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GEOMORPHOLOGICAL CHARACTERSTICS OF WESTERN GHATS REGION

PART I - UPPER KRISHNA BASIN

NATIONAL INSTITUTE OF HYDROLOGY
JAL VIGYAN BHAWAN
ROORKEE-247 667

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PREFACE

The advanced knowledge of Geomorphology is important since geomorphology of a region affects formation of floods in that region. Such studies become much more important in the catchments where rainfall runoff data are either unavailable or scarse, since geomorphological parameters help in regionalisation of hydrological models dealing with runoff estimations for such catchments and establishing regional formulae for flood estimation.

In view of evolving various geomorphological parameters describing linear, areal and relief aspects of KRISHNA BASIN, geomorphological study has been taken up at National Institute of Hydrology, Roorkee. As first part of this study, Upper Krishna catchment has been selected and three basins have been studied and presented in this report.

Present work has been carried out at a scale of 1:250,000 and that's the reason for some of the parameters not being studied exhausitevely. It is proposed that subsequent studies will be carried out at a larger scale so that overall parameters for the basin could be in a better form.

This report entitled "Geomorphological characteristics of Western Ghat Region Part I: Upper Krishna Basin" is a part of work program of Mountain Hydrology Division of the institute. The study has been carried out by Sh. Avadhesh Kumar, Scientist 'B' and Sh. A.K.Singh, Senior Research Assistant. Services of Sh. Narendra Kumar, Draftsman, Smt. Kiran Ahuja, Steno and Sh. Attar Singh, Messenger are also acknowledged herewith.

Satish Chandra

SATISH CHANDRA

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ABSTRACT

Geomorphology is science of landforms. It describes landforms and attempts to explain the evolution of landform in terms of lithology, structure, climate and geomorphology. The advance knowledge of geomorphology of the region is of importance in the field of flood control measures and engineering projects, since the geomorphological characteristics of river basins in mountainous areas affect runoff process and formation of flood in these areas.

Parameters of Hydrologic models describing rainfall-runoff process may be estimated either by optimisation technique using rainfall-runoff data or using topographical and climatic informatin of the basin. Since most of the locations in mountainous areas are either ungauged or sufficient data is not available for them, the study of geomorphological characteristics of such areas become much more important and significant. Thus one of the main objectives of geomorphological studies is to regionalise the hydrologic models describing rainfall-runoff process.

Various geomorphological parameters which have mostly been used by various investigators can be broadly classified as those describing (1) Linear Aspect of Channel System (2) Areal Aspect of Channel System and (3) Relief Aspect of the basin.

The river systems of western ghats region are non-snowfed. Since the rain falling over these basins is directly converted into overland flow and channel flow, it becomes all the more important to have clear idea of geomorphological characteristics of these basins.

The main objectives of present study is to evaluate some of the widely used geomorphological parameters of few selected sub-basins in western ghats region. 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

The estimation of runoff from the watershed is needed for comprehensive water resources planning, flood flow forecast, adequate design of hydraulic structures etc. The climatic and physical characteristics of the watershed are the main factors affecting runoff. The climatic factors include nature of precipitation, evapotranspiration, interception, rainfall intensity, duration of rainfall, areal and temporal variation of rainfall and direction of storm movement. The primary physical characteristics of the watershed which influence runoff are its area, length, shape, elevation, slope, orientation, soil type, drainage system, water storage potential and vegetal cover etc.

Geomorphology is the science of landforms. It describes landforms and attempts to explain the evolution of landforms in terms of lithology, structure, climate, and geomorphology which has its importance not only as an academic discipline but also in present day world has more applied application in the field of terrain evolution, flood control measures, energy resources and engineering projects. There is need to have an advance knowledge of geomorphology of the region and the limitation which they impose on operation and movement of forces involved with it. The main objective of Geomorphological studies is to regionalize the Hydrologic Models, describing rainfall-runoff process. Regionalization of a model simply means to develop a scientific basis for predicting the model parameters on ungauged watersheds from hydrologic and physiographic characteristics of that watershed. Parameters of Hydrologic models may be estimated either by optimization technique using rainfall data or using topographical and climatic information of the basin. Since most of the locations in mountainous areas are either ungauged or sufficient data is not available for them, the study on geomorphological characteristics of such areas becomes much more important and significant. Various geomorphological parameters required for regionalization of a model are those describing (i) Linear aspects (ii) Areal aspects (iii) relief aspects of the basin. Some important parameters have been described and evaluated for western ghat catchments in this study.

The western ghats area has many of the major river systems of India which are primarily non-snowfed. 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 landform characteristics of the catchments in this area.

The present study aims at establishing Geomorphological parameters in some of the Western-Ghats catchments with a full description of various methods available for computation of such parameters. The study may be useful in carrying out overland flow routing or any other hydrological analysis for the catchments in this region.

2.0 REVIEW

2.1 General

Various parameters to be studied and established in the study can be broadly classified into three categories:

i) Linear Aspects of the channels

ii) Areal Aspects of the basin

iii) Relief Aspects of the catchment and channel network

2.1.1 Linear Aspects

Linear Aspects - Various parameters which involve length of channels in different ways are grouped under this category. Linear aspects of channel network are listed below:

a) Length of the Main Channel (L)

b) Length of the channel between the outlet and a point nearer to C.G. (Lc)

c) Total length of channels

d) Wandering Ratio.

e) Basin Perimeter

f) Fineness Ratio

g) Watershed Eccentricity

Details of each of these parameters alongwith different methods for their measurement or computations are discussed next.

a) Length of the main channel (L) : This is the length along the longest water course from the outflow point of designated sub-basin to the upper limit to the catchment boundary. The following are five methods which may be used for length measurement from topographic maps:

i) Pair of dividers

ii) Thread length

iii) Edge of paper strip

iv) Opisometer

v) Analog to digital converter

i) Pair of Dividers: In this method, the stream length can be measured by setting a pair of dividers to a small interval compared to the meander length of the stream. The points of the devider can be 'walked' up the centre line of the stream counting each strip. The stream length is :

stream length = (Number of Divider Steps)
× (Length of Divider Step)
× (Map Scale Factor) .....(1)

ii) Thread length : In this method, the stream length is measured using the thread. The stream length on the map is carefully pointed with rubber cement. A distinctive coloured thread or thin copper wire is stuck to the adhesive surface over the stream or contour image. The point of a divider can advantageously be used to attach the thread to the map image following all of the twists and bends. The ends of the thread are carefully trimmed with a single edge razor blade or sharp racto knife blade. The thread is then carefully lifted from the map and stretched along a scale for measurement. The rubber cement can be gently rubbed from the map or areal photo without damage to the map surface.

iii) Paper strip : In this method, the edge of a sheet of a paper is laid tangent to the stream at the beginning point. The beginning point is indicated by an arrow on the edge of the paper. Now, hold the position of the edge of the paper with the point of a drawing pencil at the point where the straight edge of the paper begins to deviate from the stream alignment. After this the sheet of paper is rotated until its straight edge is again tangent to the stream. Then the point of pencil is advanced to the edge of the paper where the stream again deviates from the straight edge of the paper and it is to be continued till the end of the stream which is marked with another arrow.

The length of the stream is the distance along the edge of the paper between the start and end arrow measured in inches or centimeters (as appropriate) times the scale factor for the map scale ratio. If one sheet of paper has insufficient edge length for the stream length being measured, a second sheet of paper may be employed. This method has the advantage that the sheet paper provides the length data in a form which can easily be checked again at a later time by some one else.

This method also provides a procedure for obtaining data for constructing a profile of the stream. Whenever the edge of the paper encounters a place on the map where the stream intersects a contour line, indicate this point with a small "tick" mark on the paper and label the tick mark with the contour elevation. The elevation difference between these tick marks divided by ground distance is the average stream slope between the points.

iv) Opisometer : The opisometer is an instrument having a dial connected by gears to a small roller wheel which is guided over the centre line of the stream. The distance traversed by the roller wheel is indicated on the dial. The units are either in inches or centimeters. It is usually difficult to reset the dial to zero reading at the start of the measurement, therefore, it is customary to read the initial and final readings from the dial. Then the initial dial reading is deducted from the final dial reading to obtain the length of stream.

Because it is difficult to guide the wheel accurately over the stream, it is recommended that the distance be traced at least three or four times and the distance taken as the average of the measurements. These measurements, which have deviations more than five percent of the average measurement, should be discarded and replaced with other measurements.

v) Analog to digital Convertor: Stream lengths and contour lengths can be obtained in an indirect way by tracing the line or stream to be measured in a special machine. This machine is used to record X and Y coordinates of closely spaced points on magnetic tape or punched on paper tape or IBM cards. The required stream length is found by running distances computed from the equation

$$\text{Distance} = ((X)^2 + (Y)^2)^{1/2} \quad \ldots\ldots(2)$$

High speed digital computer is used in the procedure. As a result, the basic map data can be quickly, accurately and inexpensively converted into a form or automatic machine data processing. This method is capable of resolving X and Y distances to the nearest 0.001 inch.

b) Length of channel between the outlet and a point nearer to C.G. (Lc) :

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 centroid of the basin is determined using the following steps :

i) Cut a cardboard piece in the shape of the catchment

ii) Locate the C.G. of the catchment shape card board piece using point balance standard procedure

iii) Superimpose the card board piece marked with centre of gravity over the catchment plan.

iv) Press a sharp edge pin over the centre of gravity of the card board piece to mark the centre of gravity of catchment.

Once the centre of gravity is located the length Lc can be measured by any method described for stream length measurement.

c) Total length of Channels :

Total channel length is the sum total of the lengths of channels of all the orders in the basin. This parameter is important as it gives an idea of over land flow and channel flow in the basin. Channel storage also varies with stream length as a simple power function.

d) Wandering Ratio :

Wandering ratio is defined as the ratio of the main stream length to the valley length. Valley length is the straight line distance between outlet of the basin and the farthest point on the ridge. It has been shown in fig 1. Wandering ratio represents the deviations of the mainstream path from the straight line length from the mouth to the top of the main stream. The wandering ratio should be clearly distinguished from sinuosity or meandering as the wandering ratio represents a more gross deviation of the path of the master stream from straight length.

e) Basin Perimeter: It is measured along the divides between basins and may be used as an indicator of basin size and shape.

f) Fineness Ratio : The ratio of channel length to the length of the basin perimeter is fineness ratio, which is a measure of topographic fineness.

g) Watershed eccentricity : the watershed eccentricity is given by the expression :

$$\tau = \frac{(|(Lc^2 - W^2)|)^{1/2}}{W}$$

where τ = watershed eccentricity, a dimensionless factor
Lc = Length from the watershed mouth to the center of mass of the watershed in the same unit
W = the width of the watershed at the center of mass and perpendicular to Lc.

The measurement for Lc and W are shown diagramatically in fig 2. it is also to be noted that if Lc = W, τ =0, and as either Lc or W get large, τ increases. Thus the lower the value of τ, the greater the compactness of the watershed concentrated near the mouth and the higher the flood peak.

2.1.2 Areal Aspects of the Basin :

The parameters which are governed mainly by the area of the drainage basin are classed as Areal aspects of the basin. Following areal aspects have been considered for the present study :

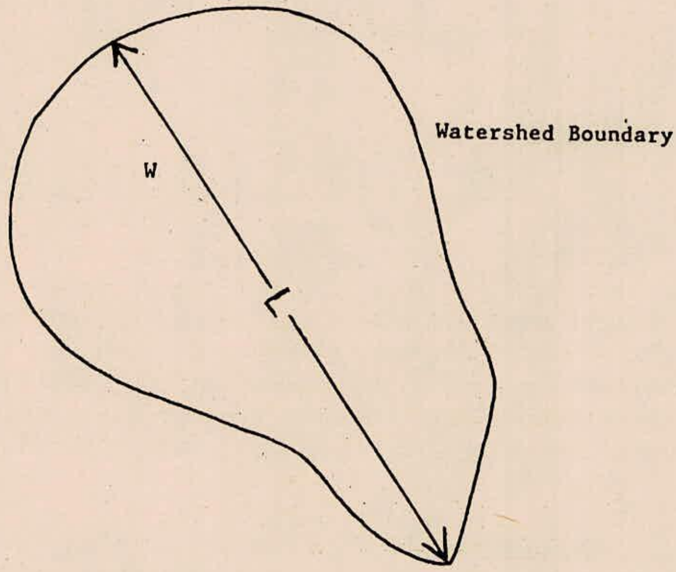
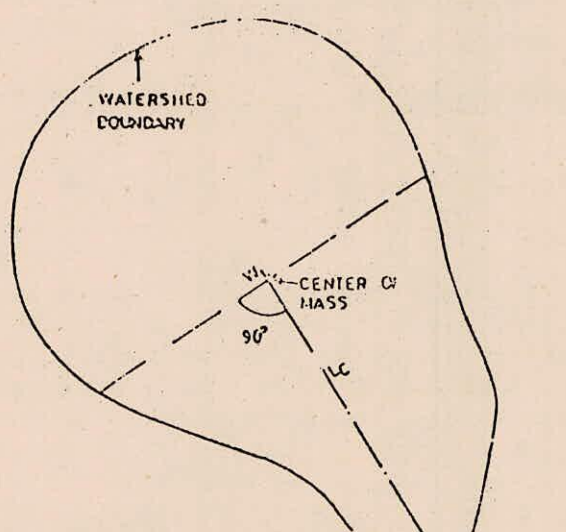


Fig. 1: Basin Length for Wandreing Ratio



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

Fig. 2: Watershed Ecuntricity

a) Drainage Area
b) Drainage Density
c) Constant of Channel Maintenance
d) Channel Segment Frequency
e) Circularity Ratio
f) Elongation Ratio
g) Watershed Shape Factor
h) Unity Shape Factor

In the following text the above parameters have been discussed in detail and various methods proposed for their evaluation have been explained briefly.

a) <u>Drainage Area :</u>

Drainage area is defined as collecting area from which water would go to a stream or river. The boundary of the area is determined by ridge separating water flowing in opposite directions. This parameter is hydrologically important because it directly affects the flood hydrograph and the magnitude of flood peaks in mountainous areas. The larger the size of the basin, the greater is the amount of the rain intercepted and higher the peak discharge that results.

The following methods are used for the determination of the area of a drainage basin from the available toposheets of the basin.

i) Estimation

ii) Polar planimeter

iii) Dot grid

iv) Strip sub division

v) Geometric sub division

vi) Analog to digital converter.

<u>i)</u> <u>Estimation :</u> The area of a watershed can be visually estimated by comparison of the watershed as traced on a topographic map with a square or rectangle of similar size and the known dimensions can be used to easily estimate the area. The method is quick and easy to use but is very subjective.

<u>ii)</u> <u>Polar planimeter :</u> It is a widely used analog device which yields a reading from a series of recording dials. The reading is proportional to the area of the figure traced around. The tracer point or optical cursor is set to a beginning point on the periphery of the watershed. An initial reading of the dials is taken (Some planimeters to be set to zero at the beginning of the tracing operation). The tracer point is then carefully guided around the area in a clockwise direction returning to the starting point. The dial reading after the area has been traced around is proportional to the area enclosed. It is customary to

trace around the area three times and taking a reading on the completion of each circuit. The area in a map units is taken as the average of these three values.

The watershed area is Area in square miles or square kilometer = (Planimeter units) x (area per planimeter unit) .. (4)

The area per planimeter unit may be determined by tracing around a square whose area can be computed in watershed units. For this purpose a map scale line at the bottom of the topographic map can be used.

Some planimeters, which are fitted with an adjustable tracer arm to allow the setting of the instrument, give a direct indication of the area in any units. If the carriage block is in a fixed position on the tracer arm, the instrument will give the area traced in square inches.

iii) Dot grid : The area of the watershed can be determined by the use of a dot grid. The dot grid can be constructed from a sheet of graph paper printed on tracing paper. The intersection of the grid lines represent "dots". The tracing paper grid is layed over the map on which the watershed boundary is outlined for the measurement of area. All dots falling within the watershed are counted. One half of all the dots falling exactly on the watershed boundary are counted. The other half are dropped from the count.

The presence of the major grid lines (the heavy line occuring every 10th or 20th line) facilitates the speed and ease of obtaining a count of the dots. In the interior part of the watershed where the entire major square falls within the area, the dots (grid intersections) are quickly counted by inspection (10x10=100 intersections). Light check marks made with a sharp drawing pencil may be used to indicate those intersections counted. These check marks are particularly useful in counting those intersections which fall exactly on the watershed boundary.

The area is converted to the desired units by the equation :

Area in square miles = (square miles) x (intersections) ÷ (intersections per square inch) ..... (5)

iv) Strip sub division : In this method the watershed area is sub divided into narrow strips. The length of each strip falling within the area is sealed. The area in map units is given by :

Map area = (Length of all strips) x (Strip width) ..(6)

The watershed area is obtained by :

Area in square miles = (Maps area) x (square miles per map unit) ..(7)

A sheet of 10x10 per inch or 5x5 per inch graph paper on a transparent tracing paper can be used to define the strips.

v) Geometric subdivision : The watershed areas as outlined on the topographic map can be approximated by a series of simple geometric shapes whose areas can easily be computed. The areas of squares, rectangles and triangles can be easily determined. The area in map units is given by :

Map area = (computed area of simple sub divisions)..(8)

The watershed area is obtained by :

Area in square miles = (Map area)x(Square Miles per map unit) .....(9)

vi) Analog to digital converter : The basic data, obtained by tracing around the watershed boundaries drawn on the topographic map with the cursor of the analog to digital converter, may be used to compute the watershed area by a computer programme. The analog to digital converter is already described in section 2.1 (a) under the discussion dealing with length measurements.

The output from the analog to digital converter consists of a large number of X and Y coordinates on the pariphery of the watershed. The coordinates are recorded on magnetic taps or punched on paper tape or IBM cards. A computer program uses the basic data to compute the area of the watershed converted to square miles, the length of the periphery of the watershed and coordinates of the centre of area.

b) Drainage Density :

Drainage density is defined as the ratio of the total length of channels of all orders in a basin to the area of the basin. It should therefore be measured on the topomaps of large scales (1:50,000) so that first order streams can also be taken into account. Drainage density is a textural measure of a basin which is generally independent of basin size. It is considered to be a function of climate, lithology, and stage of development. Numerically this ratio expresses the number of kilometers of channel maintained by a square kilometer of drainage area.

c) Constant of Channel Maintenance :

Constant of channel maintenance is defined as the ratio between the area of a drainage basin and the total length of all the channels expressed in square feet per foot or square meters per meter. It is virtually the reciprocal of drainage density.

The importance of this constant is that it provides a quantitative expression of the minimum limiting area required for the developmental of a length of the channel.

d) Channel Segment Frequency :

Channel segment frequency or stream frequency is defined as the number of streams per unit area in a drainage basin. Horton suggested that the composition of a drainage basin provided a more adequate characterization of a stream, than did drainage pattern. His "composition" was completely described using the two textural measures of drainage density and stream frequency.

e) Circularity Ratio :

Basin circularity ratio is defined as the ratio of the basin area to the area of a circle having a circumference equal to the perimeter of the basin. The value of this ratio approaches unity as the shape of a drainage basin approaches a circle.

f) Elongation Ratio :

Elongation ratio of a basin is defined as the ratio between the diameter of a circle with the same area as the basin and basin length. The value of the elongation ratio approaches unity as the shape of drainage basin approaches a circle.

g) Watershed Shape Factor :

Watershed Shape factor is defined as the ratio of main stream length to the diameter of a circle having the same area as the watershed.

h) Unity Shape Factor :

Unity snape factor is defined as the ratio of the basin length to the square root of the basin area.

The indices such as Circularity Ratio, Elongation Ratio, Watershed Shape Factor and Unity Shape Factor are the measures to compare basin shapes. Basin shape is very important factor influencing the peak flow and other hydrograph characteristics such as steepness of rising and recession limbs, the time spread of hydrograph etc. All other things being equal the hydrograph resulting from basins of different shapes have been compared in Fig. 3.

2.1.3 Relief Aspects of Catchments and Channel Networks

Relief Aspects are the functions of the elevation or elevation difference at various points in a catchment or along the channels. Contour lines on a toposheet are made use of while determining the relief aspects. Various parameters involving the relief aspects are as follows :

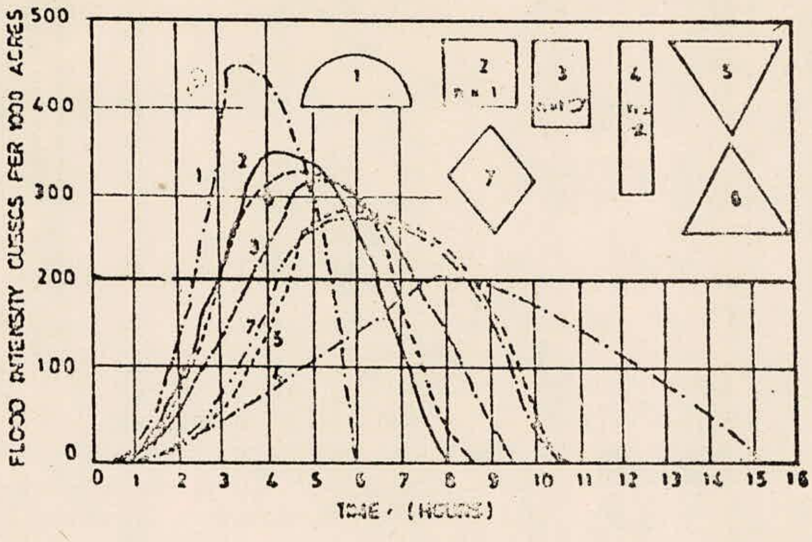


Fig. 3: Hydrographs for catchments of the same and other characteristics but varying shape. (Reproduced Murray and Prasad, 1971)

a) Basin Relief

b) Relief Ratio

c) Relative Relief

d) Ruggedness Number

e) Taylor & Schwartz Slope

f) Nash's measure of slope

g) Nash's measure of overland slope

h) Co-eff of variation of squareroot of the overland slope

Variables involving relief aspects of the basin are the most significant parameters in hydrological studies of the watershed. The slope is related to rate at which the potential energy of the water at high elevation in the headwaters of the catchment is converted into kinetic energy. Losses in various forms occur in the process. Water is held in storage and the travel time in the hydrologic system is in general inversely related to the slope. Mountainous catchments (as under study) are characterised by the steep slopes and hence these parameters become still more importnt for mountainous catchments. These parameters, therefore, have been discussed at length in the following text.

In the different methods given below, the lengths wherever required, are measured by any of the methods discussed in the previous section on linear aspects.

a) <u>Basin Relief :</u>

Relief of a basin is the maximum vertical distance from the stream outlet to the highest point on the dividing ridge. The total relief of a basin is a measure of the potential energy available to move water and sediment downslope.

b) <u>Relief Ratio :</u>

The relief ratio is defined as the ratio between the basin relief and the basin length. In normally shaped basins the relief ratio is a dimensionless height length ratio equal to the tangent of the angle formed by intersection at the basin mouth of a horizontal plane with a plane passing through the highest point on the divide. This parameter permits comparison of the relief of two basins without regard to the scale of the topomaps used.

c) <u>Relative Relief :</u>

Relative relief is defined as the ratio of the basin relief expressed in units of miles to the basin perimeter. Relative relief is an indicator of the general steepness of a basin from summit to the outlet. It has an advantage over the relief ratio in that it is not dependent on the basin length which is questionable parameter in spreaded basins. When the main channel consists of two branches more or less of equal catchment the channel slopes are taken as the mean of the two values calculated separately and weighted with the appropriate catchment area.

d) Nash's Measure of Overland Slope :

Nash (1960) defined another measure of slope that is known as the overland slope. For this a grid of rectangular mersh is drawn on the 2.5 inch map of the catchment, the mesh size being such that about 100 nodes occur with in the catchment boundary. At each intersection the minimum distance between adjacent contours is measured and the slope at each point is taken as the contour interval divided by this distance. This provides a set of slope values, of which the arithmatic mean is calculated and taken as the overland slope. When the intersection occures at a point between two countours of the same value, the slope is taken as zero if the point is in valley and as indeterminate if the point is on a hill. Indeterminate points are omitted while calculating the mean. (Fig. 4).

e) Co-efficient of Variation of the Square Root of Overland Slope :

This measure was also suggested by Nash in 1960. Here the mean and standard deviation of the square roots of the values of over land slope at the intersections of the grid are calculated and the coefficient of variation is taken as the standard deviation divided by the mean. This is a statistical measure of the variation of overland slope in the catchment.

f) Ruggedness Number :

The product of drainage density and relief (in the same units) is termed as the ruggedness of a basin. Areas of low relief but high drainage are, therefore, as ruggedly textured as the areas of higher relief having less dissection.

g) Taylor and Schwarts Slope :

Taylor and Schwartz (1938) described the slope of the main channel in parts per 10,000. Here the channel was treated as series of lengths (1) of approximately uniform slope (S), whose time of flow was taken as being proportional to (1). The slope of the channel (TS) was given by L\TS = (1\s), where TS is the slope of a uniform channel of the same length and time of flow as the actual length. The definition sketch for this parameter is given in Fig. 5.

h) Nash's Measure of Slope :

Nash (1960) defined another measure of slope where the

287	231	245
189	417	144
93	309	I

I - INDETERMINATE

Mean Slope $= \frac{1915}{8}$

$= 239$ parts per 10,000

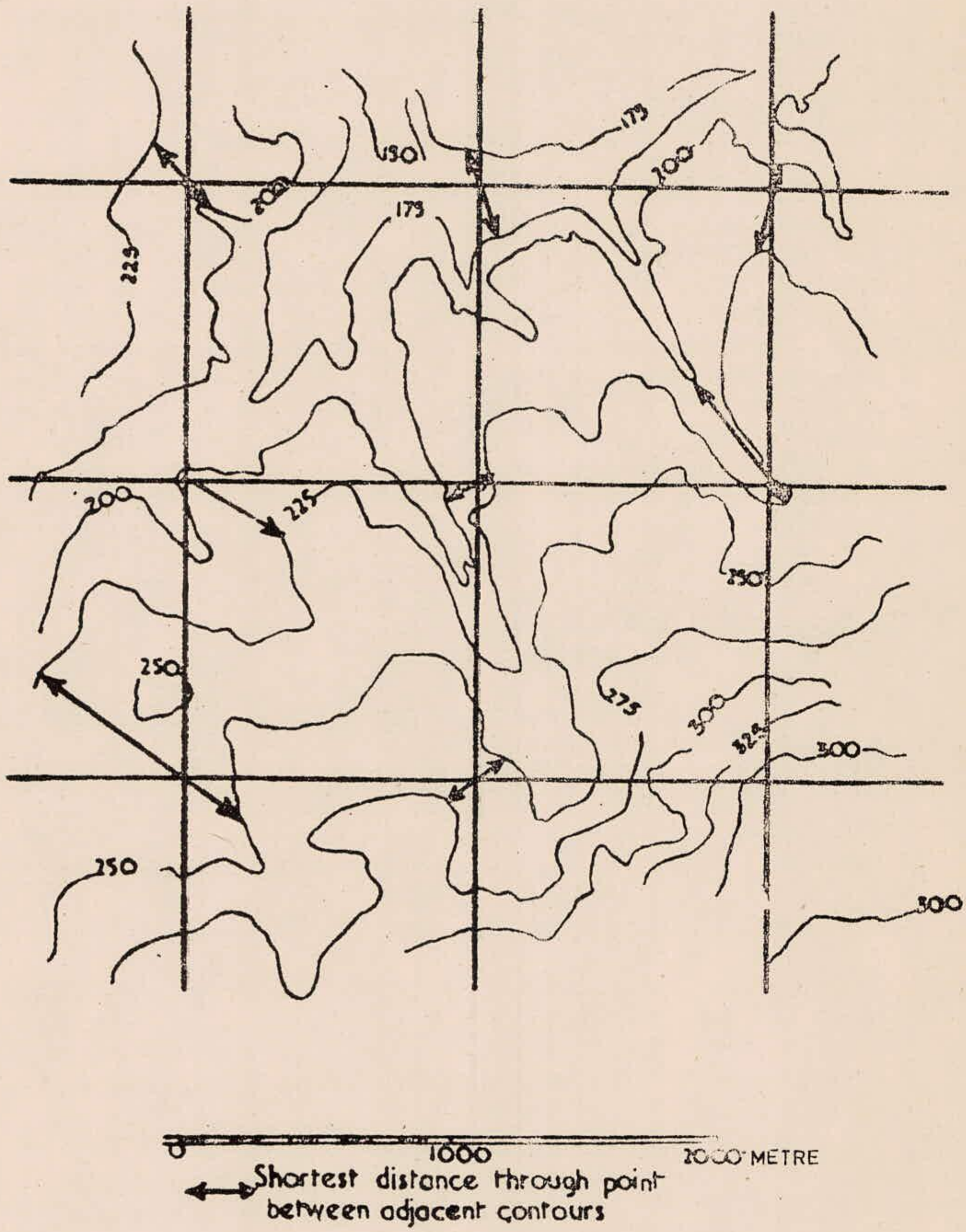


FIG. 4. METHOD OF OBTAINING O.L.S OF CATCHMENT

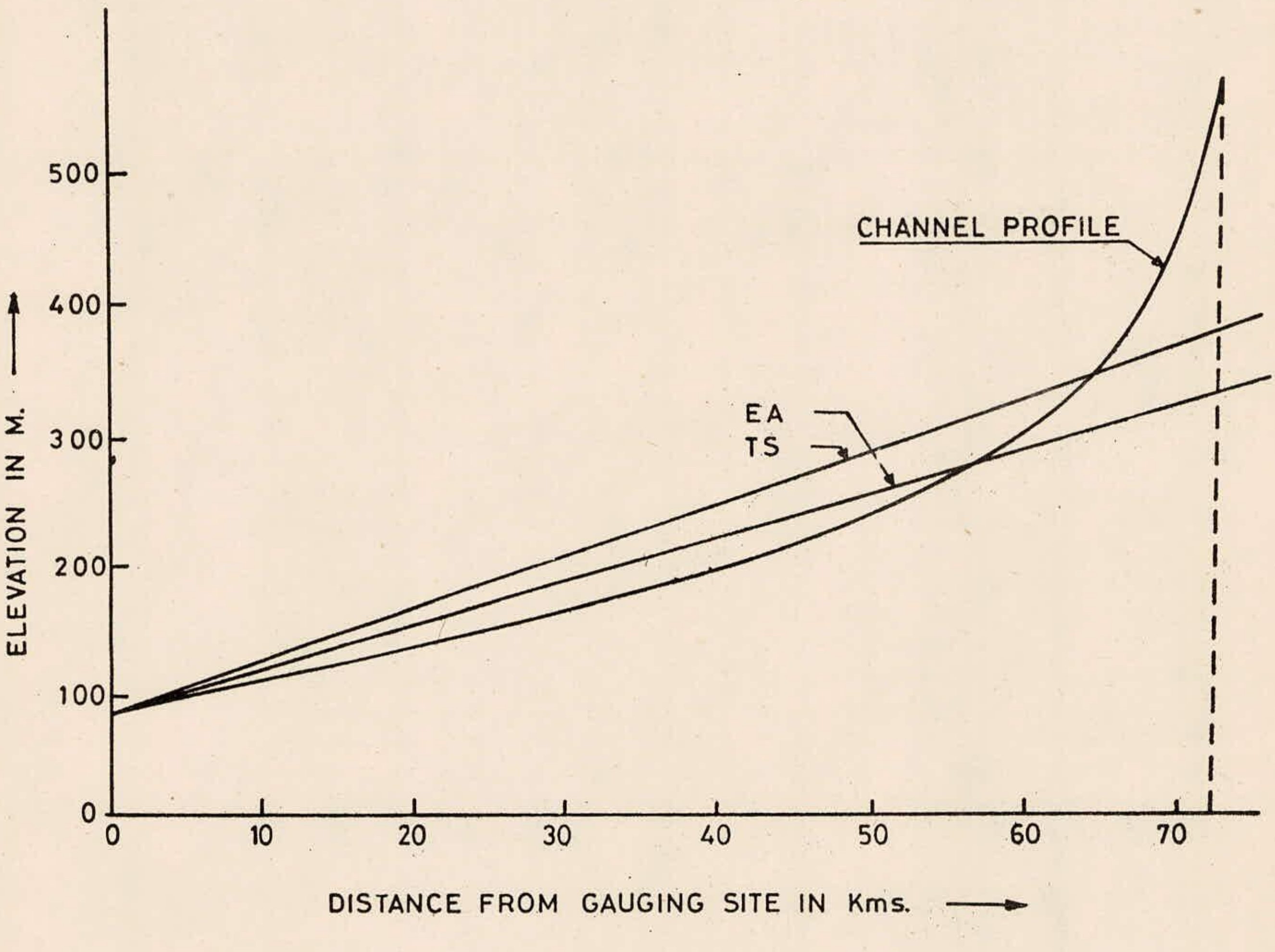


FIG. 5-MAIN CHANNEL SLOPES

profile of the main channel having been plotted from the gauging site to the catchment boundary, a straight line was drawn through the gauging station and the vertical through the highest point of the main channel. Further the slope of the line being so chosen that the area of the triangle was equal to the area contained below the channel profile as shown in fig.5.

2.2 Forest cover and Agricultural Land Uses :

It has been recognised that the type and extent of forests and vegetation cover influences a number of components in the hydrologic cycle. These components are direct interception of a part of precipitation by vegetation, affect of vegetation on evaporation from soil, increase of infiltration by opening up soil channels through development of roots, evapotranspiration resulting in long term depletion of available soil water storage, trapping and shadding of snow pack, binding soil against erosion and so on and so forth. The land use pattern is also important in hydraulic modelling of the basin as the surface roughness, local storage and effective slope etc. vary substantially with forest and vegetation cover.

Forested catchments are predominantly covered by deciduous or coniferous trees. Other small trees, shrubs and grasslands are other common features of the forested basins. Active soil organisms, organic matter present in the top layers and porous channels caused by roots of the trees, account for increased infiltration through the soil of forested catchments. Forest vegetation has deep root zone and heavy tension for binding the root zone water. This increases the amount of detained water in the soil storage. Big trees and shrubs reduce the rate of flow and volume of the overland flow and thus affect the surface runoff hydrograph resulting from storm rainfall. Deforestation increases the total runoff as a result of variation in interception, snowmelt, soil moisture and infiltration etc. The amount of increased surface runoff and peak flow caused by heavy rainstorm of the forested catchments whose vegetation has been removed vary according to the rainstorm and catchment characteristics.

2.3 Earlier Studies

2.3.1 Balganga basin :

Asthana and Anantharaman have carried out Geomorphological study of Balganga Basin which was published in 1987. The Balganga basin falls between 30° 25'40" and 30° 41'4" N Longitude and 78° '45" & 78° '45" Latitude. The total basin area is 472 Sq Km. The basin is of leaf shape, being broad in the middle and comparatively narrow in NE and SW directions.

The study carried out by Asthana and Anantharaman is almost of similar nature as the one presented here. I emphasis on evaluating relief, slope and drainage parameters of the basin.

Relief Analysis :

Physiographically, the Balganga basin consists of diversified fluvial relief features like interlocking spurs, incised meanders, summit saddles. The altitudes of the basin vary from 1000 to 4600 m above m.s.l. which implies a total relative relief of 3600 meters.

The basin has substantial snow cover area, which is the high mountain relief region confined to the north eastern part of the valley and is above 4000 m in altitude. The snow bound area is directly linked with steel gauge glacier.

The moderate mountain relief region of the basin consists of interfluve landscope of Balganga and Dharamganga and it has quadrilateral shape with flat top. Both Balganga and Dharamganga are griddled with entrenched meanders. The interfluve ranges from 1600 m to 3000 m.

The low mountain relief region comprises of broad terraces of valley bottom towards the confluence of Balganga and Dilanganga. The cross profile of Balganga basin near the confluence shows paired terraces supported with stumps and concave convex spurs. This type of morphology reflects open V shaped formation with steep sides. The longitudinal profiles of Balganga valley depicts uniform slope gradually rising from steep slope to extremely steep slope towards the source. The profiles depict that the landscape towards the source of the river forms free faced slopes with concave convex morphology. The longitudinal profiles conspicuously depict for erosional surfaces as depicted by four kink points, showing major recending waterfalls. The cross profiles drawn from the sides of kink points reveal the morphology of river valley becoming narrower and V shaped towards the source.

Slope Analysis :

The slope structure follows the altitude zones of the basin "Extreme steep slope" occures along the free faces of the hills, hillocks and spurs in the high relief regions. These slopes are of the order of 4000 m/km to 6000 m/km.

In the North-West moderate relief region of the basin, the slopes are of the order of 3000-4000 m/km to 200-500 m/km and are termed as "Steep to extremely steep slopes".

Gentle to steep slopes occur in low relief region (2000-3000 m/km to 100-300 m\km). Gentle slopes are observed in the valley bottom.

Drainage Analysis :

The Balganga basin comprises of various drainage patterns in different regions. The main drainage patterns observed in the basin are dondritic, subparallel, barbed, underground and intermittent. It has both perenial and non-perenial streams which fall into first order to sixth order streams.

The drainage density varies from 2 to 7 km length\sq.km of basin area. For obvious reasons maximum drainage density occures in the low relief region (near the outlet) where the valley becomes narrower and bottlened by others. The minimum density of 2 km\Sq km occurs in the high relief region where minimum area of landforms has been consumed by the denudation processes of streams.

Similarly drainage texture varies from as high as 6-8 streams\sq.km. in low relief region to lower values of about 4 streams\sq.km. in the high relief region.

2.3.2 Chenab Basin :

A very rigorous analysis of Chenab catchment has been carried out by Roohani & Gupta (Pub. 1988). the total basin area upto Akhnur site is 22850 sq km. this large catchment has been divided into eight subbasins and these subbasins then analysed on a large scale.

Chenab is a major river of Indus river system originating from southern slopes of the Great Himalayan region. The river rises in two branches namely Chandra river and Bhaga river and after the confluence the main channel is known as Chandrabhaga or Chenab. The river makes many knee band curves and sharp turns to come out of the Himalayas near Akhnur. After Akhnur site the river enters alluvial Indo-Gangetic planes and enters Pakistan to meet the Indus. The study area has therefore been confined to the hilly region upto Akhnur.

The study mainly emphasises on stream order aspects, Relief aspects and Areal aspects of the basin.

Stream Order Studies :

Since the catchment has been analysed on a large scale (1:50,000) the analysis of stream order has been carried out well in detail.

Plots have been presented of stream number v\s stream data on both 1:250,000 as well as 1:50,000 scale. Both the cases show general parralism according to Horton's law. On large scale some curves seem to be steeper than the others showing a very high bifurcation ratio (of the order of 8.4). Similarly following curves are also presented :

a) Steam order v\s mean stream length.

b) Cumulative stream length v\s stream order.

c) Mean drainage area v\s steam order.

d) Mean drainage area v\s mean stream length.

All the above plots show good agreement with Horton's laws given for these type of plots.

Relief Analysis :

Longitudinal profile of the main channel has been drawn co show the channel slope. In the high relief region a very steep slope (=.0843) has been observed which turns to gradual slopes (=.0024) in the lower regions. Composite profile nas also drawn to compute the slopes orderwise. It is observed that lower order streams have steeper slopes. Slope of first order streams being 668.18 m\km with that of seventh order streams being as gentle as 3.84 m\km.

A very high relief ratio (ratio of maximum basin relief to maximum measured length in the basin) is obtained for the whole catchment upto Akhnur. It is computed to be 0.92053 while the average value reported for many catchments has been reported to be 0.005. Similarly the ruggedness number is also very high (=3.89) while for mature catchments it is reported to be 0.4-0.5. This further gives an idea of the rugged nature of terrain.

Besides these, Hydrometric analysis has also been carried out and reported.

Areal & Linear Aspects :

Drainage Density, Length of overland flow and Stream lengths stream frequency are the main parameters studied based on Areal and Linear Aspects of the basin. Drainage density and length of overland flow have been found to be systematically varying in the basin. Drainage density being low in the higher (steep) regions and high in the lower (flat) regions while length of overland flow varies the other way. Stream frequency is high in the low altitude regions and reduces linearly with drainage density in the high altitude zones.

Basin configuration factors such as circularity ratio, Basin-Elongation and Form factor confirm the elongated shape of the basin, with different factors having low values for individual sub-basins as well as for the catchment as a whole.

3.0 STATEMENT OF THE PROBLEM

In view of the discussion so far, it is clear that various geomorphological parameters are important and significant in order to regionalize various hydrological models. The estimation of such parameters gains further importance in case of hilly catchments because direct measurement of rainfall and flow etc. is difficult in such areas.

The basic objective of present report is to study various geomorphological parameters for three models catchments selected in the Western Ghats region. Some of the methods discussed in review section have been applied for the estimation of various parameters. Geomorphological characteristics of the catchments under analysis may be used to test hydrological models for these catchments.

4.0 DESCRIPTION OF STUDY AREA

River Krishna rises in the Sahyadri hills (Western Ghats) near Mahabaleshwar, and passes through Nallamali gorge (near Atrnakur) at the base of Srisailam temples, through the shrines of Nagarjuna Konda and Strides into the wide coastal plains to fan out into tight delta before ending its 1290 km long journey into the Bay of Bengal. It drops most of its silt load in the lower reaches of flow which makes the most enriched soil for rice production. With Tungabhadra and Bhima`as its major tributories Krishna is the third longest river in India but has a rather poor water wealth, because of fairly low rainfalls in the basin.

Location :

The total basin area covered in this study lies between 16^o 45′ to 18^o 00′ latitude and 73^o 30′ to 74^o 45′ longitude. The two subbasins studied seperately area also covered in this area. Study area lies in the state of Maharashtra.

Climate :

The basin is characterised by general dryness except during South-West monsoon which comprises the major part of the rainfall of this area. The cold season in the basin commences from the middle of November and ends in the month of February. December is the coldest month of the year with mean daily maximum temperature of 29.12 ^{o}C and mean daily minimum temperature of17.2 ^{o}C. During the cold season the basin is sometimes affected by cold wave in association with the passage of western disturbances across north India. This makes the temperature to drop down to values as low as 4 to 5 ^{o}C. From March onwards the day temperature increases progressively, till the break of south west monsoon in early June. The nights during this period remain comparatively cool. The period from March to first week of June is the hot season. May is the hottest month with individual maximum temperatures rising to around 40 ^{o}C. From June to October the monsoon remains active and this period is thus the rainy season. The relative humidity during this period goes high, upto 60 to 80% which during dry period remains at 22% on the average. The basin experience loudy to overcast skies with widespread heavy rain in association with the monsoon depression that forms in the Bay of Bengal and moves across the central part of the country.

Soil :

The study area comprises of laterite, and red clay-loams. Rocky terrains are another characteristic of the basin. The laterite and loamy soils are generally non saline, non alkaline and well drained. The permeability of the soil being high, it is necessary to apply organic mamures to the soil in order to increase its water holding capacity and thereby making them suitable for poddy crop.

Data Used

Present study covers upper reaches of Krisnna basin. Total watershed studied is from the origin of Krishna river upto Arjunwad Gauge Site. Apart from considering the watershed as a whole two sub-basins of the same catchment have also been studied. The upper most part of the watershed has been taken into study upto Karad Gauge Site and catchment of Varna river has been taken upto Samdoli Gauge Site. The toposheets used for these basins have been given in the table below :

TABLE : 1 Details of Topo-sheets used for Different Catchments

S.No.	Name of the Catchments	Toposheets used	Scale
1.	Krishna basin upto Arjunwad	47F, G, H, I, K, L	1:250,000
2.	Krishna basin upto Karad	47F, G, J, K	1:250,000
3.	Varna basin upto Samdali	47, G, H, K, L	1:250,000

5.0 GEOMORPHOLOGICAL CHARACTERISTICS OF SELECTED CATCHMENTS

The three catchments selected for this study have been discussed in secton 4. (Fig. 4.1 to 4.3). Various geomorphological parameters established for these catchments have been presented in the following text.

5.1 Parameters Based on Linear Aspects :

As discussed in section 2. Edge of paper strip and thread length methods have been used for various length measurements. The values of different parameters have been shown in Table 2. below :

TABLE 2: GEPMORPHOLOGICAL PARAMETERS BASED ON LINEAR ASPECTS OF THE BASIN

Parameter	Verna Basin upto Samdoli	Krishna Basin upto Karad	Krishna Basin upto Arjunwad
1. Length of main channel (L)	135.75 Km	139.25 Km	260.00 km
2. Lc	80.50 Km	78.25 Km	125.25 Km
3. Total length of channels	45.25 Km	4781.25 Km	11006.50 Km
4. Wandering Ratio	1.3852	1.4973	1.6024

5.2 Parameters Based on Areal Aspects :

Areas of the all the three catchments have been measured based on strip sub division method discussed in Section 2. Different parameters based on areal aspects are given in table 3.

TABLE 3: GEOMORPHOLOGICAL PARAMETERS BASED ON AREAL ASPECTS OF THE BASIN :

Parameters	Verna Basin upto Samdoli	Krishna Basin upto Karad	Krishna Basin upto Arjunwad
1. Drainage Area	2055.56 Km	5521.69 Km	12201.94 Km
2. Drainage Density	0.8977 km\ sq km area	0.8659 km\ sq km area	0.9020 km\ sq km area
3. Constant of Channel maintenance			
4. Circularity Ratio	0.3290	0.6664	0.6117
5. Elongation Ratio	0.5219	0.9014	0.7680
6. Watershed Shape Factor	2.6540	1.6610	2.0863
7. Unity Shape Factor	2.1619	1.2515	1.4688

5.3 Parameters Based on Relief Aspects :

Some of the parameters based on the relief aspects of the watersheds have been computed and presented in Table 4. Detailed study of elevational behaviour of the catchments is very difficult to carry out on the small scale maps used.

TABLE 4: : GEOMORPHOLOGICAL PARAMETERS BASED ON RELIEF ASPECTS OF THE BASINS

Parameter	Verna Basin upto Samdoli	Krishna Basin upto Karad	Krishna Basin upto Arjunwad
1. Basin Relief	428 m	485 m	585 m
2. Relief Ratio	4.367×10^{-3}	5.215×10^{-3}	3.60×10^{-3}
3. Relative Relief	1.527×10^{-3}	1.503×10^{-3}	1.168×10^{-3}
4. Ruggedness Number	0.384	0.420	0.528
5. Average overland slope	3.14%	3.97%	3.75%

6.0 CONCLUSIONS AND RECOMMENDATION :

6.1 Conclusion

This report describes various geomorphological parameters and methodology for evolving these parameters. Based on this the geomorphological parameters of three basins namely Krishna basin upto Karad, Varna basin upto Samdoli and Krishna basin upto Arjunwad; have been established. In brief the following conclusions may be made :

Since the watersheds studied include one large basin (Krishna upto Arjunwad) and two of its sub-basins. One can infer that drainage density is low in the higher reaches. In the present case the variation is small because of total study area being small. The constant of channel maintenance, for this reason, is high at higher altitudes.

The shape parameters such as circularity ratio, elongation ratio, and watershed and unity shape factor indicate that Karad watershed has most evenly distributed area while Samdoli watershed is an elongated one.

Relief studies clearly reveal that basin is steep in higher altitude regions. Relief Ratio in the present case varies from 5.215×10^{-3} to 3.6×10^{-3}, and overland slope varies from 3.14% to 3.97%. Such small variation confirms the topographical homogeneity of the basin as a whole.

6.2 Recommendations for Further Studies

For further studies more basins can be selected in the same catchment so as to have a broader picture of Krishna basin. The parameters so obtained can be used for model regionalization as discussed earlier. Further studies should essentially be carried out on larger scales (preferably 1:50,000) so as to take smaller order streams into account.