these hillocks ranges between 10-30 m (25'-100') above ground level. These are considered as secondary domelets or whalebacks and are called as flat domes.

c) Inselbergs aud Koppies

There are a group hillocks NE and N of Kudligi, which stand out of plain terrain, exhibiting rugged scenery with different sets of jointing. The trend of these hills indicates that in the geological past they have been connected with each other, but now they stand separated due to selective weathering and erosion. Based on these features, they are identified as inselberge and the smaller geomorphic features are called as Koppies. There are the typical features of tropical weathering (Twidale, 1968).

d) Tors

Gneissic and granitic hills especially on the west of the road from Harapanahalli to Arsikere are abound with tors, which are the results of weathering on these rocks with mural jointing.

e) Pediments

The transition between the hills and the plain is abrupt which is the typical feature of semi-arid regions, receiving rainfall as infrequent thunder storms (King, 1968). Soil, around hill ranges is reddish or reddish brown, with predominant angular to subangular grains of quartz and felspar. Pediments are concave in longitudinal section, which is observed in this basin also. Pediplains are formed by coalescence of numerous pediments. By comparing the features described by King (op.cit) it is suggested that the area bound by the Chikkahagari basin divide has reached the stage of pediplanation.

Drainage Pattern

The Chikkahagari basin is elongated being narrower in the southern and northern portion, whereas it is wider in the middle. Generally, the basin exhibits dendritic pattern of drainage which is typical of hard homogenous crystalline rocks (Fig. 1). A special mention has to be made about the course of trunk stream in a grid bounded by 14°35' and 14°40′ parallel and 75°5' and 76°10' longitudes. Here the river course is remarkably straight in two segments which are interconnected by a short but straight course. These are picked up in the landsat image also as major lineaments. The straight course of a stream is considered due to faulting or joints which have local but pronounced effect on the river course. As the river reaches its confluence (which is at present submerged in the backwater of the Tungabhadra dam) the valley becomes much

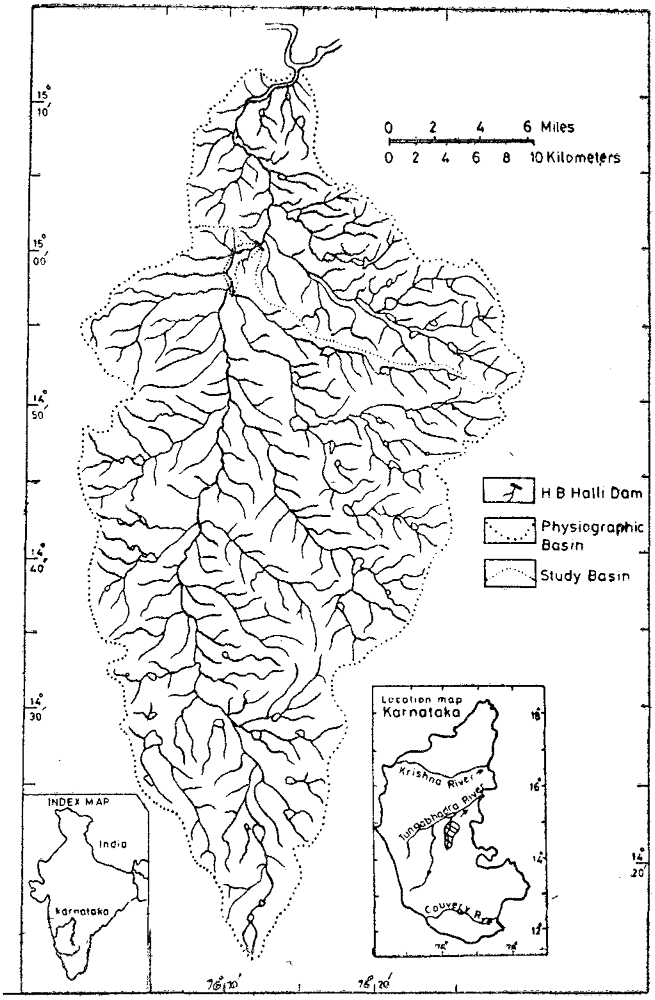

Fig. 1

wider and is filled with fine to coarse sand and starts meandering.

Methodology and Material for Fluvial Morphometric Analysis

For the morphometric analysis of the Chikkahagari basin, the toposheets on 1" = 1 mile scale, published by the Survey of India are used. The linear measurements are carried out with a map measurer (Opisometer), areal measurements are carried out with a planimeter and elevations within the basin are picked up from the toposheets only, for the hysometric analyssis. For convenience, the fluvial morphometric analysis of the basin is divided into three aspects – linear, areal and relief (gradient).

Linear Aspects of the Basin

(a) **Stream Orders**

There are different methods of designating the stream order, however the modified method of Strahler (1952) is adopted for the present analysis, and the number of segments of channels of each order are tabulated in Table I. The Chikkahagari basin is a seventh order basin with 4088, 1130, 27ↄ, 52,14, 4 and 1 segments in first second, third, fourth, fifth, sixth and seventh order respectively.

Table I

Morphological Data of the Chikkahagari Basin

Stream order u	Total No. of segments Nu	Bifurcation ratio (Rb) $\frac{Nu}{Nu+1}$	Total length of segments stream order u, Lu in miles	Mean length of segments $\bar{L}u$ in miles	Cumulative mean length in miles $\Sigma \bar{L}u$ miles	Length ratio (Rl) $\frac{\bar{L}u}{\bar{L}u-1}$	Total area, Au in miles	Mean area, $\bar{A}u$ in sq. miles	Area ratio $R_a = \frac{A_u}{Au-1}$
1	4080		1622.25	0.40	0.40		528.35	0.13	
		3.62				1.70			5.00
2	1130		766,25	0.68	1.08		735.35	0.65	
		4.11				2.12			4.89
3	275		396.25	1.44	2.52		873.76	3.18	
		5.19				2,84			6.05
4	53		216.75	4.09	6.61		1019.55	19.24	
		3.79				1.44			4.03
5	14		82.50	5.89	12.50		1084.60	77.47	
		3,50				3.26			3.83
6	4		76.75	19.19	31.69		1147.76	286.94	
		4,00				1.65			4.08
7	1		31.75	31.75	63.44		1171.95	1171.95	

It is further observed that there are more number of channels of a particular order than the next higher order. This observation leads to the recognition of 'bifurcation ratio' (Rb), which is the ratio between the number of a given order (Nu) to the number of segments of the next higher order (Nu + 1), Mathematically it is :

$$R_b = \frac{N_u}{N_{u+1}} \qquad \ldots \quad \ldots \quad (i)$$

The bifurcation ratios for each set of streams have been calculated (Table I)

Horton (op. cit) considered the bifurcation ratio as an index of relief and dissection. Bifurcation ratio ranging between 3-5 indicate the mature surfaces (Shreve, 1966 and Ongley, 1974). The bifurcation ratio of the basin $\frac{N_6}{N_7}$ is 4. Using the formula of Schumm (1956) the weighted mean bifurcation ration (WR_b) of the basin is calculated :

$$WR_b = \frac{\Sigma [R_{bu:u+1} \times (N_u + N_{u+1})]}{\Sigma N} \quad (ii)$$

and it is 4.8 for the basin. Both these indicate the mature stage of the basin, which is further confirmed by the hypsometric curve described later.

The law of stream numbers of Horton (op. cit.) stated that the numbers of stream segments of successively lower orders in a given basin tend to form a geometric series, beginning with a single segment of highest order and increasing with a constant bifurcation ratio. This law is proved to be consistant with basin (Fig. 2). The same law can be mathematically presented as under :

$$N_u = R_b^{(k-u)} \qquad \ldots \quad \ldots \quad (iii)$$

where,

'K' is the order of the main stream and other symbols are as defined earlier. This mathematical relation also holds good for the basin in a general way, as the relation is for an ideal basin. Minor variations are found even in the studies carried out by Strahler (1971).

Horton (op. cit.) further derived the following relation between the total number of steam segments and the bifurcation ratio :

$$\sum_{i=1}^{k} N_u = \frac{R_b^k - 1}{R_b - 1} \qquad \ldots \quad \ldots \quad (iv)$$

If the relevant values of R_b and k of the Chikkahagari basin are inserted in the equation (iv) the total number of segments of the basin works out to be 5461 whereas the observed number of segments is 5564. That means, there is a difference of 1.85 per cent which is permissible and it can be held that there is a fair agreement between the observed value and the calculated value.

b) Stream lengths

Other geological, climatological factors being the same, stream length (s) has an important relationship with the surface flow discharge - longer the length, slower the apearance of flood and larger the surface flow.

Horton observed that mean length of channel segments of a given order is smaller than that of higher order in a particular ratio called 'Length Ratio', which is defined as the ratio of mean channel length of an order to that of lower order. Mathematically the 'Length Ratio' is given by the following formula :

$$R_L = \frac{\bar{L}_u}{L_{u-1}} \qquad \ldots \quad \ldots \quad (v)$$

where,

R_L = Length ratio

L_U = Mean length of segments of order u

L_{U-1} = Mean length of segments of order u-1

The length ratios of the basin are calculated, and are presented in Table-I,

The study of stream lnagths lead Horton to formulate the law of stream lengths (similar to law of stream numbers) which states that the cumulative mean lengths of stream segments of successive orders of a basin tend to form a direct geometric sequence in which the first term is the average length of first order segments. Thus the law is presented mathematically in the following way :

$$\bar{L}_u = \bar{L}_1 R_L^{(u-1)} \quad \ldots \quad \ldots \quad (vi)$$

In case of the Chikkahagari basin when the order of stream was plotted against the cumulative mean lengths, the law is substantiated,

Areal Aspects of the Basin

a) Law of stream areas

As a corollary of the law of stream lengths, the law of stream areas states that the mean basin areas of successive stream orders tend to form a direct geometric series beginning with the mean basin area of first order basins and increasing with the constant area ratio (Schumm op. cit.) the law can be stated mathematically as under :

$$\bar{A}_u = \bar{A}_1 R_a^{(u-1)} \quad \ldots \quad \ldots \quad (vii)$$

where

Au is mean area of basins of u order, A_1 is the mean basin area of first order basin and R_1 is an area ratio similar to the length ratio R. The basin areas of different orders from 1–7 have been planimeted and corresponding R_a have been calculated (Table I), and the data plotted exhibit a positive relation.

b) Relation of area with length

Borrowing the analogy of allometric growth from biological sciences the geomorphologists developed the relation of basin area with mean length (cumulative) of the basin (Morisawa op. cit. and Hack 1957). The data of basin area with the corresponding cumulative mean length of the Chikka hagari basin are plotted on a double log paper (Fig 3) and they form a direct relation which can be stated mathematically as follows :

$$\bar{A}_u = a\bar{L}_u^b \quad \ldots \quad \ldots \quad (viii)$$

where

a is a numerical constant and b is an exponent. For the Chikkahagari basin the values are 0.6263 and 1.8175 respectively.

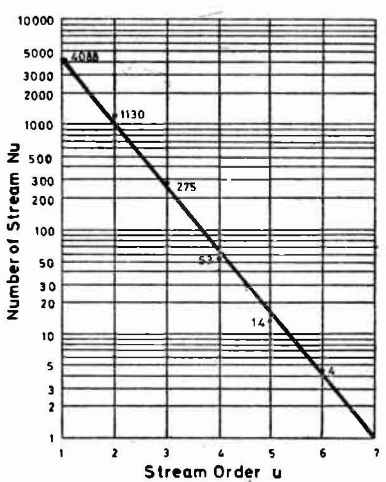

Fig. 2

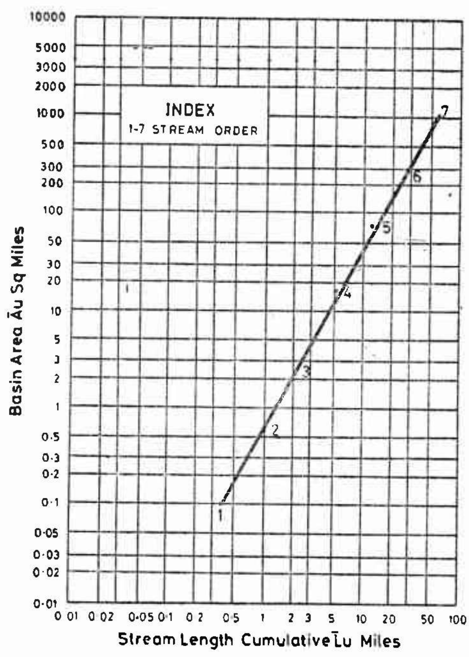

Fig. 3

Table II

Basin Shape Measures of the Chikkahagari Basin

Shape factor	Definition	Source
1. Form P	$\frac{\text{Basin area}}{(\text{Basin length})^2}$ $= \frac{1171.95 \text{ sq. miles}}{(65.9)^2 \text{ miles}} = \frac{1171\ 95}{4342\ 81}$ Form F $=$ 0.27	Horton (1932)
2. Shape S	$\frac{(\text{Basin length})^2}{\text{Basin area}}$ $= \frac{(65.9)^2}{1171\ 95} = \frac{4342.81}{1171.95}$ Shape S $=$ 3.71	Corps of Engineers
3. Shape S	$\frac{\text{Basin length}}{\text{Basin width}}$ $= \frac{65.9}{32.3} = 2.04$ Shape S $=$ 2.04	Horton (1932)
4 Circularity ratio C	$\frac{\text{Basin area}}{\text{Area of a circle with same basin perimeter}}$ $= \frac{1171.95}{2562.9603}$ C $=$ 0.457	Miller (1953)
5. Elongation Ratio E	$\frac{\text{Diameter of circle of basin area}}{\text{Maximum length of basin}}$ $= \frac{38.626}{65.9}$ E $=$ 0.5861	Schumm (1956)
6. Lemniscate Ratio K	$\frac{(\text{Basin length})^2}{4\ (\text{basin area})}$ $= \frac{(65.9)^2}{4\ (1171.95)}$ $= \frac{4342.81}{4685.00}$ K $=$ 0 9269	Chorley et. al. (1957)

c) **Basin shape**

The shape, or outline form, of a drainage basin, as it is projected upon the horizontal datum plane of a map may have effect on the discharge characteristics of a basin. A flood takes a longer time to travel in an elongated basin when compared to a circular hasin. Many methods have suggested to quantify this property of a basin. In Table II the different values, obtained by different formulas are listed.

d) **Drainage density**

Horton (op. cit.) considers drainage density of a basin as an important factor affecting the flow etc. It is defined as the ratio of the total channel lengths within a basin to the total basin area. The unit is miles per sq. mile or km, per sq. km. The drainage density (D) for the Chikkahagari basin is worked out as under.

$$D = \frac{\text{Total length of channel segments (miles) of all orders}}{\text{Area of the basin (sq.miles)}}$$

Singh (1967) has graded basins of 5 different textures based on the drainage density as given below:

D	2	2–4	4–6	6–8	8–9
Texture	Very coarse	Coarse	Moderate	Fine	Very fine

Accordingly the Chikkahagari basin is graded as coarse textured basin.

e) **Constant of channel maintenance**

Schumm (op. cit.) used the inverse of drainage density as a parameter termed as constant of channel maintenance 'C'. Thus

$$C = \frac{1}{D} \quad \ldots \quad \ldots \quad (ix)$$

The unit of C is sq. mile per mile. It indicates the number of square mile of water-shed surface required to sustan 1 linear mile of channel. The C for the Chikkahagari basin is 0.37 square mile per mile.

f) **Stream frequency**

It is defined as the number of channel or stream segments per unit area and a value of 4.75 or 5 per sq. miles is obtained for the Chikkahagari basin.

Melton (1958) after analysing several drainage basins found the following universal relation :

$$F = 0.694\ D^2 \quad \ldots \ldots \ldots \quad (x)$$

where F is the stream frequency. Substituting the value of D^2 for the Chikkahagari basin F is calculated at 5.14 which is very close to the observed value of 5.

Relief (Gradient) Aspects of the Basin

a) **Average ground slope (Sg.)**

The average ground slope of the basin is determined by grid method of Horton (1926). A grid is superposed on a contour map of the basin 1"=4 miles, (1 cm = 2.53 km.) with 250' (76.2 m) contour interval, since the map 1" = 1 mile (1 cm = 0.6335 km) is too unwieldy for laying a grid. Number of inter-sections between each contour line with the horizontal and vertical lines of the grid are counted and the lengths of grid lines within the basin divide are measured as per the scale. The land slope or ground slope in vertical and horizontal directions are calculated using the following equations :

$$S_v = \frac{N_v \cdot Z}{I_v} \quad \ldots \quad \ldots \quad (xi)$$

$$S_h \equiv \frac{N_h \cdot Z}{I_h} \quad \ldots \quad \ldots \quad (xii)$$

where S^v = Slope in the vertical direction.

S_h = Slope in the horizontal direction.

N_v = Total number of contour intersections with the vertical grid lines.

N_h = Total number of contour intersections with the horizontal grid lines.

I_v = Total length of vertical grid lines within the basin divide in miles.

I_h = Total length of horizontal grid lines within the basin divide in miles.

Z = Contour interval in ft.

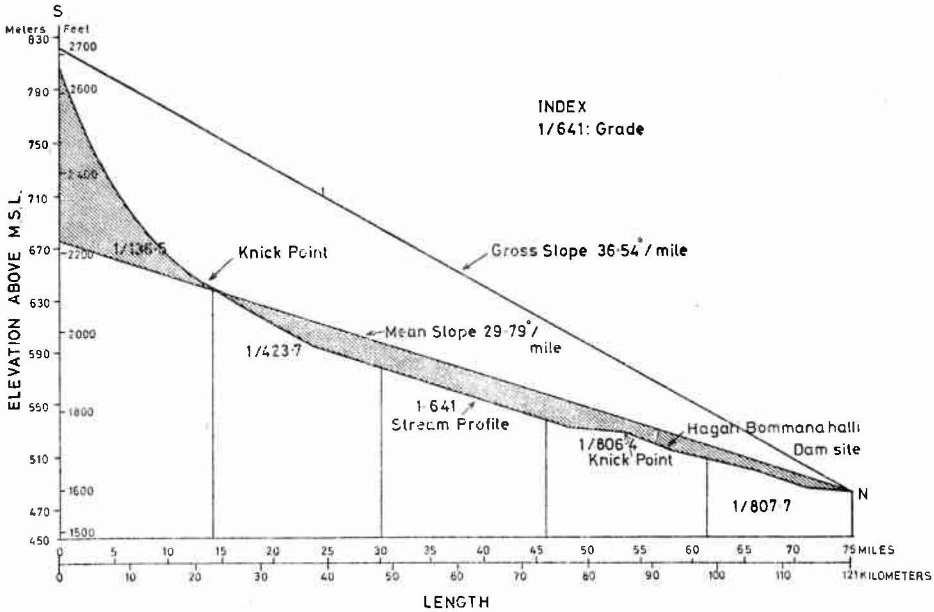

Fig. 4

For the Chikkahagari basin by substituting the suitable values, S_v, S_h, and S_g are obtained as under.

S_v = 56.29 / mile (10.66 m/Km)

S_h = 72.53 / mile (13.74 m/Km)

S_g = 64.91 / mile (12.3 m/Km)

S_g is obtained as the average of S_v and S_h.

b) Main channel slope (Sc)

The profile of the main channel is drawn by plotting the altitude on ordinate and the distance of each such point from the head to mouth on abscissa (Fig. 4). It is divided into four sections and it is observed that the slope of the profile is higher in the higher reaches and lower in lower reaches ranging from 1/136.6 to 1/807.7. While the gross slope of the profile is the ratio of the total fall in elevation to length of the stream (36.54' / mile), the mean slope (29.79'/mile) is obtained by drawing a line in such a way that the areas (hatched) between the line and the stream profile are equal (Fig. 4).

There is a knick point on the longitudinal profile (Fig. 4). A knick point is defined as a point where the slope of the channel changes appreciably and abruptly. Knick points are casued due to the variable resistance offered to by the bed rock for erosion. In the case of the Chikkahagari it is due to the change of formations from granitic gneiss to schist and then to gneiss. Knick points cause the steep slope which results in shooting flow, with increased erosion from impact, eddies, and cavitation. Thus knick points are actually the cause of their own disappearance (Morisawa op. cit.).

c) Frequency of spot heights

According to Clarke (1966) analysis to the frequency of spot heights was first carried out by Bauling (1926, 1928a, 1928b). The analysis of heights includes the picking up the spot heights in an area from the concerned toposheets. In the present study, spot heights picked up from the toposheets of Survey of India, and the altitudes of the observation wells (ground surface) fixed with analtimeter, are also considered to draw frequency diagram with different class intervals. Further, it is evident that peaks of the frequency curves of all the intervals fall within the height range of 1450' – 2350' even though there is shift of peaks in each class inverval.

d) **Hypsometric analysis**

Strahler (1952 and 1957) demonstrated the advantages of hypsometric analysis and has drawn type curves for different stages of erosion. Hypsometric curve involves two ratios of relative height $\left(\frac{h}{H}\right)$ and relative area $\left(\frac{a}{A}\right)$, where the former is the ratio of height of a given contour h to the total height H and the later is the ratio of horizontal cross - sectional area ' a' to entire basin area A. The relative height is plotted on the y axis and the relative area is plotted on the x axis. The hypsometric curve of the basin compares very well with that of the type curve depicting mature stage of cycle o erosion. This conclusion is in conformity with the conclusion arrived based on the study of the bifurcation Rb.

Morphogenetic Analysis

Budel (1963) was the first to specifically define climate - process - landform assemblages. Even though Peltier (1950) was the earliest to recognise morphogenetic regions, he was concerned with climate -process systems only. Leopold et. al. (1964) and Tanner (1961), had proposed some other morphogenetic classifications. Wilson (1961), presented a better type of morphogenetic classification and analysis, which is followed in the present study. According to him rainfall and temperature (which are the climatic factors) play a dominant role in morphogenesis and hence he uses only these two parameters for the construction of the graph.

When the mean annual values of these parameters for the Chikkahagari basin, plotted on the graphs of Wilson suggests that the action of mechanical weathering chemical weathering and mass wasting are moderate, whereas the action of running water is maximum with the action of the wind being at the minimum.

Wilson (op. cit.) in order to bring out seasonality in the morphogenetic processes has prepared a diagram using monthly values of climatic parameters. The mean monthly values for the basin when plotted on this figure of Wilson indicate that the climate here oscillates between semi arid and arid conditions.

Conclusions

Based on the above analysis and discussions the following conclusions are drawn :

i) The Chikkahagari basin with arid to semi arid climate exhibits different geomorphic features like, domes, whalebacks, inselberge and koppies, tors and has typical dendritic drainage pattern.

ii) The basin obeys the Laws of the Stream Numbers, the Stream Length and the Stream Areas of Horton.

iii) The basin is seventh order basin, with a drainage density of 2.7, which is classified as a coarse textured density.

iv) The weighted mean bifurcation ratio of 4.8 and the hypsometric analysis indicate that the basin has reached a mature stage of erosion, which is in conformity with the hypothetically accepted general view concerning the river basins of South India.

v) The relation between area of the basin with the length has been established for the basin, as $Au = aLu^{-b}$, where $a = 0.6263$ and $b = 1.8175$.

vi) The average ground slope of the basin is determined to be at 64.91 ft/mile, whereas the average main channel slope is 29. 79 ft./mile.

vii) Wilson's morphogenetic analysis indicated the dominant action of stream water with the minimum action of wind erosion. The mechanical weathering, the chemical weathering and mass wasting are moderate.

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