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GEOMORPHOLOGICAL STUDIES OF BAGMATI BASIN OF KOSI RIVER SYSTEM

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PREFACE

The advancement and adequate knowledge of geomorphology of the region is of importance. For synthesizing and understanding the hydrological behaviour of a basin, different geomorphological parameters can be employed. Geomorphological studies are very much essential in the catchment where sufficient data are not available to carry out hydrological studies. The geomorphological parameters help in regionalisation of hydrological models dealing with runoff and sediment estimations for such catchments and establishing regional formulae for flood estimation.

In this report various important geomorphological parameters including linear, areal and relief aspects have been discussed in detail. An attempt has also been made to compute various geomorphological parameters of the inter-country Bagmati river basin.

This report entitled "Geomorphological Studies of Bagmati Basin of Kosi River System" is a part of work programme of Ganga Plains Regional Centre of the institute. The study has been carried out by Shri A.K.Lohani, Scientist'B', Shri Manohar Arora, Senior Research Assistant, Shri Anup Kumar, Research Assistant under the guidance of Dr. K.K.S.Bhatia, Scientist 'F' & Head, Ganga Plains Regional Centre, Patna. Services of Shri A.K.Sivadas, Tech. Gr. III are also acknowledge herewith.

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ABSTRACT

Geomorphology is generally considered as the science of land reforms. In the field of flood control measure and engineering projects, the adequate knowledge of geomorphology of the region is of importance, since the geomorphological characteristics of river basins in mountainous areas affect run-off process and formation flood. In spite of the fact that the hydrologic balance of a region is dynamic and everchanging, different approaches have been made to obtain relationships involving morphological, geological and climatic characteristics.

For the purpose of hydrological studies of a basin the geomorphological characteristics of basins are very much essential for understanding the hydrological behaviour. The most important factors influencing the runoff and sediment production rate are the climate, soil conditions, vegetation, land use, geology and topography of a watershed. Vegetation and geology are difficult to be quantified. Therefore, a logical alternative, which has already been used successfully, has been utilised in order to model the hydrologic responses such as mean annual runoff, average sediment production rate and probabilistic annual runoff of a watershed by using mean annual rainfall and basin characteristics in the form of geomorphic parameters.

The geomorphology study of Bagmati basin has been suggested by Bihar State Irrigation Department. The river Bagmati

is a inter-country river which has more than fifty percent catchment area in Nepal. This restricts the availability of hydrological data of complete basin. The river Bagmati passes through two distinctly different terrains. From the origin to a little above the Indo-Nepal borders, the catchment is hilly and forested while further down to its confluence with the Kosi, it is almost plain. As the river Bagmati has been shifting its course constantly in the past within the measuring zone, it become necessary to have a clear idea of geomorphological characteristics of the basin.

In this report a comprehensive review of various geomorphological properties covering the linear, areal and relief aspects of the basin is presented. Methodology for the estimation of some of the important geomorphological parameters is also described. Further some of the major and widely used geomorphological parameters of the Bagmati basin upto Hayaghat have been evaluated. The review of various hydrological studies reveals that the different geomorphological parameter derived for Bagmati basin can be utilised for modelling of hydrologic response.

1.0 INTRODUCTION

For comprehensive water resources planning, flood flow forecasting, design of hydraulic structures etc. it is very much important to know the climatic and physical characteristics of the basin. The primary physical characteristics of the basin which play a vital role in augmentation of various process are its area, length, shape, elevation, slope, orientation, soil type, drainage system, water storage potential, vegetal cover etc. Also now a days geomorphological techniques have added new dimension to application of geomorphology to the hydrologic simulations particularly to the effective rainfall direct runoff relationship.

Geomorphology is the science of landforms or more precisely it is a science which deals with the basin composition with respect to the topographical and geometric configuration of the basin. Geomorphological studies have application in the field of flood forecasting, flood control measures, energy resources and engineering projects. The geomorphological studies are helpful in regionalising the hydrologic models. Since most of the basins are either ungauged or sufficient data is not available for them, the study on geomorphological characteristics of such basins becomes much more important. The linking of geomorphological parameters with the hydrological characteristics of the basin provides a simple way to understand the hydrologic behaviour of different basins. Various geomorphological parameters required for hydrological studies are linear aspects, areal aspects, and relief aspects of the basin. In this study some important geomorphological parameters have been evaluated for Bagmati basin, typical in nature. These geomorphic parameters can be readily evaluated from the topographic maps of the watershed.

Bagmati is a river originating at Shivpuri range of hills in Nepal. The upper catchment of Bagmati river is hilly and forested while the lower one, to its confluence with the Kosi, is almost plain. It has been observed that the river Bagmati has been shifting its course constantly in the past within the measuring zone. Therefore, it is necessary to have a clear understanding of geomorphological characteristics of the Bagmati basin.

In this report various geomorphological characteristics representing the linear, areal and relief aspects are discussed in detail with a full description of various methods available for computation of such parameters. The study may be useful for any hydrological analysis for the basin.

2.0 REVIEW OF LITERATURE

Hydrological investigations are fundamental to any watershed management programme. The problem of controlling run-off and soil loss from the watersheds has been a challenging problem for the watershed managers and soil conservationists. The best way to tackle the problem is to have watershed approach in the entire catchment by dividing and demarcating it into well defined watersheds and to draw up watershed management plan for each watershed properly. In spite of the fact that the hydrologic balance of a region is dynamic and ever-changing, different approaches have been made to obtain relationships involving morphological, geological and climatic characteristics. This chapter briefly deals with the review of the research work carried out in India and abroad in relation to the quantitative geomorphology and an prediction of run-off and sediment yield.

2.1 Quantitative Geomorphology

Until 1945, the geomorphologists operated almost entirely on a descriptive basis and were primarily concerned with the history of evolution of land forms as geological features. Horton (1945) laid down the foundation of quantitative geomorphology. With this impetus, and under growing realisation that the classical descriptive analysis had very limited scope in practical engineering problems, a few geomorphologists began to attempt quantification of land-form description of the drainage basins. Important revisions to these techniques and concepts were made by Strahler (1957,1958) in which he defined two general classes of descriptive numbers, they are :

(i) Linear scale measurements whereby geometrically analogous units of topography can be compared to the size and,

(ii) dimensionless numbers, usually angles or ratio of length measures whereby the shapes of analogous units can be compared.

Linear scale measurements include length of stream channels of given orders, drainage density, constant of channel maintenance, basin perimeter, and relief. Surface and cross sectional area of basins are length products. If two drainage basins are geometrically similar, all corresponding length dimensions will be in a fixed ratio. Dimensionless properties include stream order numbers, stream length ratio and bifurcation ratios, junction angles, maximum valley side slopes, mean slopes of the the watershed surfaces, channel gradients, relief ratios and hypsometric curve properties and integral. It is postulated that the two drainage basins if geometrically similar even though different in size, will have correspondingly identifiable dimensionless number. Numerous addition to this field were made by Maxwell (1955), Schumn (1956), Melton (1959) and Morisawa (1957,1962).

2.1.1 Drainage network

Various factors defining the drainage pattern of a watershed are given below.

The first step in drainage-basin analysis is designation of stream orders. Stream ordering provides a basis by which drainage network characteristics are related to each other as well as to hydrologic and erosion process. Horton (1932) first introduced the concept of stream ordering which was later modified by Strahler (1957). The Horton and Strahler ordering procedures begin in the same way. According to Strahler, all the first unbranched streams at the beginning of stream flow are designated order 1. Where two first order streams join a channel segment of order 2 is formed; where two of order 2 join a segment of order 3 is formed; and so forth. The trunk stream through which all discharge of water and sediment pass is therefore the stream segment of highest order. For Horton ordering, some streams are reclassified. At each point where two streams of the same order join, the stream that enters the junction more nearly parallel to the segment immediately downstream is given the order of the segment; if both enter at about the same angle, the longer stream is given the order of the downstream segment; finally, in the words of Horton (1945) "Exceptions may occur where geological controls have affected the stream courses".

The order of a drainage basin is that of its highest order stream. Shreve (1957) proposed a method of ordering called segment ordering in which each outer link or first order segment is designated magnitude and each subsequent link designated as a magnitude equal to the sum of all the first order segments which are tributary to it.

Certain objections to the Strahler and Horton ordering methods have been rinsed by Scheidegger (1965) and others. These are :

(1) Both basin order and the order of individual streams depends on the scale of map used.

(2) The stream order in a drainage basin changes when two streams of equal order join, but the physical properties changes at any kind of junction.

(3) The streams combining rule is not associative. These objections are surely well founded and various other ordering schemes have been proposed to avoid them. These alternative methods have their own inherent difficulties, however, and most geomorphologists and hydrologist have continued to use the Strahler method.

In general the usefulness of the stream order system depends on the premise that, if a sufficiently large sample is analysed, order number is directly proportional to the size of the contributing watersheds to channel dimension, and to the stream discharge (Chow, 1964). Fig 2.1. illustrates different methods of stream ordering.

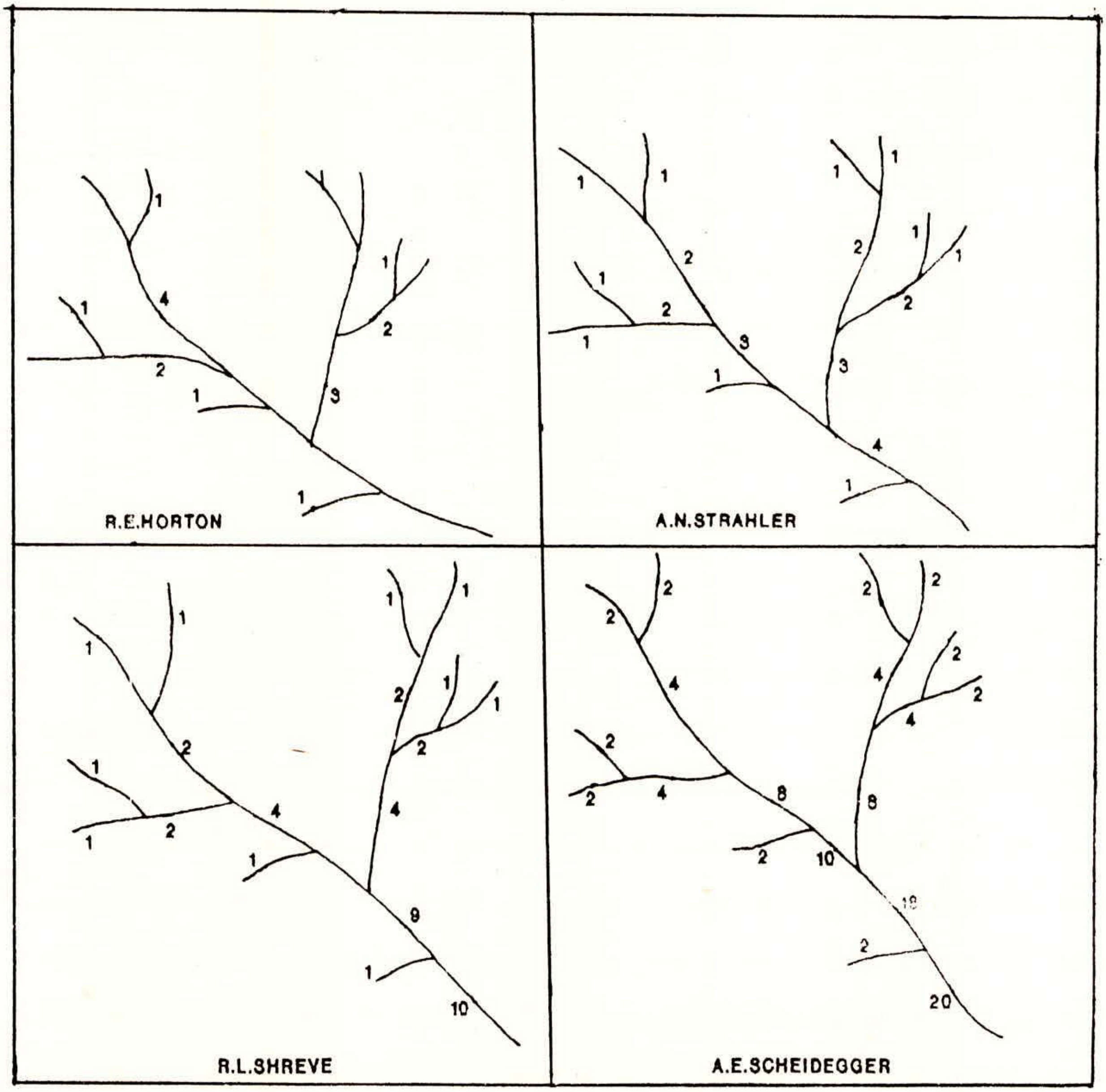


FIG. 2.1. STREAM AND SEGMENT ORDERING METHODS

Stream azimuth is defined as the number of degrees of arc in a horizontal angle measured clockwise from the direction of geographic north. The inflection angle (ϵ) of a contour line is the angle which a contour line makes with itself across a stream channel. Usually, the size of the inflection angle decreases as the stream order increases. The stream axial (ϕ) is the angle formed between two stream channels. Horton found the valley slope (θ), axial angle (ϕ) and channel gradient (μ) to be related by,

$$\text{Cos } \phi = \frac{\tan \mu}{\tan \theta} \qquad \text{.....(2.1)}$$

Bifurcation ratio which is the ratio of total number of segments of the given order to the total number of segments of the higher order, would not precisely be the same from one order to the next because of chance variations in the geometry of watersheds but would always tend to be a constant throughout. This observation is the basis of Horton's law of stream numbers, which states that the number of stream segments of each order form an inverse geometric sequence with order number. The law has received verification by accumulated data from many localities (Strahler, 1952; Schumm, 1956). Most drainage networks showed a linear relationship with small deviation from a straight line, When logarithm of number of streams was plotted against order. (Maxwell 1955).

One might think that the bifurcation ratio would constitute a useful dimensionless number for expressing the form of the drainage system. Actually the number is highly stable and shows a small range of variation from region to region, except where powerful geologic control dominates.

Tyagi et al (1970) and Varshney et al (1970) reportedly plotted stream orders in the reverse orders against number of streams per hundred hectares and found the following relationship.

$$\text{Log } N = K\ OR - C \qquad \ldots\ldots(2.2)$$

Where,

N = Number of streams per 100 hectares

K = Slope of curve with respect to N-axis

OR = Stream orders in reverse order

C = Negative value of log N where OR is 0.

Channel length is a dimensional property which can be used to reveal the scale of units comprising the drainage network. Miller (1953) studied the frequency distribution of segment lengths of a given order by treating each channel segment as a statistical variate and observed that the stream lengths are strongly skewed right. This skewness was corrected by Schumm (1956) using of logarithm of length. Horton (1945) postulated that the stream length ratio which is the ratio of mean length of segments of an order to mean length of segments of the next lower order tends to be constant throughout the successive orders of a watershed. If this law of stream length is valid, a plot of logarithm of stream length (ordinate) as a function of orders (abscissa) should yield a set of points lying essentially along a straight line. Confirmation of this law seems amply demonstrated by data from many watersheds (Schumm, 1957; Leopold et al, 1956; Broscoe, 1959; Morisawa, 1962).

Area of a given drainage basin, a property of squire of length, is a prime determinant of total runoff or sediment yield. Miller (1953) and Schumm (1956) studied frequency distribution of areas. They found that strong right skewness in the distributions could be largely corrected by using logarithms of area. Morisawa (1962) plotted both logarithm of mean stream length and logarithm of cumulative length against logarithm of basin area for each order of representative basins of the Appalachian Plateau Province and obtained highly linear relationships. Similar results for the basins of ephemeral streams in Central New Mexico were obtained by Leopold and Miller (1956). Leopold and Miller (1956) and Hack (1957) also studied the relationships between stream discharge and basin area and developed empirical equations of the form,

$$Q = j\ A^m \qquad .....(2.3)$$

Where,

Q = discharge such as mean annual flood in cumecs.

A = watershed area in suitable units

j & m are constants derived by fitting regression lines to the available data.

Drainage density is an important indicator of the linear scale of land-form elements in a drainage basin. It is defined by Horton (1945) as the ratio of cumulative channel segment lengths of a drainage basin to the basin area. It is a very important parameter and expected to have a closed positive relationship with sediment yield. Strahler (1956) outlined a rational theory of the relation of drainage density to erosion intensity. Stream frequency is another drainage parameter defined as the ratio between the number of streams in a watershed and its area. It is observed by Horton (1945) that the intensity of erosion in a watershed increase with the increase in stream frequency. Melton (1957) postulated that it was possible to have two watersheds with same drainage density but different stream frequency.

Linsley et al (1975) and Varshney (1977) studied different stream patterns and presented a classification of different drainage network patterns. The effect of patterns on the hydrologic and sediment behaviour was studied and discussed by the researchers.

2.1.2 Basin shape

The shape of a normal drainage basin has been described by Horton (1941) as a pear-shaped ovoid which may conceivably affect stream-discharge characteristics. Long narrow basins with high bifurcation ratios would be expected to have attenuated flood discharge periods, whereas round basins of low bifurcation ratio would be expected to have sharply peaked flood discharges. Horton (1932) made a quantitative expression of drainage-basin outline through a form factor which is the dimensionless ratio of basin area to the square of basin length. In its inverted form, this ratio was used in unit hydrograph applications by the U.S. Army Corps of Engineers.

A dimensionless circulatory ratio, defined as the ratio of basin area to the area of a circle having the same perimeter as the basin has been used by Miller (1953). He found that circularity ratio remained remarkably uniform in the range of 0.6 to 0.7 for the first and second order basins in homogeneous shales and dolomites, indicating the tendency of small basins in homogeneous geologic materials to preserve geometrical similarity. By contrast, first and second order basins situated on the flanks of moderately dipping quartzite strata of Clinch Mountain, Virginia, were strongly elongated and in general had circularity ratios between 0.4 and 0.5.

Schumm (1956) used an elongation ratio, defined as the ratio of diameter of a circle of the same area as the basin to the maximum basin length. This ratio runs between 0.6 and 1.0 over a wide variety of climatic and geologic types. Values near to 1.0 are typical of regions of very low relief, whereas values in the range of 0.6 to 0.8 are generally associated with strong relief and steep ground slopes. The effectiveness of basin outline measures as factors in the hydrology of a watershed was tested by Morisawa (1958). For 25 watersheds of the Appalachian Plateau, regressions of the runoff-rainfall ratio on five measures of form showed a significant regression coefficient at 5 % level of significance only with elongation ratio and circularity ratio, but the standard error or estimate was relatively high in both cases. It can be concluded from this that controls other than drainage-basin outline form dominate the hydrologic characteristics of a basin.

2.1.3 Topographic factors

The gradients or inclinations of the ground surface elements of a watershed are indicative of the potential energy of a drainage basin by virtue of its relief (elevation difference with reference to a given datum). The difference in elevation between the most remote point in the divide line and the discharge point of a watershed is the total watershed relief. Where relief is high erosion intensity is correspondingly large. Schumm (1956) measured basin relief along the longest dimension of the basin parallel to the principal drainage line. While Maxwell (1960) measured relief along the basin diameter, an axial line found by use of rigorously defined criteria.

A dimensionless relief ratio (Schumm, 1956) results when basin relief is divided by the horizontal distance on which it is measured. The relief ratio thus measures the overall steepness of a drainage basin and is an indicator of the intensity of erosion. Melton (1957) used relative relief expressed as the ratio of maximum basin relief to the length of perimeter. Use of perimeter as a horizontal length dimension does away with difficulties of locating a suitable axial line in the basin. Maxwell (1960) used basin diameter as the horizontal distance for calculation of relief ratio.

Possibility of a close correlation between relief ratio and hydrologic characteristics of a basin is suggested by Schumm (1954), who found that sediment loss per unit area is closely correlated with relief ratio. Strahler (1958) used the term ruggedness number which is a product of total relief and drainage density. Extremely high values of the ruggedness number occur when both variables are large, that is, when slopes are not only steep but long as well. Observed values of this number range from as low as 0.06 in subdued relief of the Louisiana coastal plain to over 1.0 in coastal ranges of california. He also computed geometry number and found them to fail in the range of 0.4 to 1.0 for six regions.

2.1.4 Hypsometric analysis

Hypsometric analysis or the relation of horizontal cross-sectional drainage area to elevation, was developed in its modern dimensionless form by Langbein and other (1971) and applied to large watersheds. Application to small drainage basins has since been applied to determine how the mass is distributed within a basin from base to top (Strahler, 1952; Miller, 1953; Schumm, 1956). Similar methods have been described by Golding and Low (1950). The shape of hypsometric curve varies in early geologic stages of development of the drainage basin, but once a steady state is attained (mature stage) tends to vary little thereafter, despite lowering relief. Isolated bodies of resistant rocks may form prominent hills (Monadnocks) rising above a generally subdued surface; the result is a distorted hypsometric curve (Monadnock phase). Hypsometric curves plotted for hundreds of small basins in a wide variety of regions an conditions show generally stable curve properties where the rock masses are homogeneous and the erosion stage is unconventionally described as mature. Small but distinct differences in the form of curve appear to exist from region to region.

Rastogi and Sharma (1976) presented a quantitative analysis of drainage basin characteristics for developing various geomorphic relations in northern part of Garhwal district of Uttar Pradesh. The analyses have shown the validity of Horton's law of stream numbers, law of stream length and law of stream slopes for the streams under study. The S-shape percentage hypsometric curve reveals that the drainage basin is in the equilibrium stage.

2.2 Hydrological Studies Using Geomorphological Characteristics

Geomorphological studies have been frequently used in hydrological studies such as water availability studies, runoff estimation and design flood estimation to make the required estimates for ungauged catchments. Some of the hydrological studies, wherein geomorphological characteristics are utilized are reviewed in the following section.

2.2.1 Regional unit hydrograph studies

For estimation of design flood most popular technique available is unit hydrograph technique. It is easier to evaluate unit hydrograph for gauged catchments but as most of the catchments are ungauged or having limited data, the geomorphological characteristics play vital role in determining unit hydrograph for such catchments. Most commonly used physical characteristics of the catchment include length of the main stream, length of a stream from a point on the stream nearest to the centroid of the catchment to the outlet, catchment area and average slope of the main stream etc.

In different parts of world various studies have been carried out on regional unit hydrograph for estimation of designed flood. Some of the prominent studies were carried out by Benard (1935), McCarthy (1938), Taylor and Schwarz (1952), SCS (1955,1971), Clark (1945), Nash (1960), Gray (1961), Nevjevich (1977). In India also work has been carried out by CWC and the regional unit hydrograph relationships have been derived.

It is seen that the derivation of physical and geomorphological characteristics of the catchment is necessary in order to develop the better regional unit hydrograph relationships.

2.2.2 Flood frequency analysis

With the available historical flood records, the flood frequency analysis approach can be used for estimating the design flood of the desired frequency. The flood frequency analysis depends on the length of record available but generally annual flood series available at site of interest is short. Therefore, in such cases the regional flood frequency approach where the site data together with regional information is the basic input, may be preferred. For ungauged sites the regional frequency analysis may be carried out using only the regional information in the form of regional frequency curve together with an estimate of mean annual flood obtained from the appropriate relationship established between the mean annual flood and geomorphological characteristics for hydrologically homogeneous regions. The geomorphological characteristics which influence the annual flood are catchment area, streamflow, land slope, stream density, stream pattern, elevation etc. alongwith channel storage, artificial and natural storage in lakes and ponds, orographic conditions, underlying geology, soil cover and cultivation etc.

2.2.3 Geomorphological instantaneous unit hydrograph (GIUH)

Various researchers have attempted development of geomorphological instantaneous unit hydrograph with geomorphological parameters. Rodriguez Iturbe & Valdes (1979) synthesized the hydrologic response of a catchment to surface runoff. The IUH is expressed as a function of Horton's numbers R_a, R_b, and R_L, and internal scale parameter and a mean velocity of streamflow. The IUH is time varying due to variation in the mean streamflow velocity. The unit is carried over by hydrologic response that occur in nature. A dimensionless ratio which is a characteristic variable constant for a basin is derived for each basin. It is dependent on the storm characteristics and is linked with geomorphology of the watershed and to its hydrologic response structure.

Gupta et al (1980) has related approximate linear response of a basin to its geomorphological characteristics and a representative linear response of channels of a given order.

Instantaneous unit hydrograph were derived from the geomorphologic characteristics by Valdes et al (1979). The study was carried out on several basins. The geomorphologic IUH was compared with the instantaneous unit hydrograph's derived from the discharge hydrograph produced by a physically based rainfall-runoff model of some basins.

Parameterization of the channel linear response exponential distribution assumed by Rodriguez, Iturbe & Valdes (1979) was studied by Rodriguez et al (1982) and Wang et al (1981). The studies indicated that the IUH of each channel may be derived from the differential equations of motion.

M. Krishan & Bras (1983) has derived the IUH as a function of basin geomorphological and physiographic characteristics. The response of the individual channels is derived by solving the continuity and momentum equations for the boundary conditions defined by the IUH. Both the effects of upstream and lateral inflow to the channels is taken into account in the derivation of the basin's IUH.

Beven & Wood (1983) examined the dynamic nature of runoff contributing areas and their relationship to the geomorphological structure of catchments. It has been shown that both runoff and flood frequency predictions are very much sensitive to assumption about the nature of the contributing area.

2.2.4 Development of empirical formula

Due to non availability of rainfall data and discharge data, the regional empirical formula have been used for flood flow computation. The formulas were developed not only in India but different parts of the world. The result show a need for better knowledge of actual hydrological process and watershed characteristics at basin scale.

The approach involving the establishment of the relationship between model parameters and physically measurable watershed characteristics is well recognised for the estimation of runoff for gauged watersheds and many empirical relationships have been developed (Kinnison and Colby, 1945; Chow, 1962; Thomas and Benson, 1970; Duru, 1976; Chang and Boyer, A.C. Miller, 1978; Chong and Boyer, 1977; Aron and A.C. Miller, 1978; Dingman 1978; Crippen, 1982; Aron, Kibler and Taghati, 1981; Mosley, 1981; Adezuwon, Jege and Ogunkava, 1983; Mimikou, 1983; Harlin, 1984).

The peak discharge has been most popular which have been frequently used in hydrograph synthesis (Snyder, 1938; Carter, 1961; Rao, Assengo and Harp, 1966; Bell, 1967; Larson and Machmeier, 1968; Bell and Omkar, 1969; Cordery, 1971).

The relationships developed should be generally used in the regions for which they were developed.

3.0 DESCRIPTION OF THE STUDY AREA

3.1 Bagmati River System

The river Bagmati rises in the Shivpuri range of hills in Nepal at latitude 27°47'N and longitude 85°17'E. The source is situated at about 16 km north east of Kathmandu in the Siwalik foot hill at an elevation of 1500 m (Fig 3.1). To the north of its source the Himalayan range of hills lies which is at higher elevation draining into its neighbouring rivers Kosi and Gandak. The river is perennial like other Himalayan rivers. It flows through the land of Nepal and Bihar and out falls into the river Ganga through the river Kosi. This river system is located between the Burhi Gandak on the west and the Adhwara Group of river including Kamala Balan on the east.

The river flows south east in beginning and enters the Kathmandu valley which is a saucer shaped area bounded by hills. At about 21 km from the source it is joined by the combined stream of the Hanumanta and Manchara river. Thereafter, it makes two hairpin bends near Patan and Kathmandu respectively and approaches the Mahabharat range of hills which it cuts through flowing first due south and then south east. Two tributaries one from the west and the other from the east draining the northern portion of the Mahabharat range of hills join the river in the reach.

The river then enters relatively open tract passing through the Chouria range of hills. In this reach it is joined by

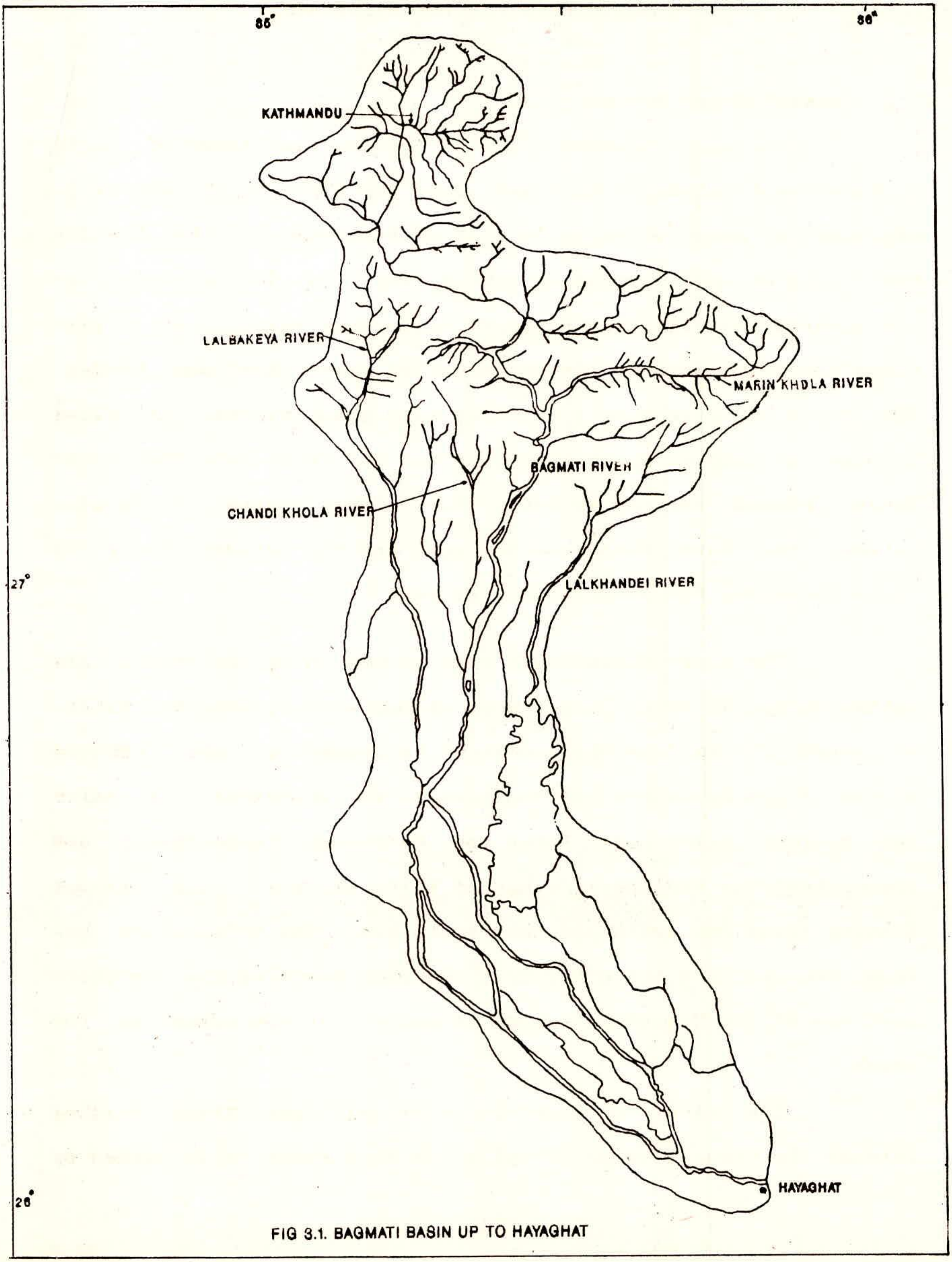


FIG 3.1. BAGMATI BASIN UP TO HAYAGHAT

the Chouria Khola on the right bank and the Marine Khola on the left. Then it enters the Tarai near village Mangalpur and Karmaiya lying on either side of the river at its crossing with Mahendra Raj Marg. Below Karmaiya the river flows in two channels. The eastern channel which is also perennial has rejoined the parent channel near village Bairiya. Then flowing south west the river is joined by the Jhaj, Chandi and Paurani rivulets from right side. Long time ago before meeting the Jhaj rivulet, the river Manusmara used to join the Bagmati. But it has now changed its course and meets the Bagmati river in Bihar much lower down stream.

In India, the Bagmati river flows through East Champaran, Sitamarhi, Muzafferpur, Darbhanga, Madhubani and Samastipur districts of Bihar. It enters Bihar near the village Shorwatia, P.S. Majorganj in the district Sitamarhi about 2.5 Km north of Dheng railway station. The river flows due south after crossing the Indo-Nepal border. At about 20 Km from the border near village Khoriapaker the river is joined by the Lalbakeya, which is one of its major tributaries. In this reach the river used to spill on both its banks during high flood inundating area in Shivhar Block. It has therefore been embanked on both the banks together with that of the Lalbakeya upto Indo-Nepal border.

The reach from Khoripakar to Kalanjarghat is the most important reach of Bagmati as far as shifting of its course is concerned. Down the confluence point with Lalbakeya the Bagmati changed its course in the floods of 1969 and aluvialised into Kola Nadi on its left. The deviation from the old course starts 1 Km downstream of village Adauri and joins the Kola Nadi near village Ratanpur Pakari. Then it flows along the entire course of the Kola upto its outfall into Manusmara a little upstream of Dumra.

The river Bagmati has only two main tributaries which are described below:

i. Lalbakeya

It rises at an elevation of 152.5 m in the Chouria range of hills. Its total length is 109 Kms, out of which 80 Km lies in Nepal. It joins the Bagmati on the right bank at Khoripakarghat 22 Km south of the Indo-Nepal border. Its right bank is fairly high land and there is also a marginal embankment along its entire length in Indian territory, The lef. bank used to spill frequently during floods upto Bargania.

ii. The Lakhandei

The Lakhandei river originates from the Marinkhola in the foothills of the Himalayas in Nepal at an elevation of 610 m. It enters the Indian territory near village Dularpur in Sitamarhi district after traversing about 112 Km in Nepal. It outfalls into river Bagmati on its left bank near Katra upstream of Kalanjarghat. During high floods it spills over both its banks but the spilling is not very serious and extends only about a mile in width. Sonam, Gaibipur, Nasi, Jadua and Baha are its tributaries, Jamura, Gobrakia dhar, Sikao and Mugraha used to offtake from Lakhandei in the past, but now these channels have independent sources and outfall into the Adhwara river system.

3.2 Bagmati Catchment

The catchment of the Bagmati river system is located on the north of the Ganga river and lies between the Burhi Gandak river system and Adhwara group of rivers including Kamala Balan. The total catchment area of the river system including Adhwara group of river is about 13,400 sq. Km. out of which about 7080 sq. Km. lies in Nepal and balance 6,320 sq. Km. in Bihar. The district wise break up of the catchment area is

		Catchment area in Sq. Km
i.	East Champaran	675
ii.	Sitamarhi	2381
iii.	Muzaffarpur	820
iv.	Samastipur	519
v.	Darbhanga	631
vi.	Madhubani	500
vii.	Begusarai	400
viii.	Khagaria	394
		6320 Sq.Km.

Out of this total catchment the area drained by its two major tributaries i.e. Lalbakeya and the Lakhandei is 896 sq.km and 1061 sq.km respectively.

3.3 Topography

The river passes through two distinctly different terrains. The upper portion of the Bagmati basin is hilly and forested while the lower portion, when the river enters in India, is almost plain. A break up of the bed slope of main river course up to Hayaghat in its various reaches is given in table 3.1.

The part of the river in India is almost flat and belongs to the Gangetic plains. It has vast stretch of upland broken by numerous streams and shallow depressions called Chaurs or change of the river course where water accumulates for most part of the year. A number of spill channels take off from the Bagmati to rejoin it later or to join the adjoining streams.

Table 3.1 Bed slope of Bagmati river up to Hayaghat

S.No.	Name of reach	Length of reach in km.	Bed slope	
			in m/km	m/m
1.	Source to Nayagoan	8.50	89.86	1/11
2.	Nayagaon to Chmpagaon	30.50	61.86	1/16
3.	Champagaon to Begna	23.00	36.29	1/27.6
4.	Begna to Dun Dungia	29.00	12.71	1/78.7
5.	Dung Dungia to Karungi	10.00	3.07	1/326
6.	Karungi to Karmaiya	30.50	2.39	1/418.5
7.	Karungi to Baria	22.50	1.44	1/694
8.	Baria to Dheng	45.00	0.53	1/1887
9.	Dheng Rly-bridge to Muzaffarpur Sitamarhi road	52.00	0.178	1/5618
10.	Muzaffarpur-Sitamarhi road to Muzaffarpur Darbhanga road	32.00	0.146	1/6849
11.	Muzaffarpur-Darbhanga road to Hayaghat	58.00	0.112	1/8929

Source: Report on Adequacy of Waterways under Road and Rail Bridges in Bagmati River System

4.0 MEASUREMENT AND COMPUTATION OF GEOMORPHOLOGICAL PROPERTIES

The methodology of measurement of various watershed parameters for quantification of watershed characteristics and then evaluation of geomorphic parameters for Bagmati basin are presented in the following sections.

4.1 Measurement and Counting of the Properties

4.1.1 Stream ordering

The first step in any drainage basin analysis is to carry out the stream order analysis. In the present study Strahler's system of stream ordering is used for the selected watershed (Fig 4.1). According to the Strahler's system or ordering, a stream which has no branches is designated as a 1st order stream. Where two first-order streams join, a channel segment of 2nd order is formed; where two 2nd order streams join, a channel segment of 3rd order is formed, and so forth. The trunk stream through which all discharge of water and sediment passes is designated as the stream segment of highest order.

It is found that the Bagmati river upto Hayaghat is a fifth order stream. The number of streams of order one, two, three, four and five has been counted and their values are 182, 39, 8, 2 and 1 respectively.

4.1.2 Channel length

The following are five methods which may be used for

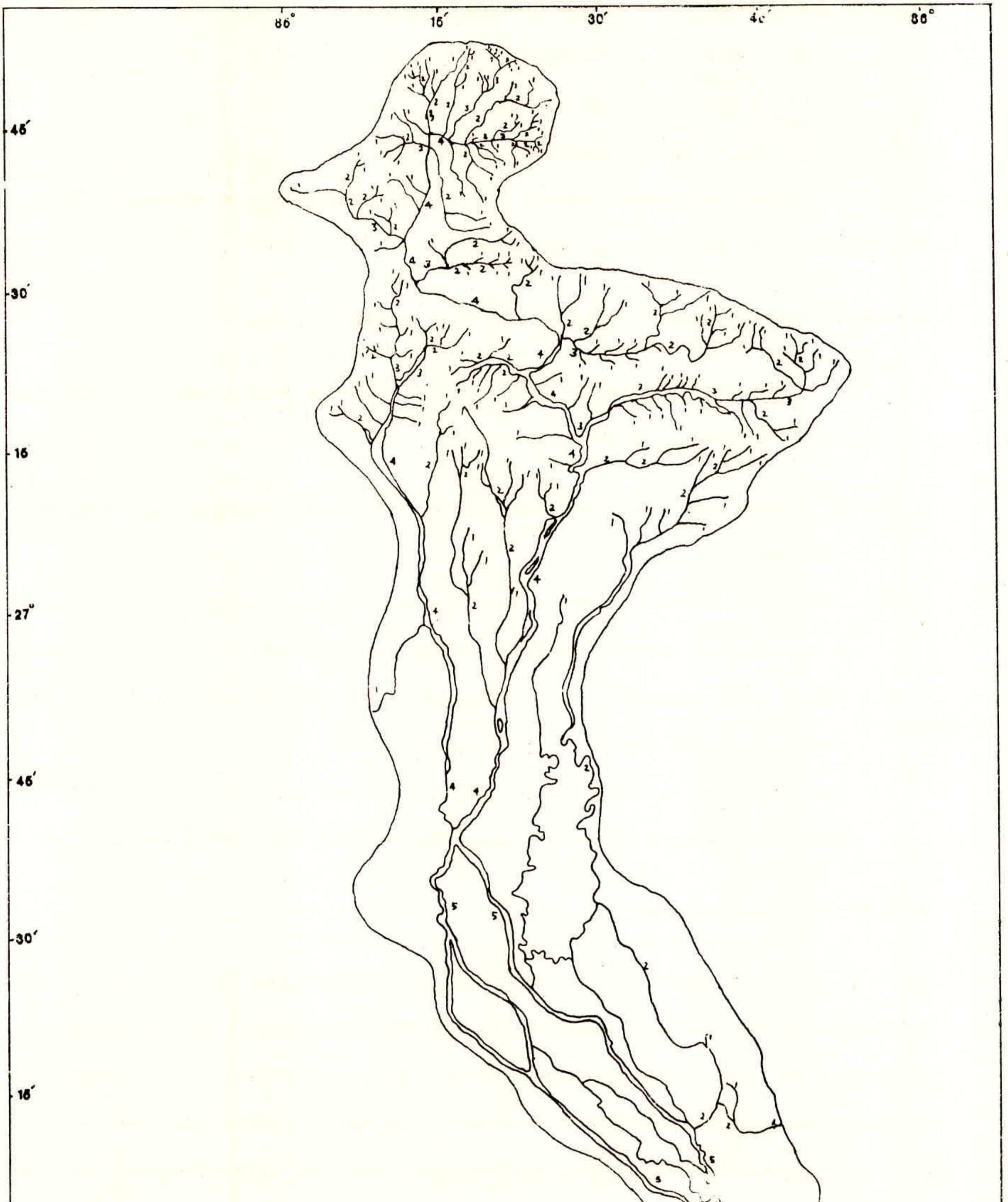


FIG 4.1. STRAHLER'S STREAM ORDERING OF BAGMATI RIVER SYSTEM

length measurement from topographic maps :

(i) Pair of dividers
(ii) Thread length
(iii) Edge of paper strip
(iv) Opisometer
(v) Analog to digital converter

For the measurement of stream lengths in Bagmati basin thread length method was adopted.

4.1.3 Determination of C.G. of the basin

The centroid of the Bagmati basin has been determined using the following steps :

(i) A cardboard piece was cuted in the shape of Bagmati catchment.

(ii) The C.G. was located on the catchment shape card board piece using point balance standard procedure.

(iii) The card board piece marked with centre of gravity was superimposed over the catchment plan.

(iv) By pressing a sharp edge pin over the centre of gravity of the card board piece it was marked on the catchment.

4.1.4 Drainage area

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 may be 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.

The basin area of the Bagmati river has been measured by dot grid method.

4.2 Evaluation of Geomorphic Parameters

Various geomorphic parameters can be broadly classified into three categories.

1. Linear aspects of channel
2. Areal aspects of the basin
3. Relief aspects of the catchment and channel network

4.2.1 Linear aspects of channel

Various parameters grouped under this category 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. (L_c).
- (c) Stream lengths (L_u)
- (d) Length of over land flow ($\overline{L_o}$)
- (e) Law of stream length

(f) Stream junction angle
(g) Basin perimeter (P)
(h) Stream length ratio (R_L)
(i) Bifurcation ratio (R_b)
(j) Sinuosity ratio (S_r)
(k) Wandering ratio (R_w)
(l) Fineness ratio
(m) Division ratio (R_d)
(n) Watershed eccentricity (r)

The methodology to quantify these parameters for Bagmati basin is given below:

4.2.1.1 Length of the main channel ($\bar{L}$)

This is the length along the longest water course from the outflow point of designated basin to the upper limit to the catchment boundary. The length of the main channel of Bagmati basin up to Hayaghat is 346.60 Km.

4.2.1.2 Length of channel between the outlet and a point nearer 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 value of L_c for the Bagmati basin is 130.30 Km.

4.2.1.3 Stream lengths (L_u)

Total channel length is the total sum 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. The stream lengths of one, two, three, four and five order has been obtained 907.50, 490.00, 221.75, 238.50 and 113.00 Km.

4.2.1.4 Length of overland flow ($\bar{L}_o$)

The length of overland flow can be defined as the length of flow of water over the ground before it becomes concentrated in definite stream channels. Horton (1945) defined length of overland flow as the length of flow path, projected to the horizontal, of non channel flow from a point on the drainage divide to a point on the adjacent stream channel. He noted that the length of overland flow is one of the most important independent variables affecting both the hydrologic and physiographic development of drainage basins. Horton recommended using half the reciprocal of drainage density D for the average length of overland flow $\bar{L}_o$ for the entire watershed,

$$\bar{L}_o = \frac{1}{2D} \qquad \text{.....(4.1)}$$

Where,

D = drainage density

4.2.1.5 Law of stream length

Horton's law of stream lengths, which states that the mean lengths of stream segments of successive orders of a given watershed tend to approximate a direct geometric series in which the first term is the meanlength of segments of the first order:

$$\overline{L}_u = \overline{L}_1 R_L^{u-1} \qquad .....(4.2)$$

Broscoe (1959) obtained a geometric series using cumulative mean length L_u^c instead of mean length:

$$L_u^c = L_1^c R_L^{u-1} \qquad .....(4.3)$$

4.2.1.6 Stream-junction angles

Horton (1945) was the first to discuss the stream-entrance angle. He showed that this angle was related to the slopes of the joining stream segments as

$$\text{Cos } \theta = \frac{\tan \theta_1}{\tan \theta_2} \qquad .....(4.4)$$

Where

θ = junction angle

θ_1 = slope of the higher order channel, and

θ_2 = slope of the lower order stream or tributary

Schumm (1954a, 1954b, 1956) has shown that the angle of junction decreases with age, as do the gradients.

4.2.1.7 Basin perimeter (P)

It is measured along the divides between basins and may be used as an indicator of basin size and shape. The perimeter of Bagmati basin is 597 Km.

4.2.1.8 Stream length ratio (R_L)

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

$$R_L = \frac{\bar{L}_u}{\bar{L}_{u-1}} \qquad .....(4.5)$$

The value of R_L ranges normally between 1.5 to 3.5 in natural networks. The value of stream length ratio for Bagmati basin has been determined by taking the anti-logarithm of slope of regression plot of logarithm of average stream length versus stream order (Fig 4.2).

4.2.1.9 Bifurcation ratio (R_b)

Bifurcation ratio (R_b) for a given channel network can be made by determining the slope of the fitted regression of logarithm of numbers (ordinate) on order (abscissa). The regression coefficient b is identical with the logarithm of R_b. This is a dimensionless quantity and shows only a small variation from one region to another. The value of bifurcation ratio varies normally between 3 and 5 and is used as an index of hydrograph shape for watersheds similar in other respects.

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

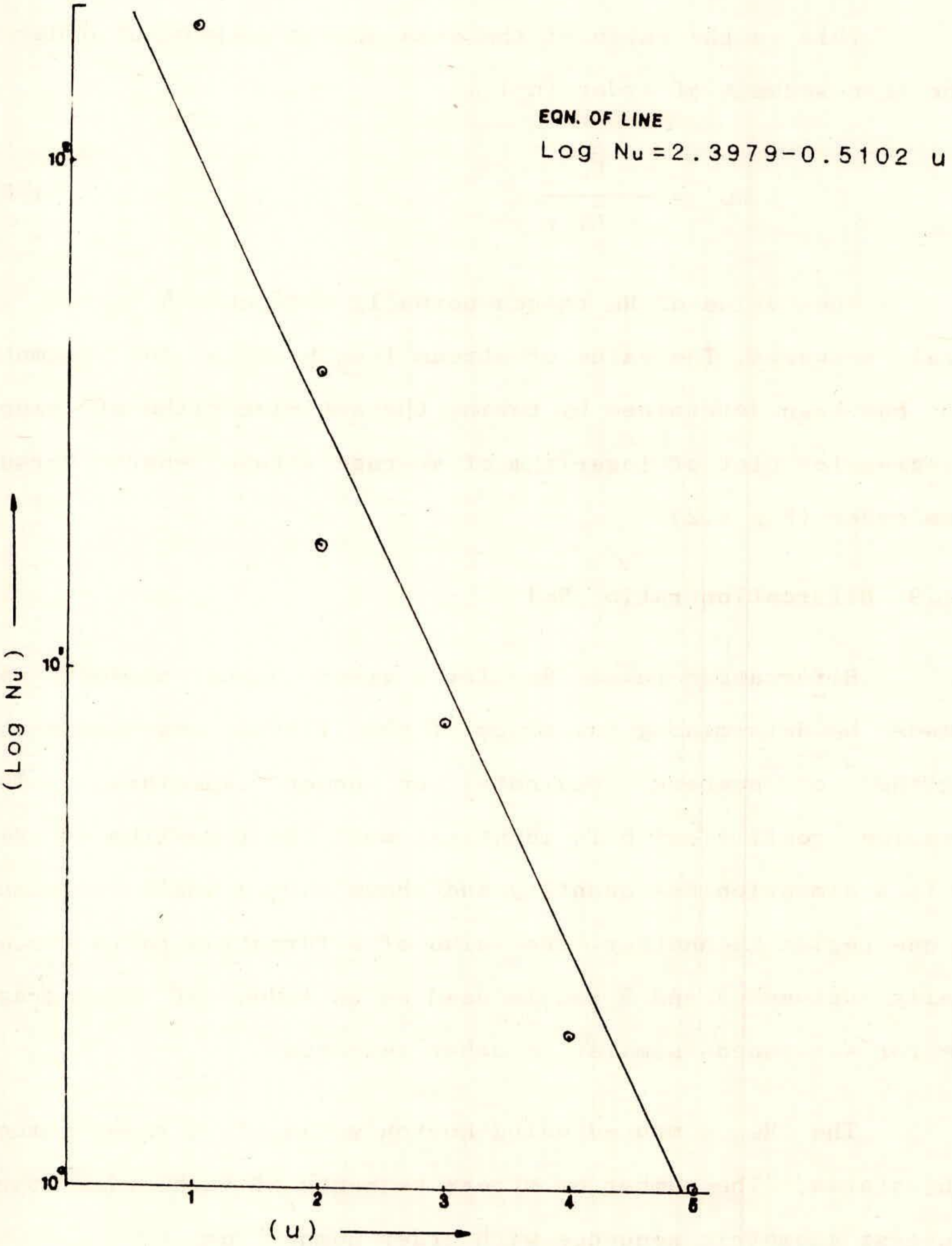


FIG 4.2. VARIATION OF NO. OF STREAMS WITH THEIR ORDER NO.

$$N_w = R_b^{k-w} \qquad \text{.....(4.6)}$$

Where,

k = order of trunk segment

N_w = number of segments of order w

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

or $$\log N_w = a - b_w \qquad \text{.....(4.7)}$$

Where,

$a = k \log R_b$ and

$b = \log R_b$

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

The bifurcation ratio of Bagmati basin has been determined by taking anti-logarithm of slope of the regression plot of logarithm of stream number versus stream order (Fig 4.3).

4.2.1.10 Sinuosity ratio (S_r)

The sinuosity ratio of a stream is defined as the ratio of the length along the center line of the stream to the length along the valley.

4.2.1.11 Wandering ratio (R_w)

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 (Fig 4.4). The value of Wandering ratio for Bagmati basin has been obtained as 1.44.

Wandering ratio represents the deviations of the

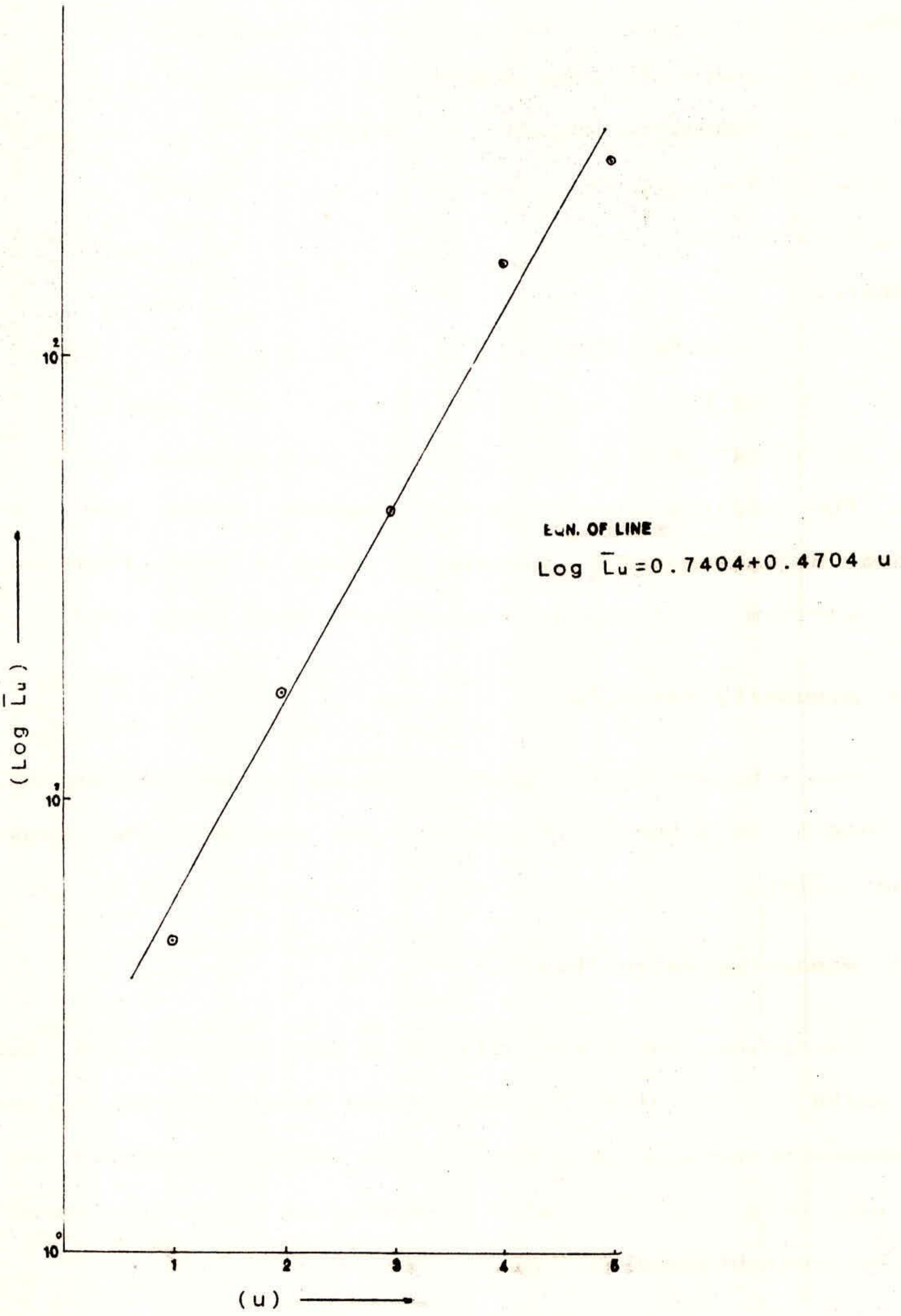


FIG 4.3. VARIATION OF AVERAGE STREAM LENGTHS WITH THEIR ORDER NO.

mainstream path from the straight line length from moutr 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.

4.2.1.12 Fineness ratio

The ratio of channel length to the length of the basin perimeter is fineness ratio, which is a measure of topographic fineness. The value of Fineness ratio has been computed for Bagmati basin and it's value is 0.58.

4.2.1.13 Division ratio (R_d)

Scheidegger (1966a, 1966b,) showed that R_b is constant in a Horton network only if the streams of order u received tributaries of order u-1 only. Thus, if the lost segments are removed and the ratio of N_{u-1} and N_u is computed according to the Horton, then this ratio is the division ratio. Evidently, R_d is analogous to R_b, except for exclusion of lost segments.

The concept of R_d may be very useful in estimating parameters of rainfall runoff models.

4.2.1.14 Watershed eccentricity (τ)

The watershed eccentricity is given by the expression :

$$\tau = \frac{\sqrt{|(L_c^2 - W_L^2)|}}{W_L} \qquad .....(4.8)$$

Where

τ = watershed eccentricity, a dimensionless factor

L_c = length from the watershed mouth to the centre of mass of the watershed in the same unit, and

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

The measurement for L_c and W_L are shown diagramatically into fig 4.5 it is also to be noted that if $L_c = W$, $\tau = 0$, and as either L_c or W get large, τ increase. Thus the lower the value of τ, the greater the compactness of the watershed concentrated near the mouth and the higher the flood peak. A very high value of watershed eccentricity has been obtained for Bagmati basin.

4.2.2 Areal aspects of the basin

The parameters which are governed by the area of the drainage basin are classed as areal aspects of the basin. The parameters grouped under this category are given below :

(a) Drainage area (A)
(b) Drainage density (D)
(c) Constant of channel maintenance (C)
(d) Channel segment frequency (F)
(e) Circularity ratio (R_c)
(f) Elongation ratio (R_e)
(g) Watershed shape factor (R_s)
(h) Unit shape factor (R_u)
(i) Form factor (R_f)

In the following text the above parameters have been discussed in detail and various methods proposed for their evaluation have been explained briefly. Some of the important parameters has been computed for Bagmati basin.

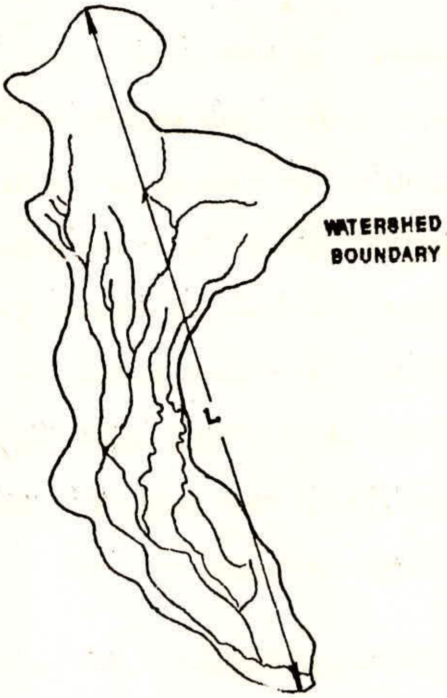


FIG 4.4. VALLEY/BASIN LENGTH FOR WANDERING RATIO

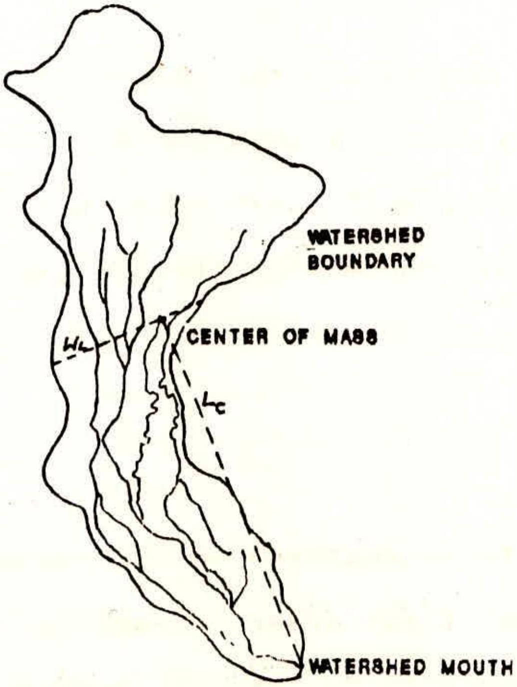


FIG 4.5. WATERSHED ECCENTRICITY

4.2.2.1 Drainage area (A)

This is defined as all land and water within the confines of a drainage divide 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 unit chosen for drainage area is sq. km.

The drainage area of Bagmati basin has been computed by dot grid method. Total drainage area of the basin up to Hayaghat is 8445.81 Km.

4.2.2.2 Drainage density (D)

Drainage density is the length of all the drainage line or stream segments per unit area which is computed by dividing the sum of stream length of each order (L_u) with the area of the watersheds. The unit chosen for the drainage density is km/sq. km.

$$D = \frac{L_u}{A} \qquad \ldots\ldots(4.9)$$

It should 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 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. It's value for Bagmati basin has been obtained as 0.233.

4.2.2.3 Constant of channel maintenance (C)

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 and for Bagmati basin it is 4.2861.

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

4.2.2.4 Channel segment frequency (F)

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 characterisation of a stream, than did drainage pattern. His composition was completely described using the two textural measures of drainage density and stream frequency. Melton (1956) analysed in detail the relationship between drainage density and stream frequency and gave following relation

$$F = 0.694\ D^2 \qquad .....(4.10)$$

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

$$F = \frac{N}{A} \qquad .....(4.11)$$

Where,

N = total number of segments of all order in the catchment area

A = drainage area of basin

The value of channel segment frequency for Bagmati basin is 0.0275.

4.2.2.5 Circularity ratio (R_c)

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.

$$R_c = \frac{4\pi A}{P^2} = 12.566\ \frac{A}{P^2} \qquad .....(4.12)$$

The value of this ratio approaches unity as the shape of a drainage basin approaches circle. For Bagmati basin the value of R_c is 0.2978.

4.2.2.6 Elongation ratio (R_e)

Elongation ratio is defined as the ratio between the diameter of a circle with the same area as the watershed and the maximum length of the watershed. This parameter is evaluated for all the watersheds to assess whether the shape of the basin approaches a circle.

$$R_e = \frac{\sqrt{(4A/\pi)}}{L_b} \qquad .....(4.13)$$

The value of elongation ratio approaches unity as the shape of drainage basin approaches a circle. The value of elongation ratio for bagmati basin is 0.5122.

4.2.2.7 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.

$$R_s = \frac{L_c}{D_c} \qquad .....(4.14)$$

For Bagmati basin the value of R_s is 1.0559.

4.2.2.8 Unity shape factor (R_u)

Unity shape factor is defined as the ratio of the basin length (L_b) to the square root of the basin area.

$$R_u = \frac{L_b}{\sqrt{A_w}} \qquad .....(4.15)$$

The value of R_u for Bagmati basin is 2.2030.

4.2.2.9 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

$$R_f = \frac{A}{L^2} \qquad .....(4.16)$$

For Bagmati basin the value of form factor is 0.0996.

4.2.3 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. Relief features are useful in determining the potential energy or erosion potential of watershed. Contour lines on a toposheet are made use of while determining the relief aspects. Various parameters involving the relief aspects to clearly understand the kind of relationship that exists between the sediment yield and the relief features, are as follows:

(a) Watershed relief (H)
(b) Relief ratio (R_r)
(c) Relative relief (R_R)
(d) Ruggedness number (R_N)
(e) Average slope of the watershed (S_a)
(f) Main stream channel slope (S_c)
(g) Taylor & Schwartz slope (T_s)
(h) Nash's measure of slope
(i) Nash's measure of overland slope
(j) Coefficient 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 travels time in the hydrologic system is in general inversely related to the slope. Mountainous catchments are characterised by the steep slopes and hence these parameters become still more important for mountainous catchments. Relief features are useful in determining erosion potential of a watershed. The method of evaluation of these parameters, therefore, have been discussed in the following text. The values of various relief parameters have also been computed for Bagmati basin.

4.2.3.1 Watershed relief (H)

Watershed relief is the difference in elevation between the remotest point in the divide line and the discharge point of the watershed. The elevation difference between the remotest point and the discharge point is obtained from the available contour maps. The total relief of a basin is a measure of the potential energy available to move the sediment downslope.

The Bagmati river originates from Shivpuri range of hills in Nepal and then enters into Bihar and flows in almost flat land. The value of H for Bagmati basin is very high and equivalent to 1453 m.

4.2.3.2 Relief ratio (R_r)

Relief ratio is defined as the total watershed relief(H) divided by the maximum length of the watershed.

$$R_r = \frac{H}{L_b} \qquad .....(4.17)$$

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.

The value of relief ratio for Bagmati basin is 0.0072.

4.2.3.3 Relative relief (R_R)

Relative relief is defined as the ratio of the maximum watershed relief to the perimeter of the watershed. It is computed from the following equation

$$R_R = \frac{H}{P} \qquad .....(4.18)$$

Relative relief is an indicator of the general steepness of a basin form 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 weighted with the appropriate catchment area.

For bagmati basin the value of relative relief is 0.0024.

4.2.3.4 Ruggedness number (R_N)

Ruggedness number is (a dimensionless term advanced by Strahler) defined as the drainage density times the maximum basin relief. Any change in either of the factors will obviously have a telling effect on the slope, steepness and ultimately on the erosion. It is computed from the following equation

$$R_N = \frac{H.D}{1000} \qquad .....(4.19)$$

Where,

R_N = Ruggedness number,

H = watershed relief in m,

D = drainage density in Km^{-1}

The value of R_N for Bagmati basin is obtained as 0.3389.

4.2.3.5 Average slope of the watersheds (S_a)

Erodibility of a watershed can be studied and can be compared from its average slope. More the percentage of slope more is its erosion, if all other things are kept constant. The average slope of the watershed is determined by the following formula:

$$S_a = \frac{H\ L_{ca}}{10\ A} \qquad \ldots\ldots(4.20)$$

Where,

S_a = average slope of watershed in percent,

H = maximum watershed relief in m,

L_{ca} = average length of the contour in km.

The average length of the contour is given by

$$L_{ca} = \frac{\Sigma\ L_c}{n} \qquad \ldots\ldots(4.21)$$

Where,

L_c = length of each contour in km,

n = number of clearly identifiable contour.

A = drainage area of the watershed in sq. km.

The average overland slope (S_a) of Bagmati basin is 4.988 %.

4.2.3.6 Main stream channel slope (S_c)

Main stream channel sloe is the slope of hypotenuse of triangle having the same base length and area under the actual logitudinal profile of the main channel from gauge to divide.

$$S_c = \frac{H_c}{1000 \times L} \times 100 = \frac{H_c}{10\ L} \qquad \ldots\ldots(4.22)$$

Where,

S_c = stream channel slope in percent,

H_c = equivalent height in m,

$$= \frac{2 \text{ X Area under the curve}}{\text{length of the main stream}}$$

L = length of the main streams in Km.

4.2.3.7 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 (l) of approximately uniform slope (S), whose time of flow are considered to be proportional to $(l/\sqrt{s_i})$. The average slope of the channel is therefore computed by

$$L/\sqrt{T_s} = \sum_{n=1}^{n} (l_i/\sqrt{s_i}) \qquad \ldots\ldots(4.23)$$

where,

T_s = slope of a uniform channel of the same length and time of flow as actual length,

n = total number of segments of the main channel,

l_i = length of the ith segment,

s_i = slope of the ith segments

4.2.3.8 Nash's measure of slope

Nash (1960) defined another measure of slope where the 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. 4.6.

4.2.3.9 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 mesh 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 arithmetic mean is calculated and taken as the overland slope. When the intersection occur at a point between two contours 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 4.7).

4.2.3.10 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

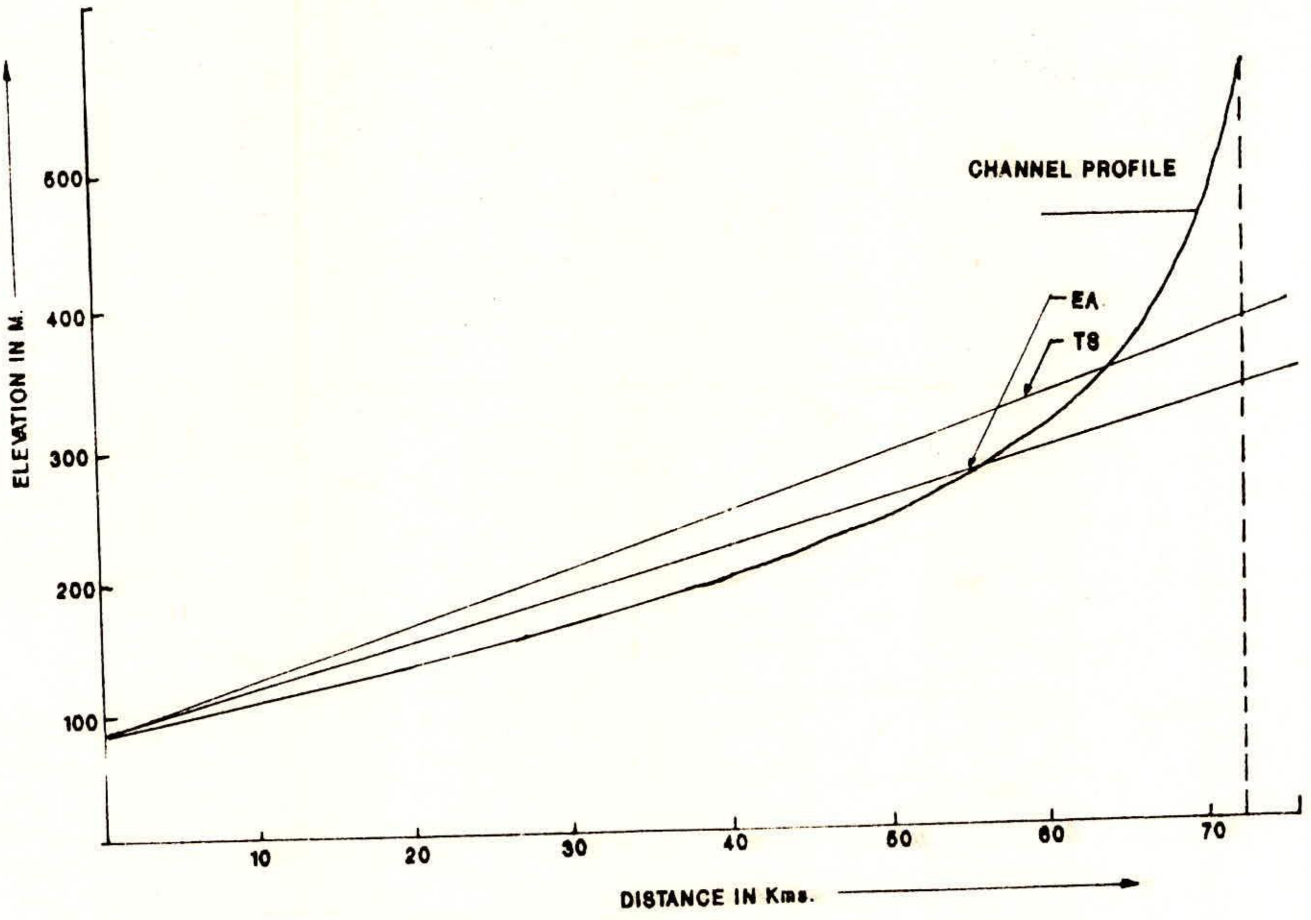
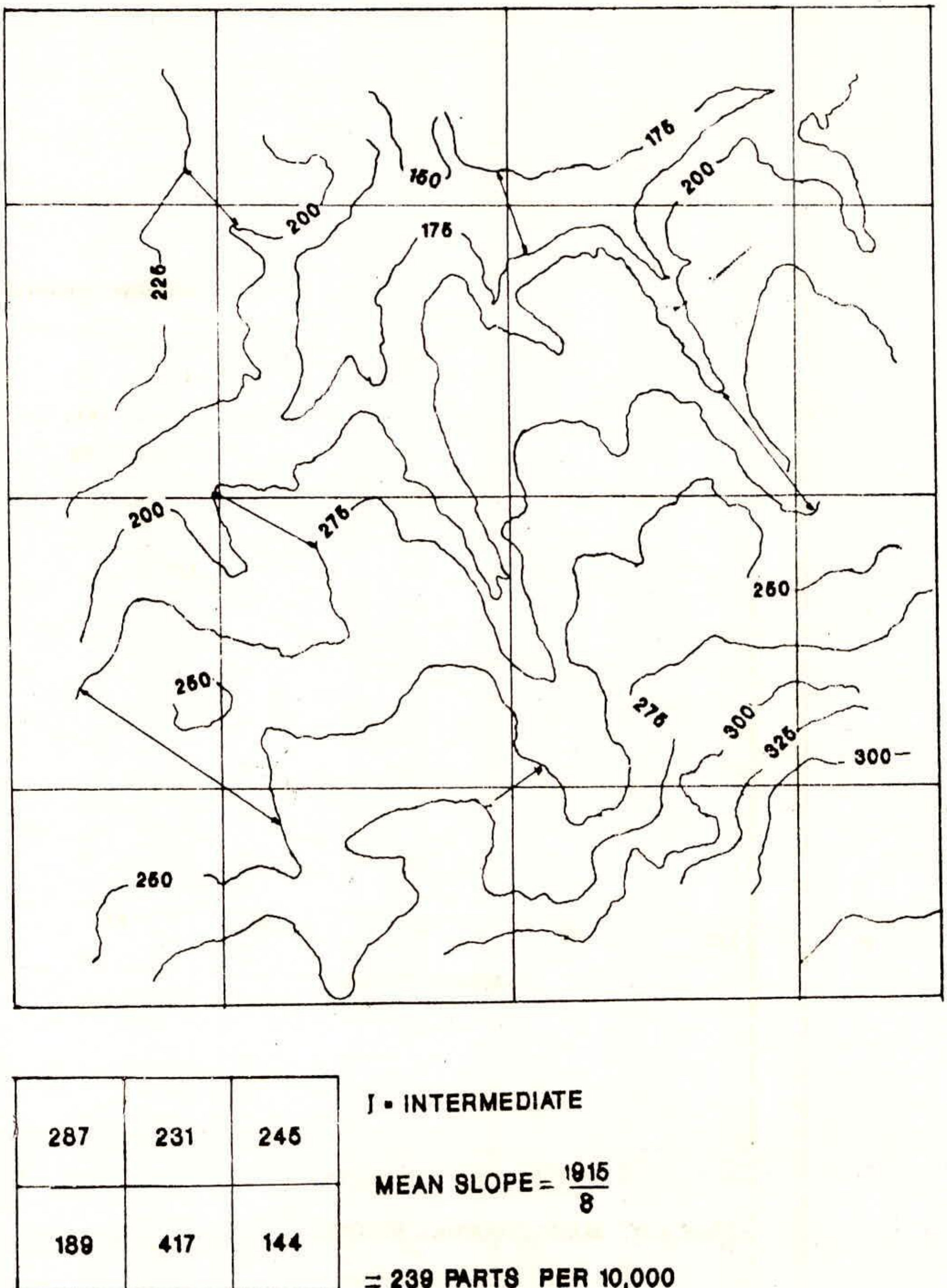


FIG 4.6 . MAIN CHANNEL SLOPE



287	231	245
189	417	144
93	309	I

I = INTERMEDIATE

MEAN SLOPE $= \frac{1915}{8}$

$\simeq$ 239 PARTS PER 10,000

⟷ shortest distance through grid-points between adjacent contours

FIG 4.7. METHOD OF OBTAINING OVER LAND SLOPE OF BASIN 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.

5.0 RESULTS AND DISCUSSION

The Bagmati basin up to Hayaghat falls in Survey of India toposheets no. 72 E,F,G,I,J,K. The stream ordering of the basin has been done using Strahler's ordering scheme. It is observed that the Bagmati river up to Hayaghat is a fifth order stream.

The number of different order of streams were counted and total length of each order stream was measured and presented in table 5.1. It is observed from the table that the mean lengths which have been computed as the ratio of the total length of specific order of streams and the total number of streams of that order, are 4.98, 12.56, 27.72, 119.25 and 113.00 km for order one, two, three, four, and five respectively. The number of streams of different order are 182, 39, 8, 2 and 1 respectively. The length of the main channel of the basin is 346.60 Km and the length of the channel between the outlet and a point near to center of gravity (C.G) is 130.30 Km. This characteristic has been frequently used in hydrological modelling using regional unit hydrograph based approaches together with other measures. Total length of streams of all order, basin perimeter, watershed eccentricity etc. have also been computed for the Bagmati basin and these values are presented in Table 5.1. Number of stream of different orders with their order number were plotted on a semilog paper. Negative slope of the straight line indicates

Table 5.1: Geomorphological parameters based on linear aspects of the basin (lengths are in Km).

Name of Parameters	Symbol	Value
1. Length of the main channel	L	346.60
2. Length of the channel between the outlet and a point near to C.G	L_c	130.30
3. Total length of channels of		
Order 1	L_1	907.50
Order 2	L_2	490.00
Order 3	L_3	221.75
Order 4	L_4	238.50
Order 5	L_5	113.00
4. Total length of streams of all orders	L_u	1970.75
5. Total number of channels of		
Order 1	n_1	182
Order 2	n_2	39
Order 3	n_3	8
Order 4	n_4	2
Order 5	n_5	1
6. Total number of streams of all orders	n_u	232
7. Mean length of streams of		
Order 1	L_1	4.98
Order 2	L_2	12.56
Order 3	L_3	27.72
Order 4	L_4	119.25
Order 5	L_5	113.00
8. Basin perimeter	P	597.00
9. Wandering ratio	R_w	1.44
10. Fineness ratio		0.58
11. Watershed eccentricity	τ	2.24
12. Bifurcation ratio	R_b	0.3237
13. Stream length ratio	R_L	2.9539

that the number of streams of a particular order decrease with the increase in stream order and it follows the law of stream numbers. This means that the number of streams of any given order are fewer than the immediate lower order but more numerous than the next higher order. However, in general, the average length of a particular order stream increases as the order of the stream increases which means that the mean length of a stream of a given order is greater than that of immediate lower order but less than that of the next higher order. The values of bifurcation ratio and stream length ratio are computed by finding out the anti-logarithms of slopes of the regression plots of log N_u versus u and Log L_u versus u respectively. The value of bifurcation ratio of the basin is 0.3237. This is a non dimensional parameter which reflects the hydrological characteristics particularly effecting the time of peak.

Various areal parameters evaluated for Bagmati basin are given in table 5.2. The drainage area of the selected basin is 8445.81 sq. km. The basin drainage area is considered to be one of the important geomorphological characteristic and has been used frequently in various hydrological studies. The values of various non dimensional areal measures e.g. elongation ratio, circularity ratio, area ratio, constant of channel maintenance, drainage density, form factor and stream frequency are also given in table 5.2. These non dimensional areal parameters are the governing factors for the peak and shape of the basin response hydrograph and these can be used in the modelling of

Table 5.2: Geomorphological parameters based on areal aspects of the basin (areas are in Sq.Km.)

Name of parameters	Symbol	Value
1. Drainage area	A	8445.8100
2. Drainage density	D	0.2333
3. Constant of channel maintenance	C	4.2863
4. Channel segment frequency	F	0.0275
5. Circulatory ratio	R_c	0.2978
6. Elongation ratio	R_e	0.5122
7. Watershed shape factor	R_s	1.0559
8. Unity shape factor	R_u	2.2030
9. Form factor	R_f	0.0996

hydrological response without considering the runoff records.

Some of the important parameters classified under relief aspects of the basin have been computed and presented in table 5.3. Total relief of the Bagmati basin upto Hayaghat is 1453 m. Various non dimensional relief measures e.g. relief ratio, relative relief, ruggedness number and average overland slope are also presented in table 5.3. In the modelling of mountainous catchment where velocity of flow are considerably high, the relief parameters have significant importance. They also govern the overland flow and stream flow process in the

Table 5.3: Geomorphological parameters based on relief aspects of the basin.

Name of parameters	Symbol	Value
1. Basin relief	H	1453.0000 m
2. Relief ratio	R_r	0.0072
3. Relative relief	R_R	0.0024
4. Ruggedness number	R_N	0.3389
5. Average overland slope	S_a	4.988 %

6.0 CONCLUSION

The geomorphological characteristic of a basin is a indicator of its hydrologic behaviour and can be successfully employed in synthesising the runoff response of the basin or prediction of sediment yield particularly for the ungauged basins. In this report various geomorphological properties covering linear, areal, and relief aspects of the catchment and channel network have been discussed in detail. Methodology to evaluate these parameter have also been described.

Various geomorphological parameters for Bagmati basin up to Hayaghat have been computed. It is observed that the main Bagmati stream is a fifth order stream and the main channel is 346.60 km. long. Total relief of the basin was computed as 1453 meters. Various non dimensional geomorphological parameters of the basin were also computed. The geomorphological parameters, thus estimated, may be utilisd for regional unit hydrograph studies, flood frequency analysis, instantaneous unit hydrograph study. simulation models. These parameters may also be utilized for the development of emprical formula.

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