HYDROGEOMORPHOLOGICAL STUDY OF TAWI CATCHMENT, J & K

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PREFACE

Defining run-off response i.e. relative concentration and timing of run-off in watersheds in quantitative expressions has been the concern of hydrologists.In the prevailing situation that in most of the basins and sub-basins few precipitation measurement stations and even fewer discharge sites exist, the relationships describing run-off process remain mostly as the guess work or crude empirical statements. Various investigators considered and showed that measurable basinal properties or geomorphological characteristics of a basin describing its linear, areal and relief aspects can reflect the hydrological properties also. This has helped many to simulate flow, synthesize hydrograph and regionalise model parameters for an ungauged catchment from the results of gauged catchment. Derivation of Geomorphologic Instantaneous Unit Hydrograph has helped renewed research in hydrogeomorphology. Though many successful uses of these basin characteristics in hydrologic analysis have been documented, substitution of these results for more traditional tool is open to view as yet.

While reviewing the various works and elements about application of quantitative geomorphology in hydrology, the report attempts to quantify some of the important hydro geomorphological parameters of Tawi sub- basin within Western Himalayan Region, as part of its overall hydrologic studies, the regional centre, NIH, Jammu has since under taken. In absence of sufficient hydrometeorological data for conventional hydrologic analysis these estimated basin descriptors should be helpful to carry out further studies in the study area.

The report has been prepared by Sh B C Patwary,Scientist 'E' and Sh Kamal Kumar, S.R.A. under the general guidence of Sh K S Ramasastri, Scientist 'F'. In compilation of the report in PC and presentation of results, Sh M K Sharma, SRA and Sh Puran Singh, RA rendered occassional helps.

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ABSTRACT

Geomorphology is the science of evolution of land forms in terms of its lithology, struture, basin geometry and other morphometric factors. Of interest to hydrology, the measurable geomorphological descriptors of basinal properties grouped under linear aspect of channel network,areal aspect of basin and relief aspect of channel system and basin form are regarded to have potential to describe hydrological properties of the basin. Therefore, faced with the common problem of non availability of hydrometeorological data for hydrologic simulation of run-off process, specially in ungauged catchment, various investigators have used these basin parameters to synthesize flow hydrographs. The relationships developed between characteristics of quantitative geomorphology of drainage basin and parameters of an instantaneous unit hydrograph have encouraged the hydrologists to look more and more into such physical and geometrical properties of drainage basins. Introduction of Geomorphological Instantaneous Unit Hydrograph has since led to the renewal of research in hydrogeomorphology.

While reviewing the various application of hydrogeomorphologic parameters in hydrologic studies it has been attempted to estimate the geomorphological characteristics of Tawi river sub- basin in this report. The Tawi, a Western Himalayan river of Indus system has vast potential of water resources development and calls for comprehensive hydrologic studies. In view of paucity of data the geomorphological parameters estimated in the report extend scope to carry out further studies and regionalise the results.

1.0 INTRODUCTION

Drainage basins are created, shaped and structured by nature in some orderly manner and it exhibits interdependence of hydrogeoclimatic factors and soil vegetation complexes. Hydrologists and earth scientists in their effort to understand and synthesize hydrologic response of such basin have started looking into its morphologic or topographic feature and establish connection of fluvial geomorphology to hydrology. Geomorphology, the science of evolution of land forms in terms of lithology, structure, climate & other climatic factors, had been mostly qualitative in its initial stage. Now geomorphologic efforts have come out of past trend and with the rational relations between the "ensemble" average response of a basin with given geomorphologic properties established, greater need for quantitative informations is felt for. To evaluate or predict the run-off response of a river basin hydrologists are faced with the vexed problem of non availability of flow precipitation data. Therefore, measurable basinal features of drainage net work which have been considered and shown to have potential to describe some of the hydrograph parameters of the ungauged system have encouraged hydrologists for hydrologic simulation and applying relationships developed for gauged basins at ungauged basins through hydrograph synthesis.

The geomorphological characteristics which relate to hydrology, as suggested by many investigators, consist of linear aspect of channel system dealing with one dimensional overland flow lengths & length of streams etc., areal aspect of catchment relating to basin shape & drainage texture and relief aspect of channel network/catchment describing elevation differences etc. The first two categories of measurement are planimetric (i.e. treat properties projected upon a horizontal datum plane) and the third category treats the vertical inequalities of the drainage basin form. Some typical catchment characteristics have also been identified which will be useful to derive unit hydrograph for the catchment. Some of the studies where quantitative geomorphological characteristics have been applied to describe hydrologic properties such as run-off response or flow hydrograph etc. are as follows:

- Development of empirical formula using geomorphological parameters.
- Regional Unit Hydrograph Studies
- Regional Flood Frequency Analysis
- Development of Geomorphological Instantaneous Unit Hydrograph
- Hydrologic modelling studies.

The report attempts to estimate the various geomorphological characteristics of Tawi river sub basin within Western Himalayan Region with the help of established laws and procedures and using Survey of India map of scale 1:50,000. In absence of sufficient network of hydrologic observation sites the geomorphological parameters derived for the basin may be used for further hydrologic studies which have been the concern of the local administrative and technical forums since years.

2.0 REVIEW :

To understand the laws of run-off processes in a watershed, hydrologists have been faced with many problems specially in respect of ungauged catchments where hydrological data are rarely available. Many approximate formulae, usually crude empirical statements, have been developed to relate precipitation with flow. For ungauged basins it has been the endevour of many hydrologists and earth scientists to quantify and relate geomorphological parameters of naturally shaped river basins to its hydrologic response characteristics.

Horton (1932,1945) pioneered the hydromorphometric analysis of drainage basin and provided a rational and systematic base, rather a framework of outline of geomorphological characteristics to relate them to various hydrological properties of the system. His works were pursued by many investigators like Langbein et al.(1947), Strahler(1952, 1954, 1956, 1957, 1964), Melton(1957), Schumm(1956), Chorley(1957), Miller(1953) and so on . These works have brought forward many laws of fluvial geomorphology connected to hydrology and study of geomorphological characteristics of river basins has become a major area of scientific research for hydrologists throughout the globe.

Hydromorphometric studies in quantitative terms are very few in Himalayan Region where the present study area is situated. Sukla and Verma (1975) studied morphometry in relation to slope development in sub Himalayan Siwalik ranges of Dehradun valley and similar study followed at Western part of it by Prasad and Verma (1975). Mithal et al. (1974,1982) carried out hydromorphometric studies in Garhwal Himalayas and morphometric elements like stream length, stream number, length ratio, basin area, basin relief etc. were related to rock types. Roohani and Gupta (1988) studied some relationships between hydromorphometric parameters like stream order vs number, stream order vs mean stream length, stream order vs mean drainage area, stream order vs channel slope etc. and inferred that the channel network lacked morphometric similarity or steady state for which the hydromorphometric relations exhibited deviations from the widely established and accepted norms. Some of the works carried out by National Institute of Hydrology, Roorkee India have been described at the end of this section.

Geomorphological characteristics and their use in various hydrologic studies, presently of interest to scientist and water resources managers are briefly reviewed below :

2.1 Empirical Relationships Based on Basin Characteristics :

In the absence of precipitation and flow data empirical relationships based on basin characteristics have been used in many parts of the world since ninteenth century to estimate flow expectations from different drainage networks. Some of such relationships are discussed in para 2.7.1. These statements are very simple but crude and have many limitations in their applicability. This calls for in depth knowledge of hydrological process and physical characteristics of the basin where they were developed so that the results can be transformed elsewhere.

2.2 Geomorphological parameters for Unit Hydrograph Studies :

Unit hydrograph studies have been very useful for flood estimation. For ungauged catchments, peak flow and run-off hydrograph can be synthesized with the help of unit hydrograph of a gauged catchment and its known basin characteristics. Effect of drainage basin characteristics upon unit hydrograph lag and peak flow has been reported by Taylor & Schwartz (1949) using the data of 20 basins ranging area from 20 to 1600 sq. miles and located in North and Middle Atlantic states. Drainage area, length of the main stream , mainstream length to the centroid of catchment and equivalent main stream slope were regarded as the most significant variables (4).

In India, the Central Water Commission conducted studies to develop regional unit hydrograph in 26 hydrometeorological sub zones covering whole of India . All the major storms for the gauged stations were analysed and derived unit hydrograph parameters were related to physical characteristics of the basin so that regional unit hydrographs can be developed for each sub zone.

2.3 Regional Flood Frequency Analysis :

To estimate design flood of certain frequency historical flood records are often not available at site. For the ungauged site regional flood frequency analysis may be done 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 the hydrologically homogeneous regions. Mean annual flood may be influenced by catchment area, stream flow, land slope, stream density and relief aspects of the basin.

U.S. Geological survey of India carried out such study and published a manual under Geological Survey Water Supply paper.1543-A by T. Dalrymple (1960). Nash (1966) analysed discharge records of 57 catchments of Great Britain and parameters of the frequency distributions of annual maximum flood peaks were correlated with the catchment area , slope and mean annual rainfall of the catchments (24).

2.4 Geomorphological Instantaneous Unit Hydrograph (GIUH) :

Rodriguez and Valdes (1979) first introduced GIUH, which led to the renewal of research in hydrogeomorphology. The concept was restated by Gupta et al. (1980) (2). For GIUH fully analytical and complicated expressions for complete shape of IUH were derived . Hence they suggested that it is adequate to assume a triangular IUH specifying peak time and peak flow.

In summary the IUH is a function of the probability that a drop,initially falls in an area that drains to a channel of given order, the transition probabilities from a stream of one order to another that are functions of the basin's geomorphologic characteristics Ra & Rb, and travel time distribution in streams of a given order. Initial and transition probabilities provide a probabilistic description of the drainage network and a link between quantitative geomorpnology and hydrology (2):

For the simplified triangular IUH:

$$Qp = \frac{1.31}{Lw} Rl^{0.43} * V \qquad (2.1)$$

$$Tp = \frac{0.44\ Lw\ Rb^{0.55}}{V.Ra^{0.55}} Rl^{-0.38} \qquad (2.2)$$

Where

Qp = Peak, given in units of inverse hours

Tp = Peak time in hours.

Lw = Length in km of highest order stream

V = Expected peak velocity in m/sec.

Ra = Area ratio

Rb = Bifurcation ratio

Rl = Length ratio

Fig. 1 & Fig. 2 show how the geomorphologic instantaneous unit hydrograph changes with parameters. Clearly there is wide variation of shapes of GIUH.

2.5 Geomorpho-Climatic IUH :

Due to difficulty that GIUH is dependent on peak velocity 'V' Rodriguez - Iturbe et al. (1982) rationalized that V must be a function of the effective rainfall intensity and duration and proceeded to eliminate 'V' from the results. Two important restatements of Qp and Tp were given as below :

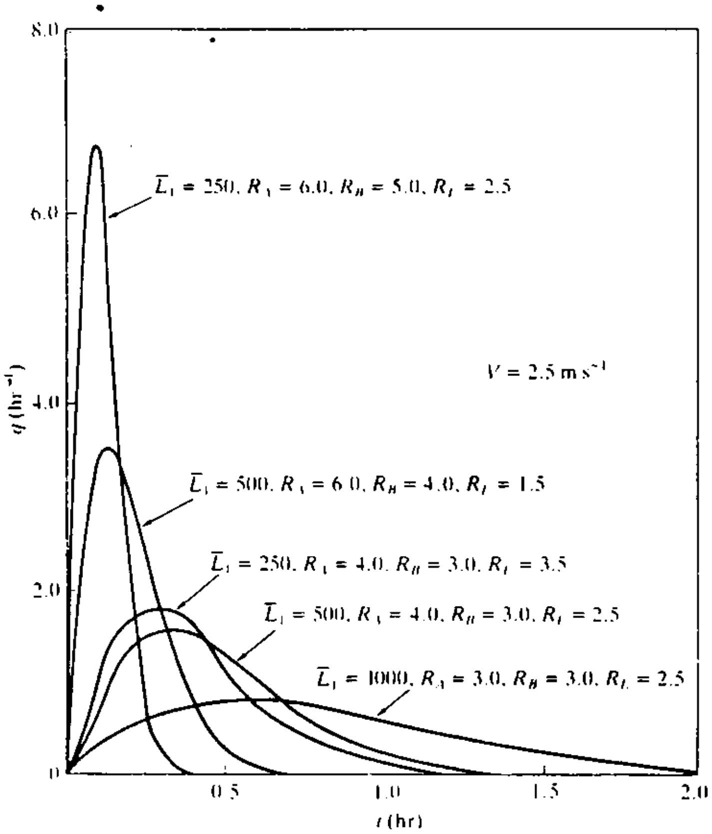

FIGURE 1. Changes in the geomorphologic instantaneous unit hydrograph when the velocity is kept constant and geomorphologic properties vary. Source: I. Rodriguez-Iturbe and J. B. Valdes, "The Geomorphologic Structure of Hydrologic Response," *Water Resources Res.* 15(6):1409–1420, 1979.

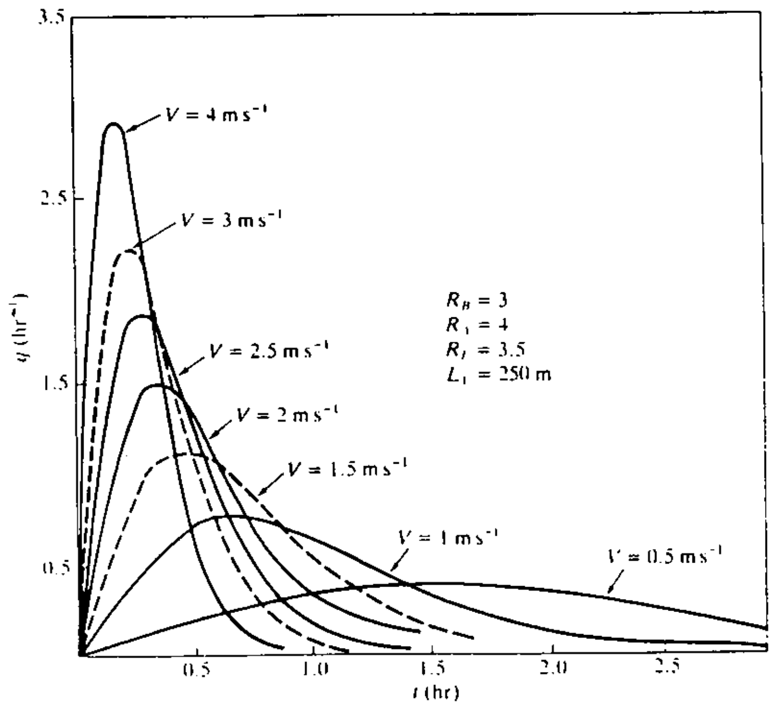

FIGURE 2. Changes in the geomorphologic instantaneous unit hydrograph when the geomorphologic characteristics are kept constant and the velocity varies. Source: I. Rodriguez-Iturbe and J. B. Valdes, "The Geomorphologic Structure of Hydrologic Response," *Water Resources Res.* 15(6):1409–1420, 1979.

$$Q_p = 2.42 \frac{I_r.A_w.T_r}{\Pi_i^{0.4}} \left(1 - \frac{0.218\, T_r}{\Pi_i^{0.4}}\right) \tag{2.3}$$

$$t_p = 0.585\, \Pi_i^{0.4} + 0.75\, T_r \tag{2.4}$$

Where

Aw = Basin area of order w

Ir = Mean effective rainfall intensity

Tr = Duration of time

$$\Pi_i = \frac{L_w^{2.5}}{I_r.A_w.R_l.L_w^{1.5}} \tag{2.5}$$

$$L_w = \frac{1}{n.b_w^{2/3}} S_w^{1/2} \tag{2.6}$$

bw = Mean width of main stream

Sw = Mean slope of main stream

n = Manning's roughness co-efficient

The above two equations imply a rainfall - run-off relationship that is not dependent on calibration with input-output data and is theoretically only dependent on geomorphologic and climatic data, hence the name geomorphoclimatic instantaneous unit hydrograph (2).

2.6 Derivation of Nash Model Parameters from Qp & tp of GIUH :

For the derivation of the complete shape of GIUH, the scale (K) and shape (n) parameters have been linked with qp and tp of GIUH . Nash (1957) had proposed a conceptual model in which catchment impulse response (IUH) can be represented as the outflow from routing the unit volume of instantaneous excess rainfall input through a series of 'n' number of successive linear reservoirs having equal delay time or storage co-efficient. The equation for IUH for Nash's model is given as :

$$U(0,t) = \frac{1}{k} \frac{1}{\Gamma n} \cdot e^{-t/k} \cdot (t/k)^{n-1} \qquad (2.7)$$

Where,

$U(0,t)$ = t^{th} ordinate of IUH (of duration 0)

Γ = Gamma function.

K = Storage co-efficient

n = no. of Linear reservoirs

Equating first derivative w.r.t. time 't' to zero then t become peak time tp and we get

$$t = t_p = (n-1).K \qquad (2.8)$$

Substituting $t = t_p$ in eq.(2.7) we get,

$$U(0,t)_{peak} = Qp = \frac{1}{k} \frac{1}{\Gamma n} \cdot e^{-(n-1)} \cdot (n-1)^{n-1} \qquad (2.9)$$

From eqns. 2.8 & 2.9

$$Qp.tp = \frac{(n-1)}{\Gamma n} \cdot e^{-(n-1)} \cdot (n-1)^{(n-1)} \qquad (2.10)$$

This eqn. is function of Nash Model parameter 'n' only.

Again multiplying eqns. 2.1 & 2.2 we get:

$$Qp.tp = 0.5764 \left[\frac{Rb}{Ra}\right]^{0.55} . Rl^{0.05} \qquad (2.11)$$

Equating 2.10 & 2.11,

$$\frac{n-1}{\Gamma n} . e^{-(n-1)} . (n-1)^{(n-1)} = 0.5764\left[\frac{Rb}{Ra}\right]^{0.55} .Rl^{0.05} \qquad (2.12)$$

In eqn. (2.12) all terms on R.H.S. are known. The Nash Model Parameter n is obtained by solving the eqn. 2.12 using Newton Raphson method of non linear optimization. The parameter 'n' when substituted in the following equation for a given velocity 'V' the value of k(inversely proportional to 'V') can be obtained .

$$K = \frac{0.44\ Lw}{V} . \left[\frac{Rb}{RA}\right]^{0.55} . Rl^{-0.38} . \frac{1}{(n-1)} \qquad (2.13)$$

Now with 'k' and n evaluated complete shape of IUH can be derived from eqn. (2.7) (14).

Rosso (1984) found the following empirical relations between the Nash Model and the GIUH

$$n = 3.29 \ (Rb/Ra)^{0.78} . Rl^{0.07} \qquad (2.14)$$

$$k = 0.70 \ (Ra/(Rb.Rl))^{0.48} . V^{-1} . L \qquad (2.15)$$

Where L is the length of highest order stream and V is the average cross sectional velocity at the out let during peak flow (15).

2.7 Hydrogeomorphological Parameters :

Keeping in view of the above specialised application of geomorphological characteristics to hydrology, the report attempts to derive some of the important morphometric parameters of the study area. The parameters considered for analysis in the report and various findings & applications related to them have been discussed and reviewed in chapter 5. Some more such other parameters reported by various investigators are reviewed below :

2.7.1 Length Area Relationship :

P.S Eagleson (1970) developed relationship between mainstream length (L) and Basin Area 'A' (Fig.3) as

$$L + 1.40 \,.\, A^{0.568} \tag{2.16}$$

The ratio A/L^2 is not constant for all basins which implies that geometrical similarity is not fully preserved for the basins. The fig.3 gives geometrically similar fit as :

$$L = 1.73 \,.\, A^{0.5} \quad \text{or} \quad \frac{A}{L^2} = \frac{1}{3} \tag{2.17}$$

One of the possible explanations may be larger basins are more elongated than smaller basins since the ratio $A/(L^2)$ falls as area increases.

2.7.2 Width Function, N(x) :

Surkan (1968), Calver et al. (1972) , Kirkby (1976) Gupta et al. (1986), Troutman & Kartinger (1986) showed that the width function N(x) which measures the number of links at a given distance x from outlet, has significant effects on hydrograph shape and peak . Assuming a basin as in Fig.4 with behaviour that travel time of water is same for each link, if 19 drops of

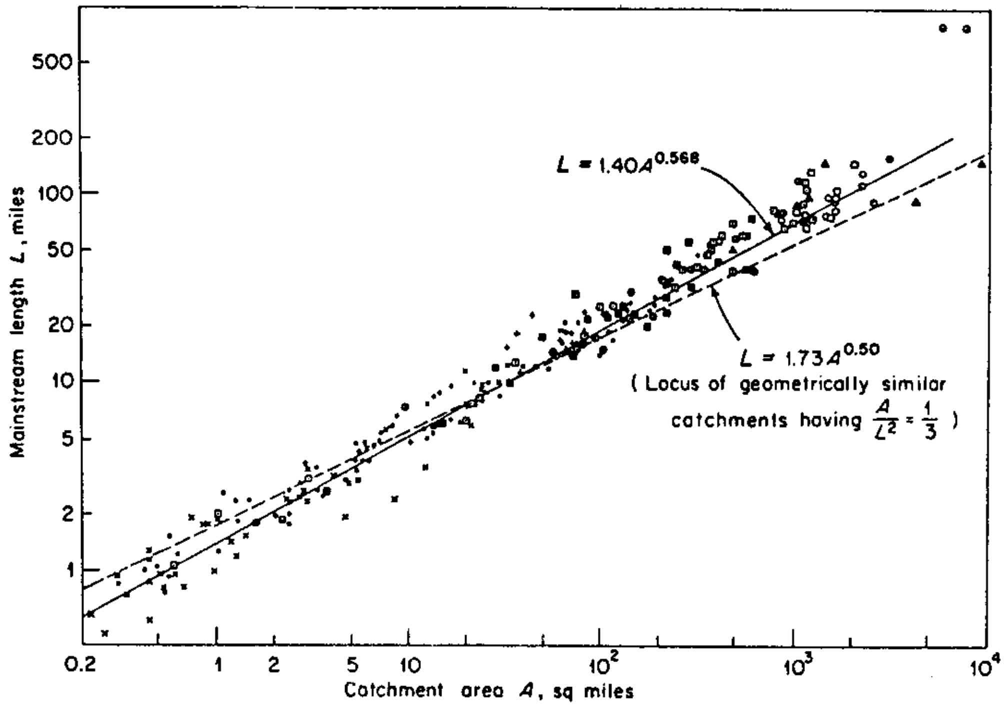

FIGURE 13 Relationship between catchment area and catchment length. Source: P. S. Eagleson, *Dynamic Hydrology,* McGraw-Hill, 1970.

water (like balls) are released at heads of 19 links, the number of drops reaching the outlet at each time interval is given by width function. In this, it is the IUH, which is nothing but the distribution of travel time of water to the outlet when unit amount of water is applied uniformly over the basin instantaneously. The length x may be geometric or straight line distance between nodes, the actual or the topologic length.

However, in practice travel time in each link of different lengths cannot be the same and IUH is derived relating travel time with geomorphologic characteristics.

2.7.3 Link Concentration Function, N(h) :

Mesa (1986) and Gupta et al. (1986) used this function to see if there is any relation between run-off sediment yield and basin elevation. Analogous to width function, link concentration function N (h) for $0<h<H$, measures the number of links in the network at elevation h i.e. the number of links cut by a particular contour line. Fig.5 shows N(h) for a basin. Like hypsometric curve (discussed later) which describes elevation relative to area, the link concentration function describes elevation relative to channel net work (2).

2.7.4 Relief Ratio and Sediment Yield :

Schumm found that sediment loss per unit area is closely correlated with relief ratio as experimented in small drainage basins in six localities of the Colorado Plateau Province with resistant rock like conglomerate & sand stone and weak rocks like

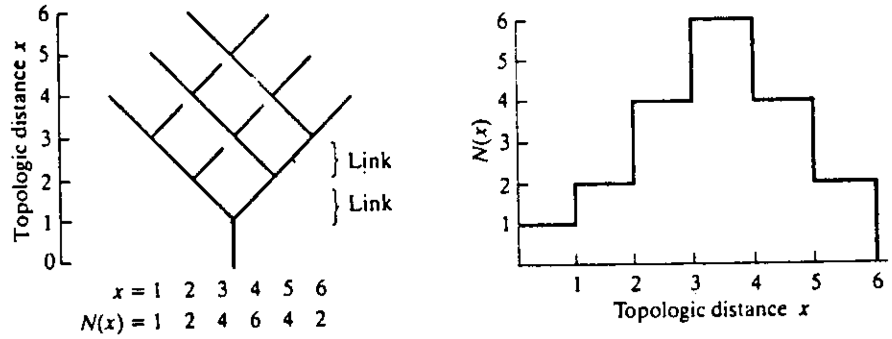

FIGURE 4 Width function defined in terms of topologic length.

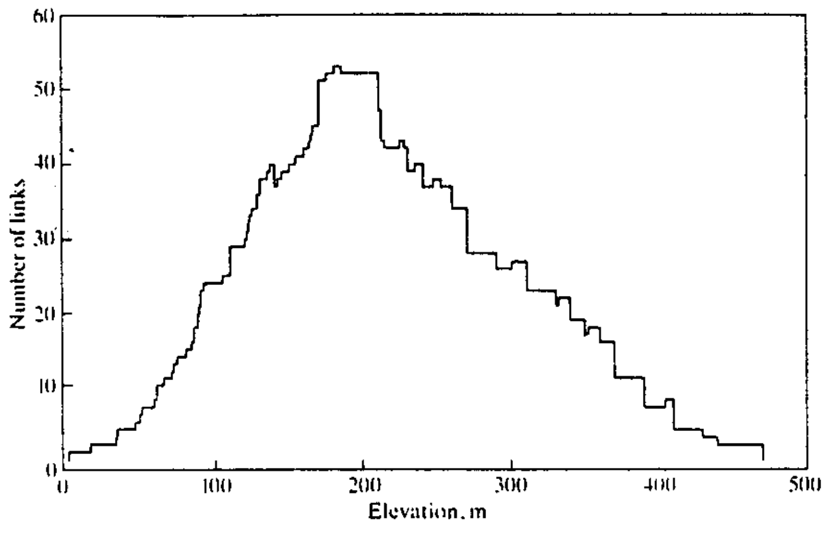

FIGURE 5. Link concentration function for the Agua Fria Basin in Venezuela. Source: V.K. Gupta and O.J. Mesa, "Runoff Generation and Hydrologic Response via Channel Network Geomorphology: Recent Progress and Open Problems," *J. Hydrol.* 102(1-4):3–28, 1988.

friable sand stone & shale. The significant regression with small scatter suggests that relief ratio may prove useful in estimating sediment yield if the appropriate parameters for a given climatic province are established (4).

2.7.5 Law of stream slope & slope Ratio (Rs) :

It is clear that the average slope of channel segments of a given order will be less than that of next lower order but will be higher than that of next higher order. Horton (1945) expressed this relationship in a law of stream slopes, an inverse - geometric series law, which is analogous to the law of stream numbers.

$$\bar{S}u = \bar{S}1\ Rs^{(k-u)} \qquad (2.18)$$

Where $\bar{S}u$ = Average slope of segments of order u.

$\bar{S}1$ = Average slope of stream of order 1
K = order of highest order segment
Rs = Slope Ratio analogous to bifurcation ratio, Rb

The law of stream slopes brings elevation and hence energy in to the description of the river basin.

2.7.6 Division ratio (Rd):

It has been shown by Scheidegger (1966) that in a Horton's net work Rb is constant only if streams of order u received streams of orders u-1. Thus if the lost segments are removed and the ratio of Nu-1 and nu is computed according to Horton, then this ratio is the division ratio, which is analogous to Rb. Coffman and Melhorn (1970) examined the consistency of both Rb and Rd within and between six fourth order basins located on glacial hill within a single drainage system in India. They reported a wide and erratic variation in Rb for the test watersheds but Rd was almost equal to 3 with one exception. The concepts of Rd may be very useful in estimating parameters of rain fall run-off models (24).

2.7.7 Nash's Measure of Slope (EA) :

To define measure of slope Nash (1960) plotted the profile of main channel from the gauging site to the basin divide (boundary) and a straight line was drawn through the gauging station so as to form a triangle with the horizontal (through gauging station) and the vertical (through the highest point of the main channel). The slope of the line was so aligned that the area of the triangle be equal to the area contained by the horizontal, the vertical and the channel profile as shown in Fig.6.

2.7.8 Nash's Measure of Overland Slope (OLS):

Another measure of overland slope was suggested by Nash (1960) in which a grid of rectangular mesh was drawn. on the 2.5" in map of the catchment, the mesh being such that about 100 intersections occurred within the catchment boundary. At each intersection the minimum distance between adjacent contours is measured and the slope at each point is taken as contour interval divided by this distance (Fig.7) . This provided a set of slope values of which the mean is calculated and taken as overland slope. When an intersection occurred at a point between two

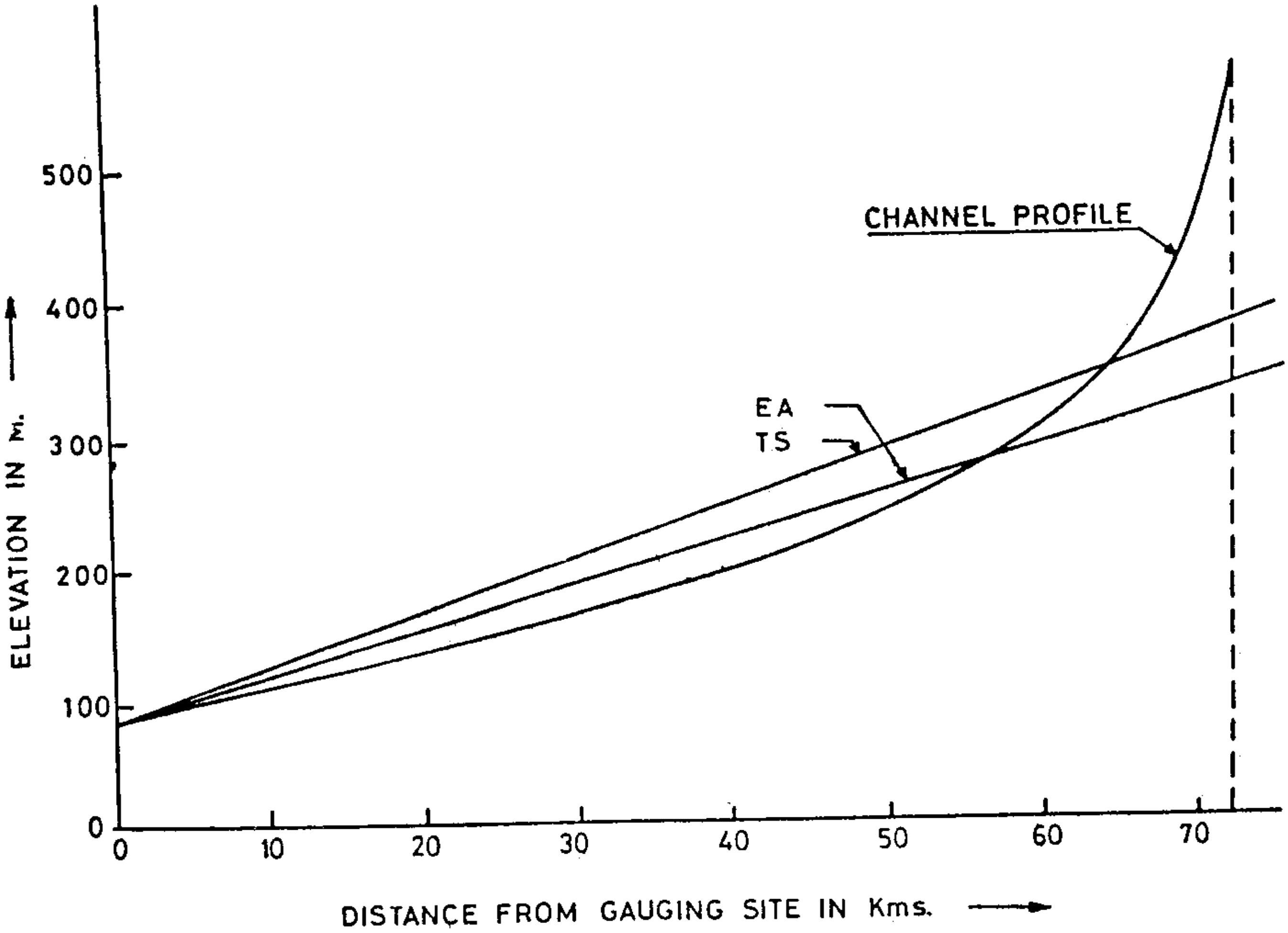

FIG. 6-MAIN CHANNEL SLOPES

287	231	245
189	417	144
93	309	I

I – INDETERMINATE

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

= 239 parts per 10,000

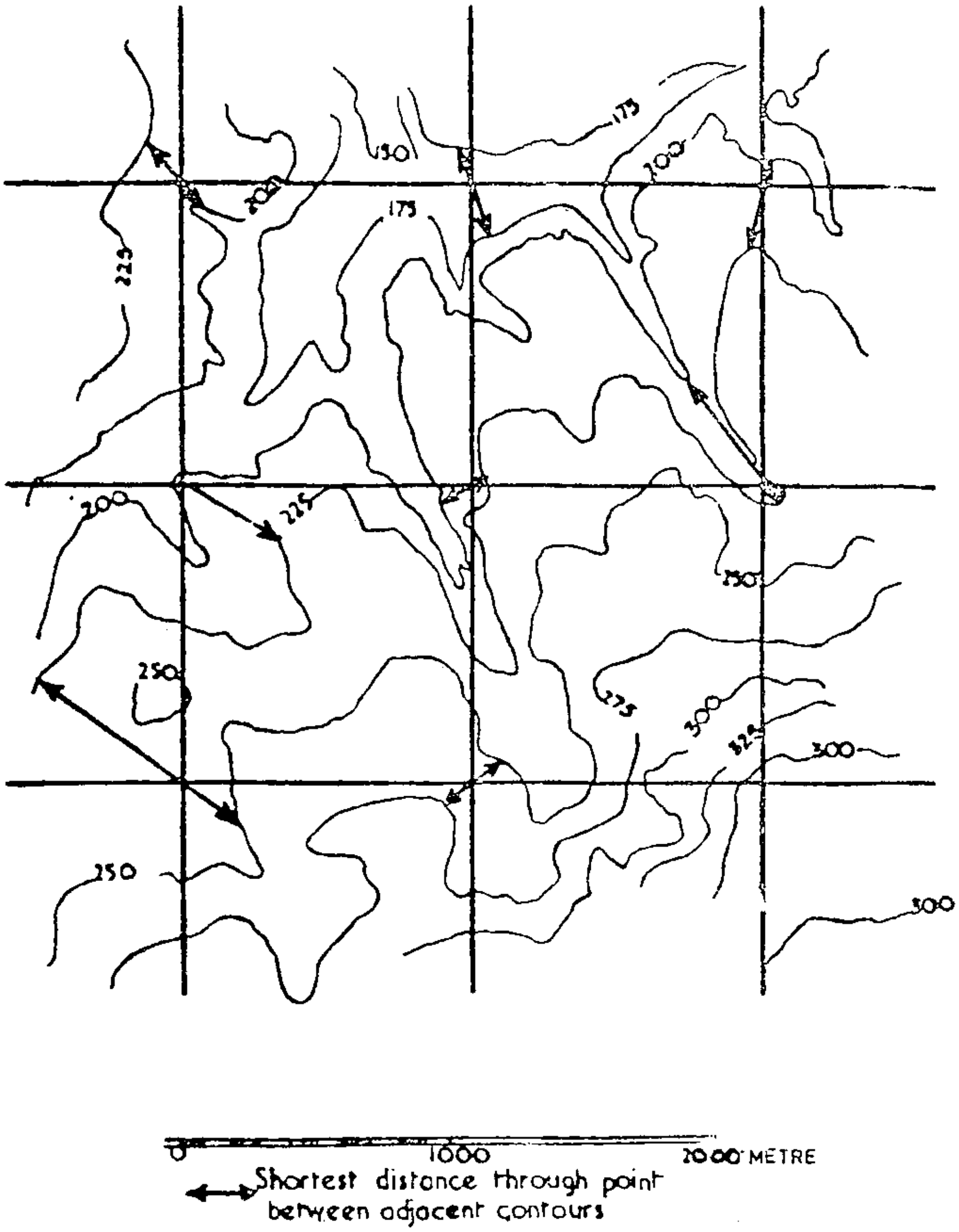

FIG 7 METHOD OF OBTAINING O.L.S OF CATCHMENT

contours of the same value the slope is taken as Zero if the point is in valley and as indeterminate if on a hill. The latter is neglected in calculating the mean.

2.7.9 Hypsometric Curve(Area-Altitude Analysis) :

Langbein et al (1947) introduced the non dimensional hypsometric curve to study the topography of watershed. The curve plots the percent area (area divided by the total basin area) of the basin found above a given percent elevation contour. The percent elevation is defined as a given elevation divided by the maximum basin relief (H). This is shown in Fig. 8 and Fig.8(c). shows several possible shapes of the curve. Davis(1899) suggested that basins evolved after some sudden tectonic uplifting and ensuing erosion & degradation. Such a model led to the identification of curve A with a young basin , curve B with a mature basin , and curve C with and old basin. Scheidegger (1987) rebuts this classification by arguing that uplifting is continuous process and that throughout the basin history there is a tendency to balance the opposing forces of tectonic build up and degradation by erosion and other mechanisms. He then attributes the various shapes of the hypsometric curve to the levels of activity of the antagonistic processes. Curve A corresponds to high activity, curve B to medium and curve C to low activity. A third interpretation is that the shape of the hypsometric curve is a measure of relative equilibrium, in terms of tectonic uplift and erosional activity. This may or may not be measure of basin age. Curve A shows inequilibrium between

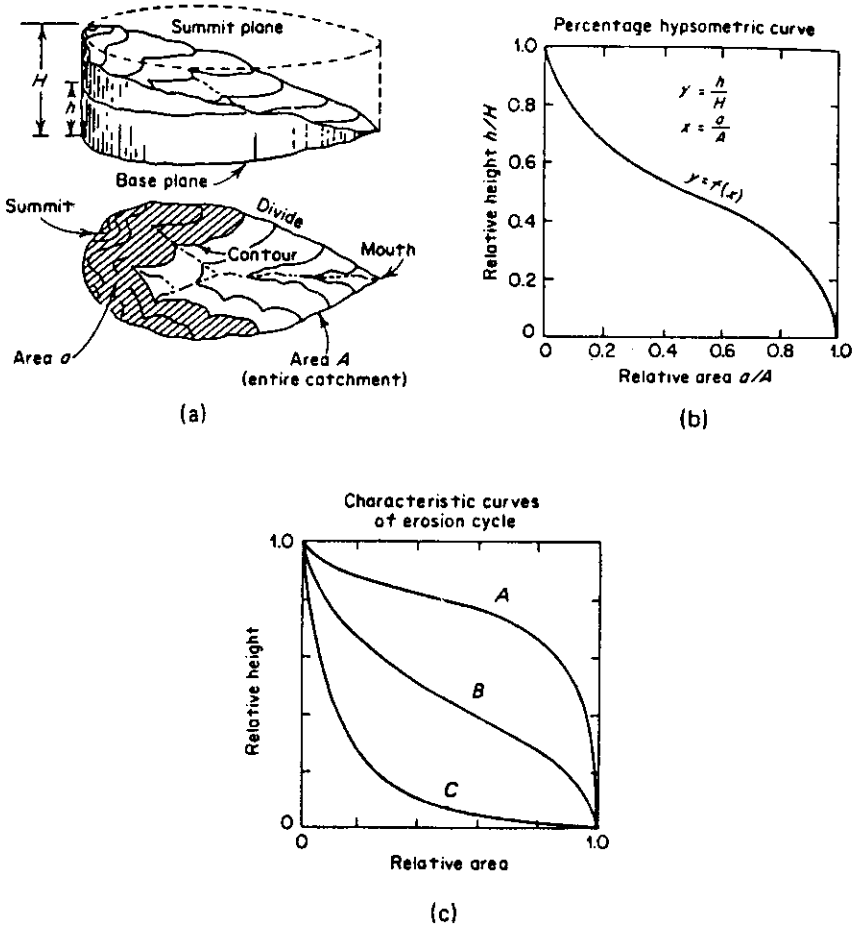

FIGURE 8 Construction of the hypsometric curve. Source: After A. N. Strahler, "Quantitative Analysis of Watershed Geomorphology," *Trans. Am. Geophys. Union* 63:1117–1142, 1957.

opposing processes. The mature curve B corresponds to dynamic equilibrium of agradation and degradation. Erosion continues during equilibrium phase,leading to a general reduction in relief but maintaining the same relative elevation-area distribution. The Monadnock phase (distorted hypsometric curve) may arise when rock outcrops, resistant to erosion, are exposed, leading to fairly large contrast between the elevations of erodable and non erodable parts of the basin (2).

The hypsometric curve which describes the overall relief of a catchment is used when a hydrologic variable such as precipitation, Vegetative cover or snow fall shows a marked tendency to very with altitude. In such cases the hypsometric curve provides the quantitative means to evaluate the effect of altitude (18).

2.7.10 Area Elevation Relation :

Distribution of areas between contours in a drainage basin is of interest for comparing drainage basins and to understand the storage and flow characteristics of the basin. For the purpose an area distribution curve can be obtained by planimetering the areas between adjacent contours or by using a square grid and forming a ratio of the number of squares between contours to the total number of squares contained within the drainage boundary. The mean elevation is determined as the weighted average of elevations between adjacent contours. The median elevation can be determined from the area elevation curves as the elevation at which the percent area is 50% This is shown in Fig.9 (30).

2.7.11 'T' Factor:

Potter defined T factor as the ratio between length of highest order stream to the sq root of average main stream slope from head to mouth. He determined empirically a regression of peak discharge upon factors of topography, basin area and rainfall for 51 basins in the Appalachian Plateau. The T factor was regarded to be significant in multiple regression with basin area and measures of rainfall intensity & frequency (4).

2.7.12 Peak Discharge & Basin Geometry :

Maxwell (1960) related stream discharge characteristics to several elements of basin geometry in the San Dimas Experimental Forest of Southern California. Correlations between peak flow & storm rainfall cover density , antecedent rainfall , and nine geomorphic properties taken five at a time. The geomorphic variables taken were 5th order area & diameter, means of 2nd order area, diameter, relief, drainage density, channel frequency and relief ratio and watershed bifurcation length, diameter and area ratios. It was concluded that 5th and 2nd order areas or diameters, together with 2nd order drainage density and relief ratio, provide a good estimate of the variability of peak discharge which can be explained by geomorphic variation between watersheds.

2.8 Geomorphological studies by NIH :

The National Institute of Hydrology a premier Institute of

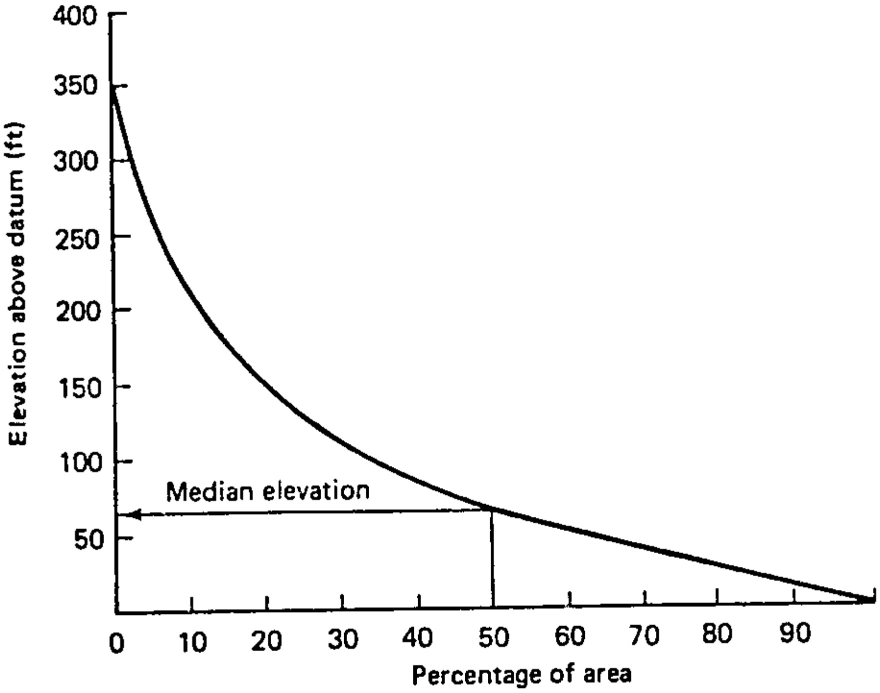

Figure 9 An area-elevation distribution curve.

the country in the field of hydrology and allied research has since taken up geomorphological studies of river basins through its regional centres spread over the entire country. Faced with the vexed problem of non availability or inadequacy of data for the river basins, particularly in mountainous areas the geomorphological studies have been taken up with the following objectives:

- Estimation of geomorphological parameters covering Linear aspects of channel network, Areal aspects and Relief aspects of drainage basins.

- To study the relationships of drainage characteristics with stream flow.

- Synthesizing flow parameters with the help of morphometric parameters.

- To regionalise hydrological models of run-off process.

The National Institute Hydrology and its regional centres have since completed studies on estimation of geomorphological characteristics for the following river basins:

1. Varna basin upto Samdoti
2. Krishna basin upto Karad (Western Ghats)
3. Krishna basin upto Arjunabad (Do)
4. Ghataprabha basin upto Daddi (Do)
5. Malaprabha basin upto Khanpur (Do)
6. Kolar Sub-basin
7. Hemavathy basin in Karnataka
8. Sabarmati basin in Gujrat

3.0 PROBLEM DEFINITION :

Hydrological studies in drainage basins and sub basins often suffer setbacks due to lack of various long term data. Then there is the need to extrapolate the results of few small sub systems (where only data are available) to other hydrologically similar regions which mostly remain ungauged for want of enormous resource and time involved in instrumentation & monitoring them. The measurable geomorphological parameters which have since been considered and shown to have potential to describe some important hydrologic properties of drainage network, provide simple means for hydrologic simulation, hydrograph synthesis and for development of empirical relationships to quantify some elements of flow process. In pertinence to hydrology, the geomorphological parameters provide reasonable scope to compare basins and transform the results of gauged basins to ungauged areas for its regionalization.

The existing network of hydrometeorological observation in Tawi basin is poor and data available are not adequate for systematic hydrologic studies. Moreover , the channel network of the basin is very complicated with most of the first, second and third order streams flowing on steep slope. Even many of the major streams remain dry during winter and experience flash flood during rainy days. There is no gauge -discharge sites on these streams. Therefore, geomorphological parameters of the basin may provide an alternative to establish relationships describing flow process of the network.

With the growing concern for comprehensive hydrologic studies at Tawi river sub-basin estimation of its geomorphological parameters has been felt necessary for further study to follow. These parameters consisting of linear, areal and relief aspects of Tawi basin, as quantified in the report, may be used to develop hydrological model and regionalize the model parameters .

4.0 STUDY AREA

4.1 General topography :

The Tawi river basin is a small part of Western Himalayas and is contained in between $32^{\circ}35'$ to $33^{\circ}5'$ North Latitude & $75^{\circ}45'$ to $75^{\circ}45'$ East Longitude(Fig.10). At its upper part the basin is narrow and elongated while it broadens down along lower part. The upper portion of the basin is characterised by rugged mountainous topography, whereas lower basin consists of low hills and aggradational plain. The average height of the basin is about 2200m. above mean sea level. The basin ground elevation varies from 4000m to 400m above mean sea level. The slope of basin is from East to west in the upper part, while North-East to South-West in the lower part. The river, at its upper reaches is fed by melting of snow and ice of Kali-kundi glacier at its origin and by rain. In the lower catchment it is predominantly rain fed. A small area of about 200 sq km. is snow bound. The upper part of the basin is covered by hard granite intrusive rocks and the lower part by loose and soft siwalik rocks.

The Tawi river basin falls mostly within the districts of Jammu, Udhampur and a small portion of Doda districts. In the present study, the area of about 1885 sq km up to Jammu has been considered.

4.2 Climate :

In the Tawi Basin July and August are generally the wettest months with about 55% rainfall and November is the least rainy month with about 2-3% of total rainfall. Tawi experiences heavy flood in July & August. Monsoon starts from first July with heavy thunder showers and up to mid September. Normal annual rainfall varies from 111cm to 150cm within the basin. The climate of the basin is characterised with three distinct features:

-The north eastern catchment area comprising of Bhaderwah and adjoining area where climate is extratropical mountain type. The mountain type climate has wide variation in temperature and rainfall depending upon the location and direction of the land features. In this area winter is very severe and influence of south-west monsoon is negligible.

-Central territory consisting of Udhampur district where also climate is of mountain type but having sufficient influence of monsoon.

-The south-western zone consisting of Jammu district where climate is warm with strong monsoon influence, can be described as similar to tropical wet & dry climate during certain part of the year. The river Tawi is snow fed at its origin from the Kali-kundi glacier. The Kali-kundi and Seoj-dhar start experiencing snowfall in November. Snow is very heavy in January and February. In high elevations, snowfall is very deep and in some years continuous till May.

4.3 Water Resources :

The river Tawi is endowed with vast water resources potential for irrigation, domestic water supply and power geneartion. A study on assessment of water availability has been done by the NIH regional centre(NIH report CS-86).The river is of about 141km length up to the point it enters Pakistan, from its origin at Himalayan Kali-kundi glacier. It has nine major tributaries carrying discharge mostly in monsoon period only. The maximum discharge of Tawi was 4.3 lakh cusec in september, 1988 at Jammu and minimum discharge was about 300-400 cusecs. Low water flow is experienced during the month of October, November and December. But there is occasional rise of water level during winter due to rains and in the early summer due to snow melt from the seasonal snow cover in the upper catchment.

4.4 Soil :

Comprehensive soil survey for Tawi basin has not yet been done. However, the soil classification of Tawi basin exhibits zonal properties as follows:

In Doda district, of which a very small portion is lying within the basin, the soils are mainly alluvial in nature. Whereas in the midlands or foot hills, the process of colluviation seems predominant. Generally the silt or other materials, brought down by the action of water gets deposited at the foothill and give rise to soil formation. The texture, in general varies from sandy loam, sandy, to silty clay loam.

In Udhampur part, the soils are moderately deep to deep on the mid hills and plateaus whereas deep to very deep at the foothills. The texture in general is coarse to medium.

Soil of district Jammu are alluvial subtropical having a texture varying between sandy loam to silty clay loam. The lower part is recent alluvium whereas the outer plains are pleistocene. The foothills of Siwaliks are moderately deep to deep soils with coarse texture having stony face in general and due to lack of irrigation, these are left as uncultivated fallows.

4.5 Geology :

Western Himalaya is geologically described as lying within moving belt of earth's crest. Like other parts Tawi basin mainly consists of Siwaliks, Murree and granite intrusions. Tawi basin has three Meso geomorphic regions:

- Kaplas Granite zone from Kaplas range to Panjal Thrust. Kaplas granite associated with Bhaderwah slate, Sewa para gniess etc. are the main features of the area. Maximum elevation of Kaplas range is 4000m.
- thrust zone from Panjal thrust to Udhampur thrust having same tectonic structures like Panjal thrust. The height of this region is from 700m to 1900m.
- Siwalik zone: Lying between Udhampur thrust and Jammu. Most of the region consists of hilly as well as plain areas.

4.6 River Profile :

From origin to outfall the long section of Tawi river exhibits (Fig.11) wide degree of variations. The variation in slopes along different river reaches are as follows:

R.L. 4000m - 1600m = Steep gradient of 1:10.42

R.L. 1600m - 900m = Slight changes in slopes

Below 800m = Slope is decreasing

However, variation is not linear. The gradient changes from very steep at upper part to concave and flat in the lower courses. The reason may be there is degradational process in upper stage and aggradational process in lower stages. Based on field investigations it has been reported that flood plains, meander, meander core and other depositional land forms are formed at the lower course of the river. These are all indicative of non regime nature of the river.

5.0 METHODOLOGY :

Procedure for estimation of various geomorphological parameters of the river basin, in requirement of many hydrological studies, is described in this section. For the purpose, a large scale basin map 1:50,000 of Tawi river up to Jammu was prepared from Survey of India toposheets. Field verification of the map was made to some extent and before finalising it, the delineation of drainage divide was also compared with Forest Survey of India map. The geomorphological parameters that are used in hydrological models and having potential to describe basin characteristics are broadly grouped under three categories.

I Linear Aspect of the Channels System

II Areal Aspect of the Catchment

III Relief Aspect of the Basin

Based on the methodology and works done by many earlier investigators like Horton(1945), Strehler (1953,1956,1964,1968), Chroley (1957), Miller (1953), Schumm (1954), Bernard (1935), Snyder (1938), Linsey (1943), Jetter (1944), Lucas (1944), Taylor (1952), Eaton (1954), Yonezol (1956), Mockus (1975), Nash (1960), Gray (1961), CWC (1980), Gundlach (1975) etc., the parameters under these three aspects are studied and quantified as described below :

5.1 Linear Aspect of the Channel System :

Linear aspect of basin characteristics includes overland flow lengths of channels of all orders. Usefulness of ordering channel system lies on the hypothesis that basin size, channel dimension, and stream flows are proportional to the stream orders provided investigation is made for quite large number of watersheds. Two basins having different Linear measures can be compared with respect to corresponding points in their geometry through use of dimensionless order number. However, such comparisons should be made at locations in the two systems that have similar geometry, that is, second order streams, third order streams, and so forth.

5.1.1 Stream Orders :

Horton (1945) pioneered quantitative study of channel networks by classifying the channels by order in United states. This was slightly modified by Strahler (1952). Melton (1959) explained the mathematical concepts involved. As per Strahler's scheme of ordering in a channel network map showing the intermittent and permanent flowlines located in clearly defined valleys, the smallest unbranched (finger tip) tributaries are designated as order one (Fig.11). The point at which two first order streams join, a channel segment of order 2 is formed. Where two streams of 2nd order join, a segment of order 3 is formed and so on. The main or trunk channel carrying the entire discharge of the drainage basin upstream of basin outlet is obviously the segment of highest order. Parameters under linear aspect of channel system and their estimations are described below:

5.1.2 Length of Main Channel, (L) :

This is the length of the longest water course when projected on a horizontal plane, (i.e. in a map) from the basin outlet to the farthest point on the basin boundary. To measure this length there are several conventional methods like pair of dividers, thread length, edge of paper strip, opisometer and so on. This can also very well be done by Analog to Digital Convertor by tracing along the main channel with the cursor which records the X and Y co-ordinates of closely spaced points. The digitized co-ordinates of the main channel points are stored in computer and distance between two points is calculated from

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

Length of the channel is the summation of all segmental distances. For the purpose a subroutine 'LENGTH' is already available at NIH (24). Similarly length of all streams of all orders can be found out.

However, in absence of facility lengths of the main channel and other channels have been measured manually with the help of opisometer in the report. Bernard (1935), Snyder (1938), Linsley (1943), Jetter (1944), Lucas (1944), Taylor (1952), Eaton (1954), Yonezol (1956), Mockus (1957), Nash (1960), Gray (1961), CWC (1980) and Gundlach (1975) considered the stream length as one of the catchment characteristics in establishing the relationship for synthetic unit hydrograph (23).

5.1.3 Length of the Channel between the Outlet and a Point nearest 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 (C.G.of the plane area of the drainage basin). The centroid is found out by cutting a card board piece in the shape of the catchment and then balancing it on a horizontal plane with a pivot. Linear measurement of the parameters is same as described in 5.1.2. This measure have been used in the studies of basin lag i.e. time between the centres of mass of effective storm input and the resulting output (30).

5.1.4 Total length of Channels :

This is the total length of channel segments of all orders within the basin. Total length of channels gives an idea of overland flow and channel flow in the watershed. Procedure to estimate this parameter is described in para 5.1.2

5.1.5 Wandering Ratio :

This is the ratio between main stream length along the course to the straight line distance between the two extremes - outlet and farthest point in basin boundary. While this factor broadly indicates the amount of deviation of main stream from straight line path, it does not necessarily explain the meandering of the main stream.

5.1.6 Bifurcation Ratio(Rb)

The ratio of number of stream segments of a given order Nu to the number of segments of the higher order Nu+1 is termed as bifurcation ratio, Rb.

$$Rb = Nu/(Nu+1) \quad (5.1)$$

Calculation on an average value of Rb for a given channel network can be made by determining the slope of the fitted regression of logarithm of numbers (ordinate) on order (abscissa). This means a plot of the Log Nu vs u will approximately yield a straight line with negative slope. The magnitude of the slope is the logarithm of Rb (identical to the regression co-efficient b). If the Rb is estimated to be 3.52, this means that on the average, there are 3 1/2 times as many channel segments of any given order as of the next higher order. Taking precipitation and other factors uniform, an elongated basin (high Rb) would give rise to a hydrograph of low but extended flow peak where as a round basin (low Rb) would produce a sharp peak (22). For a basin with a dipping rock strata where narrow valleys are confined between high ridges the Rb may be abnormally high. Strahler concludes that Rb characteristically ranges between 3.0 and 5.0 for watersheds in which the geologic structures do not distort the drainage pattern. The theoretical minimum possible value of 2.0 is rarely approached under natural conditions. The bifurcation ratio is however, not the same from one to the next order but will tend to be constant throughout the series. This is the basis of Horton's law of stream numbers.

5.1.7 Stream Number (Nu) :

Horton's (1945) law of stream Numbers states that the number of streams of a given order follows an inverse geometric relationship with stream number :

$$Nu = (Rb)^{k-u} \qquad (5.2)$$

Where k = Order of trunk segment i.e. the highest order of the stream in the drainage basin.

u = Order of interest

From eqn 5.2 it follows

$$\text{Log } Nu = (k-u) \log Rb \qquad (5.3)$$

or

$$\text{Log } Nu = a-bu \qquad (5.4)$$

Where a = k log Rb

b = log Rb

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

For computing log Rb a sub-routine "REG" based on least square approach is available. The value of Rb can be used to compute the total number of streams (N) of all orders from the eqn. :

$$N = \sum_{u=1}^{k} Nu = (Rb^{k} - 1)/(Rb-1) \qquad (5.5)$$

These results have been confirmed many times using Strahler's ordering system (2).

5.1.8 Average stream length, ($\bar{L}u$) :

Mean length $\bar{L}u$ of a channel segment of order u is a dimensional property revealing characteristic size of components of a drainage network and its contributing basin surfaces (22).

Law of stream length (Horton, 1945) states that the average length of streams of each of the different orders tend to approximate a direct geometric series (In which the first term is average length of first order streams) with the relation :

$$\bar{L}u = \bar{L}1\ Rl^{(u-1)} \qquad (5.6)$$

Where $\bar{L}1$ = Average length of streams of first order.

$\bar{L}u$ = Average length of streams of order u

Rl = A constant called Length Ratio discussed later

The validity of law of stream length relating Rl when Strahler ordering is used has been studied by several authors Maxwell (1960) & Melton (1957) and indicated considerable variation in segment length data from a geometric series. If it is assumed that the Horton's law of stream length is valid then the Length Ratio Rl of eqn. (5.6) is obtained for the watershed as the antilogarithm of regression co-efficient of a line fitted by inspection or by least square method to the plot of logarithm of stream length on order (23). Broscue (1959) found that substituting cumulative mean length for average length and cumulative Rl in equation (5.6) the geometric series was indeed obtained.

Of interest in the estimation of channel storage capacity for an entire watershed, is Horton's observation that the laws of stream numbers and lengths can be combined as a product to yield an equation for the total length of channels of a given order u, knowing only the Rb and Rl, the mean length L1 of the first order segments and the order of the trunk segment(22). Thus:

$$\sum_{i=1}^{N} Lui = \bar{L}1\ Rb^{k-u} .\ Rl^{u-1} \qquad (5.8)$$

In the report $\bar{L}u$ is calculated from the linear measurement of channel segments i.e. total length of each order is divided by the number of segments of that order such that:

$$\bar{L}u = (\sum_{i=1}^{N} Lu)/Nu \qquad (5.9)$$

5.1.9 Stream Length Ratio, (Rl) :

This is the ratio of mean length Length $\bar{L}u$ of segments of order u to mean length of segments of the next lower order $\bar{L}u-1$:

$$Rl = \bar{L}u / \bar{L}u-1 \qquad (5.10)$$

Horton stipulated that Rl tends to be constant throughout the successive orders of a watershed. Its value is normally between 1.5 and 3.5 in natural drainage networks. It is useful in synthesizing hydrograph characteristics.

Horton gave another method for computing Rl (or also to estimate total length of channels of all orders of a watershed of order k) by introducing the term Rlb (= Rl/Rb) which is found from :

$$\sum_{u=1}^{k} \sum_{i=1}^{Nu} Lui = \bar{L}1.Rb^{k-1}\ (Rlb^{k}-1)/(Rlb-1) \qquad (5.11)$$

(5.11)

Nu = Total number of streams of order u

Here RHS i.e. total stream length of all orders, $\bar{L}1$ and Rb are known and Rlb can be calculated. Then Rl is calculated from:

$$Rl = Rb/Rlb \qquad (5.12)$$

Since the form of the equation (5.11) is non linear, solution of Rlb can be obtained by technique based on Newton-Raphson non linear optimisation. For the purpose a separate sub routine, NEWTON has been developed at NIH (24).

5.1.10 Basin Perimeter (P):

Basin perimeter is the total length of the basin boundary or the length measured along the divide between basins and may be used as an indicator of basin size and shape. It was emphasized by Smith (1950) in his derivation of Texture ratio.

5.1.11 Fineness Ratio :

The ratio of the channel lengths to the length of the basin perimeter is termed by Melton (1957) as the fineness ratio which indicates fineness of the topography.

5.1.12 Watershed Eccentricity (T) :

Black (1972) gave the expression for T as:

$$T = \frac{[(Lc^2 - Wl^2)]^{1/2}}{Wl} \qquad (5.13)$$

where Lc = Length from the watershed mouth (outlet) to the centre of mass of watershed.

Wl = the width of the watershed at the centre of mass and perpendicular to Lc.

when Lc = Wl eccentricity become zero. Greater is the value of (Wl-Lc) or (Lc-Wl) more will be the eccentricity, lesser will be the compactness of watershed near the mouth and lower will be the flood peak.

5.1.13 Length of Overland Flow, (Lo) :

Horton (1945) defined Lo as the length of flow path, projected to the horizontal, of non channel flow from a point on the drainage divide (basin boundary) to a point on the adjacent stream channel (22). It is the length of overland flow of water before it joins a channel. The average length of overland flow $\overline{Lo}$ is approximately half the average distance between stream channels and is therefore approximately equal to half the reciprocal of drainage density (discussed in Areal Aspects in clause 5.2.3) such that (22) :

$$\overline{Lo} = 1/2D \qquad (5.14)$$

Horton noted that "length of overland flow is one of the most important independent variables affecting both the hydrologic and physiographic development of drainage basins (7).

5.2 Areal Aspect of Watershed :

Areal measure of a drainage basin net works relate to many of its hydrologic characteristics. Some of these characteristics and methodology of estimation adopted by various investigators are described below :

5.2.1 Area of Drainage Basin, (A) :

The basin area is the plane area within the perimeter along the drainage divide. It is one of the most important characteristics of the basin reflecting the run-off process. The area of the basin of a given order u is defined as the total area projected upon a horizontal plane contributing overland flow to the channel segment of the given order and including all tributaries of lower order. Thus Schumm (1956) stated that the area of basin of fourth order A4 would cumulate the area of all first, second, and third order basin plus all additional surface elements, known as INTER BASIN AREAS, contributing directly to a channel of order higher than first (27). Estimation by comparison of watershed tracing with square of rectangle of known dimension, polar planimeter, Dotgrid, strip sub division, geometric sub division, Analog to digital converter are some methods to measure basin area (9).

5.2.2 Law of Stream Areas : Area Ratio, (Ra) :

The concept of law of stream area is same as the law of stream lengths and stream numbers. Horton (1945) stated that mean basin areas ($\bar{A}$) of progressively higher orders should increase in a geometric sequence as do stream lengths. Schumn (1954) expressed this relationship in a law of stream areas which states that "mean basin areas of the stream of each order tend closely to approximate a direct geometric sequence in which the first term is the mean area of the first order(27). Mathematically:

$$\bar{A}u = \bar{A}1 \ (Ra)^{u-1} \qquad (5.15)$$

where $\bar{A}u$ = mean area of basin of order u.

$\bar{A}1$ = mean area of basin of order .

Ra = an area ratio analogous to Rl

which follows:

$$Ra = \bar{A}_u / (\bar{A}_{u-1}) \qquad (5.16)$$

Smart (1972) concludes that for natural basins value of Ra normally ranges from 3 to 6.

5.2.3 Drainage Density, (D) :

Horton (1945) defined drainage density as the ratio of total channel segment lengths of all orders within a basin to the area of the drainage basin projected to horizontal and expressed as the number of miles of channels per square mile of basin area.

$$D = \frac{\sum_{u=1}^{k} \sum_{i=1}^{Nu} L_{ui}}{A} \qquad (5.17)$$

Dimensionally this ratio reduces to inverse of length (L^{-1}) and hence is a quantity dependent on the level of resolution of the map from which lengths are measured. Horton relates drainage density to the Horton numbers (Z) as :

$$D = \frac{\bar{L}_1 . R_b^{k-1} . R_{lb}^{k} - 1}{R_{lb} - 1} \qquad (5.18)$$

Drainage density characterises textural measure independent of basin size and considered to be function of climate, Lithology, stage of development etc. In fact the drainage density has been considered as a basic length scale. If drainage density is constant everywhere in the basin then the average length of contributing hill slope is approximately half the average distance between stream channels as expressed in equation (5.14). Various Investigators measured drainage density for different geologic and climatic conditions as follows:

Table-1

Watershed/Location	Topography	D m/sq mile	Reference
1. Appalachian Plateau Province Pennsylvenia	Resistant Sand stone strata	3 to 4	Smith (1950) Morisawa(1959)
2. Central & Eastern United State Nashville	Rocks of resistance under deci-duous forest humid climate	8 to 16	Strahler(1952) Coates (1958)
3. Rocky Mountain Region	Drier areas	50to100	Melton (1957)
4. Coastal Southern California	Fractured & Weathered igneous & metamorphic rocks,dry summer sub tropical climate	20to30	Smith (1950) Strahler(1952)
5. - do -	Where weak Pleistocene sediments are exposed	30to 40	- do -
6. Badlands National Monument	South Dakata	200to400	Smith(1958)
7. Perth Amboy,N.J.	Badlands on Weak clay	1100to1300	Schumm(1956)

5.2.4 Constant of Channel Maintenance, (C) :

Schumm (1956) used this term as the inverse of drainage density i.e.

$$C = \frac{1}{D} \qquad (5.19)$$

With its unit as sq. ft per foot (on a horizontal plane) the term indicate the square feet of watershed surface required to sustain one linear foot of channel.

5.2.5 Stream Channel Frequency, (F) :

Stream Frequency or channel frequency was defined by Horton (1945) as the numbers of stream segment per unit area or

$$F = \frac{N}{A} \qquad (5.20)$$

where N = Total stream segments of all orders
A = Drainage area of the basin

Relationship between drainage density (D) and stream frequency both of which measure the drainage texture (but each treating a distinct aspect) was studied by Mellon (1958). Although both the terms measure different properties, Melton found a dimensonally correct equation as:

$$F = 0.694\ D^2 \qquad (5.21)$$

This implies that the dimensionless ratio F/D^2 approaches a constant value of 0.694 independently of scale.

5.2.6 Circularity Ratio, (Rc) :

Miller (1953) introduced a dimensionless circularity ratio which is defined as the ratio of the basin area to the area of a circle having circumference equal to the perimeter of the basin.

The value of this ratio approaches one as the shape of the basin approaches a circle, Miller found the value consistently in the range of 0.6 to 0.7 for first and second order basins in homogeneous shales and dolomites, indicating the tendency of small drainage 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 had values of Rc between 0.4 to 0.5.

5.2.7 Elongation Ratio (Re) :

Schumm (1956) defined elongation ratio as the ratio of diameter of a circle of the same area as the basin to the maximum basin length. Obviously for a circular basin the value tends to unity. This ratio runs between 0.6 to 1.0 over a wide variety of climatic and geologic types. Values near to 1.0 are typical of regions of very low rel ef,where as value in the range of 0.6 to 0.8 are generally asso ated with strong relief and steep ground slopes.

5.2.8 Form Factor (Rf) :

Horton (1932) used this dimensionless quantity which he defined as the ratio of basin area (A) to the square of the basin length (L), measured along the longest water course.

$$Rf = A/L^2 \qquad (5.22)$$

This is a quantitative expression of basin shape (outline form). In its inverted form, L^2 / A, this ratio was used in unit hydrograph applications by the U.S.Army Corps of Engineers (4).

5.2.9 **Compactness Ratio (Rk) :**

Basin shape has been defined by an alternate descriptor based on perimeter rather than area. The compactness ratio is the ratio of the catchment perimeter to that of the equivalent circle having area as that of the basin. This leads to (18):

$$Rk = \frac{0.282\ P}{A^{1/2}} \qquad (5.23)$$

5.2.10 **Watershed Shape Factor (Rs) :**

This was defined by Wu et. al (1964) as the ratio of main stream length L to the diameter D of a equivalent circle having same are as the basin.

$$Rs = \frac{L}{D} \qquad (5.24)$$

5.2.11 Unity Shape Factor (Ru) :

Smart & Surkan (1967) used the unity shape factor to be defined as the ratio of the basin length L to the square root of the basin area (A).

$$Ru = \frac{L}{A^{1/2}} \qquad (5.25)$$

5.3 Basin Relief Aspect :

Relief morphometry of river basin describes variation of elevations between the highest and the lowest point. This is significant to study the flow phenomena in the watershed. The potential energy of flowing water from high altitude gets converted to kinetic energy which is related to slope. Various losses of water like storage, infiltration, evaporation etc. and travel time are inversely related to slope. The parameters relating to relief aspect of the drainage network are as follows:

5.3.1 Basin Relief (H) :

Relief is the elevation difference between two reference points. Maximum basin relief (H) is the elevation difference between the highest point in the catchment divide and the catchment outlet. Methods of measurement of basin relief adopted by various investigators are different. Schumm measured basin relief along the Longest dimension of the basin parallel to the principal drainage line. Basin relief may also be obtained by determining the mean height of the entire basin perimeter above the mouth, thus minimising the spurious effects of sharply pointed summits (4).

5.3.2 Relief Ratio (Rh) :

"Relief ratio is the ratio of the maximum basin relief (H) to the catchment's longest horizontal straight distance measured in a direction parallel to that of the principal water course (18)". Schumm (1956) explained that taking vertical and horizontal distances as legs of a rightangled triangle, relief ratio is equal to the tangent of the lower acute angle and is identical with the tangent of the angle of slope of the hypotenuse with respect to the horizontal. The relief ratio thus measures the overall steepness of a drainage basin and is an indicator of the intensity of erosion processes operating on slopes of the basin.

5.3.3 Relative Relief (Rhp) :

Melton (1957) used the term relative relief which is basically the ratio of the basin relief to the perimeter and expressed in percent, as:

$$Rhp = \frac{100\ H}{5280\ P} \qquad (5.26)$$

Where
H = Maximum basin relief in ft.
P = Basin perimeter in miles

5.3.4 Ruggedness Number (Rn) :

To take into amount of both slope steepness and length, a dimensionless ruggedness number has been used by Melton (1957) and Strahler (1958). It is defined as the product of relief H and drainage density D (both in same unite) i.e.

$$Rn = H \times D \qquad (5.27)$$

Observed values of the ruggedness number range from as low as 0.06 in the subdued relief of the Louisiana coastal plain to over 1.0 in coast ranges of California or in badlands on weak clays (4).

5.3.5 Law of Basin relief :

The law postulated by Maxwell (1960) states that the mean relief of basins tends to closely approximate a geometric series and is expressed as:

$$\bar{H}u = \bar{H}\,1\ Rh^{u-1} \qquad (5.28)$$

Where $\bar{H}u$ = Mean relief of a watershed of order u.

$\bar{H}1$ = Mean relief of a watershed of order 1

Rh = Relief Ratio.

6.0 ANALYSIS AND DISCUSSION OF RESULTS :

To estimate the hydromorphologic parameters of Tawi sub-basin the topographic map delineating the basin divide and other topographic features was prepared from Survey of India topo sheets Nos. 43/O, 43/p, 43/k and 43/L published by survey of India in the scale 1:50,000 (Fig10). The stream net work has been ordered using strahler's ordering procedure (Fig.11). It is principally a 7th order network having 5561 first order 1282 second order 384 third order 116 fourth order, 23 fifth order and 11 sixth order streams contained in the drainage area under investigation of 1885 sq km up to Jammu city. Ranging from 400 m to about 3000 m the average basin elevation is about 2200 m . The longitudinal profile of the river Tawi from its origin at Kalikundi Glacier up to Jammu is shown in Fig.12.

From the map the basic linear parameters like basin perimeter, lengths of streams , basin length etc. were measured manually with the help of opsiometer. The basic parameters of areal aspects like basin area, areas of different order streams etc. were measured from the map with a planimeter and other derived parameters were estimated with the relationships discussed under clause 5.2. To study the relief aspects of the basin a contour map of the whole basin was prepared with contour interval of 200 m . The numbers lengths and areas of different channel segments are furnished in table - 2.

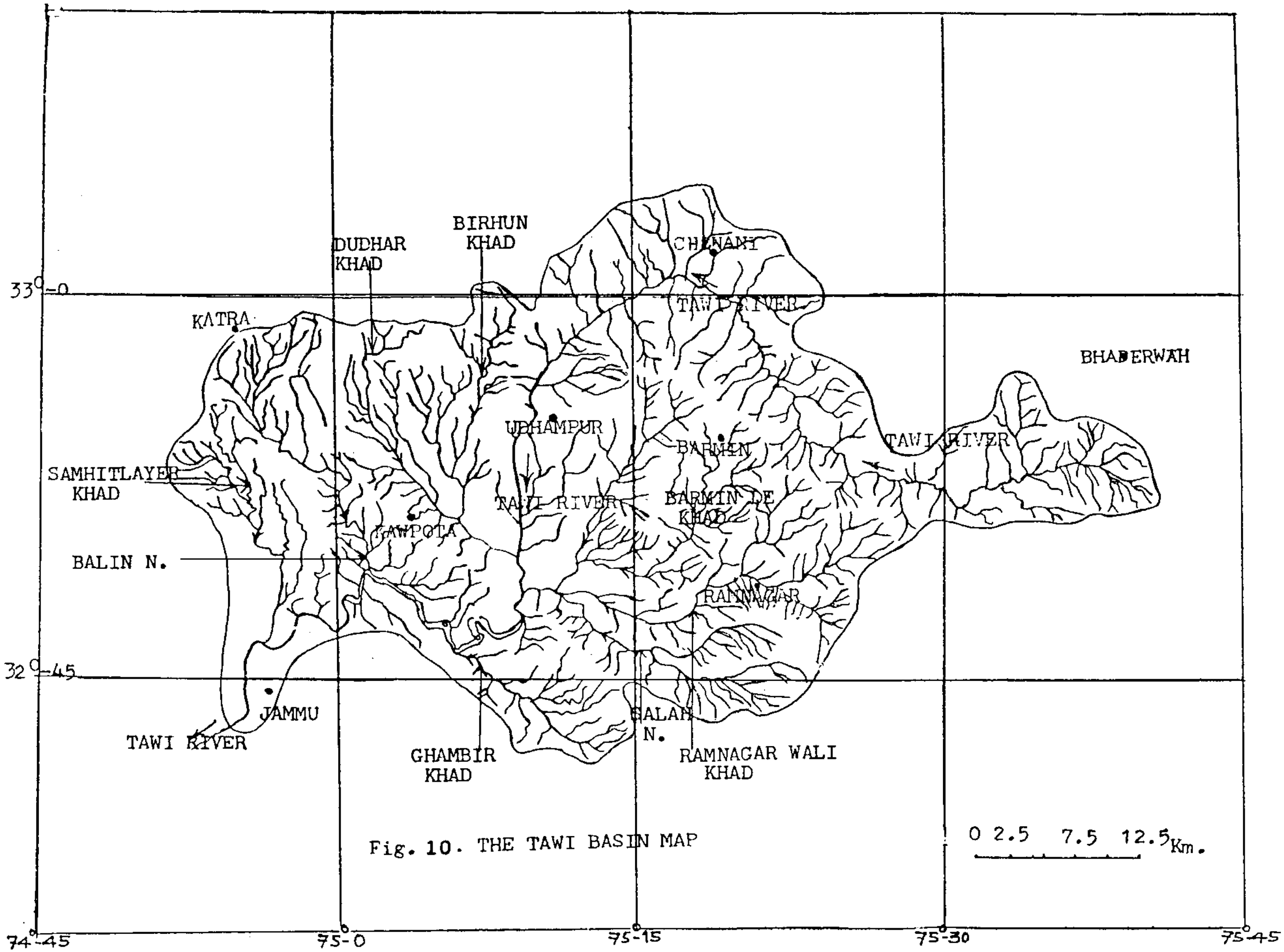

Fig. 10. THE TAWI BASIN MAP

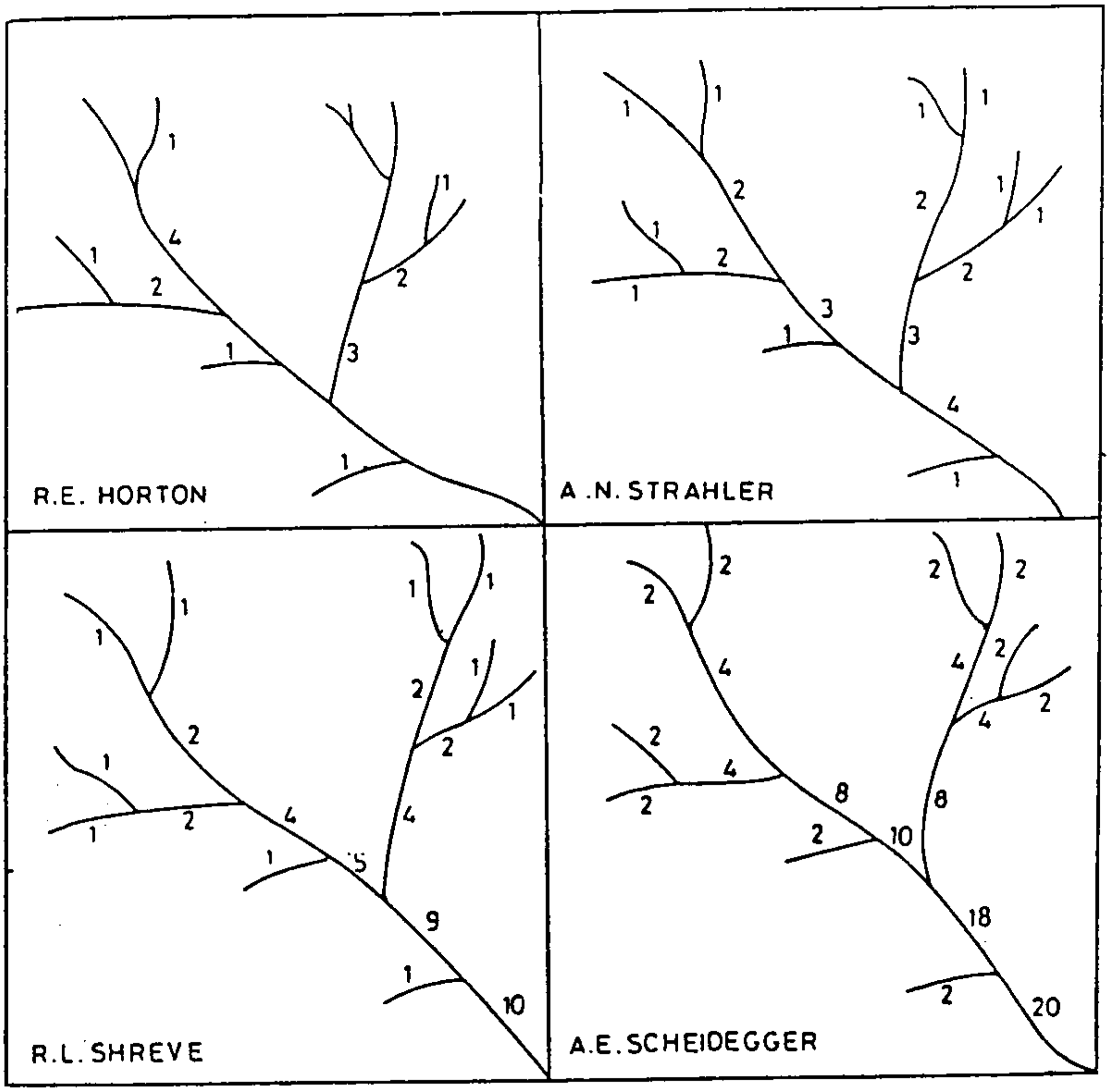

FIG : 11: METHODS OF STREAM AND SEGMENT ORDERINGS

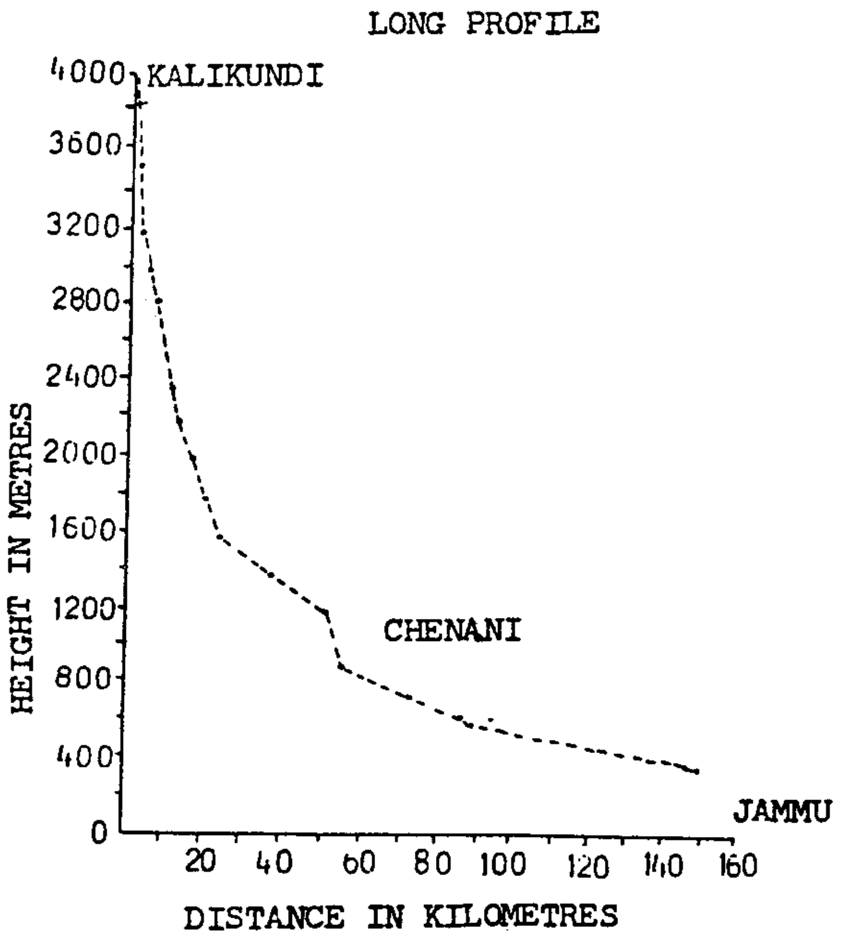

FIG. 12 : L - SECTION OF THE TAWI RIVER

Table-2

stream order	stream nos.	stream length L,km	average length $\bar{L}$ km	area,A sq.km	mean area $\bar{A}$ sq.km
1	5561	2625.5	0.4721	953.06	0.1714
2	1282	834.55	0.6510	406.82	0.3173
3	384	605.0	1.575	203.49	0.5299
4	116	305.o	2.629	111.93	0.9649
5	23	154	6.696	78.73	3.423
6	11	106	9.636	73.85	6.713
7	1	54	54	57.12	57.120

The results of the study in respect of linear, areal and relief aspects are discussed below:

6.1 Linear Aspect of Tawi Basin :

The parameters studied under this aspect and their quantitative measures are furnished in Table-3.

Table-3

1. Length of main channel, L	138.25 km
2. Length upto centroid, Lc	35.00 km
3. Length of Basin/Valley length, Lv	78.50 km
4. Total length of channel, Lt	4684.05 km
5. Length of overland flow, Lo	0.2016 km
6. Basin perimeter, P	265.0 km
7. Watershed eccentricity, Ew	0.316

Table-3 Contd.

8. Length ratio, RL	1.955
9. Wandering ratio, Rw	1.761
10. Fineness ratio, Rf	0.5216
11. Bifurcation ratio, Rb	3.809

It can be seen from the Table-2 that the average length (total length devided by the numbers) of stream increases with increasing order. Whereas number of stream shows a decreasing trend from lower order to higher order. The non dimensional parameters (i.e. bifurcation ratio and length ratio estimated), reflect to peak time characteristics of the Tawi basin and may be used in the hydrological modeling. The measure of length upto centroid may be useful in the regional unit hydrograph studies. The other linear measures shown in Table-3 for the Tawi basin will also be useful to describe the various hydrologic properties of the net work as discussed in Chapter-5. Fig. 13 shows the variation of stream number with stream order on semi-log plot. The negative slope of the line confirms the law of stream numbers indicating reduction of number from lower to higher orders. Fig.14 shows a semi log plot of the quantities of stream order vs average stream length. The plot shows the increasing trend in average length with increasing order following Horton's Law of stream length.

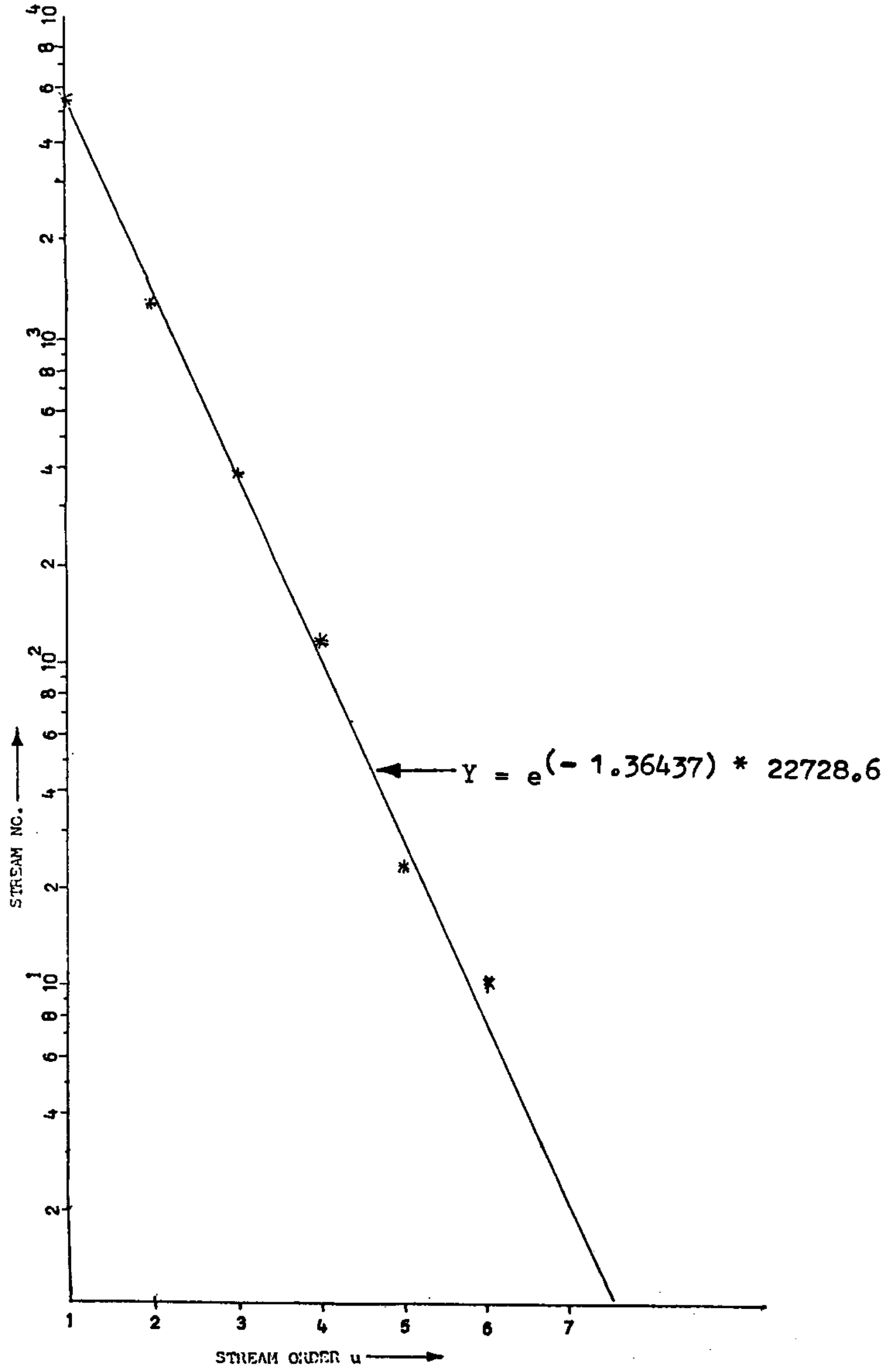

Fig. 13 VARIATION OF STREAM NO. WITH ORDER

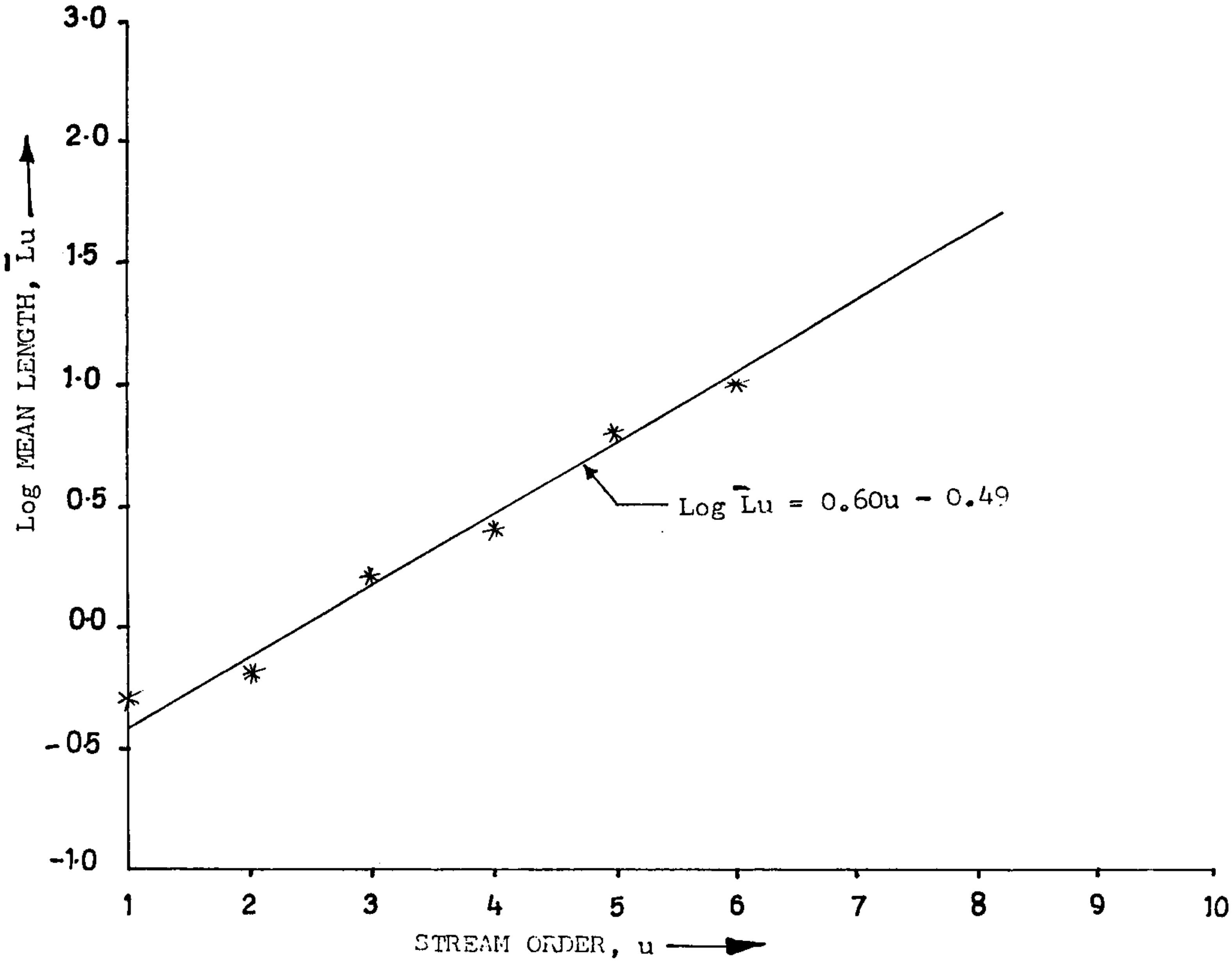

Fig. 14 VARIATION OF MEAN STREAM LENGTH WITH ORDER

6.2 Areal Aspect of Tawi Basin:

The basinal properties of the Tawi drainage network in terms of areal measures as described in clause 5.2, has been studied and the parameters of areal aspects are estimated as presented in Table-4.

Table-4

1. Drainage Area, A	1885.00 sq.km
2. Drainage Density, D	2.48 km / sq.km
3. Constant of Channel Maintenance,C	0.40 km/km
4. Channel Segment Frequency, F	3.914/ sq.km
5. Circularity Ratio, Rc	0.3373
6. Elongation Ratio,Re	0.6240
7. Watershed Shape Factor, Rk	2.820
8. Unity Shape Factor,Ru	1.800
9. Form Factor, Rf	0.3058
10. Compactness Ratio, R	1.7090

From Table-2 & Table-4, it is observed that there is an increasing trend in the mean areas of different order streams with increasing order which confirms the Schumm's Law of stream areas as discussed in para 5.2.2. A semi log plot to this effect between mean areas and orders is shown in Fig.15. The other areal measures furnished in the Table-4 above are regarded to have effect on peak and shape of the basin hydrograph and may be used in modeling the hydrological response of the basin when flow

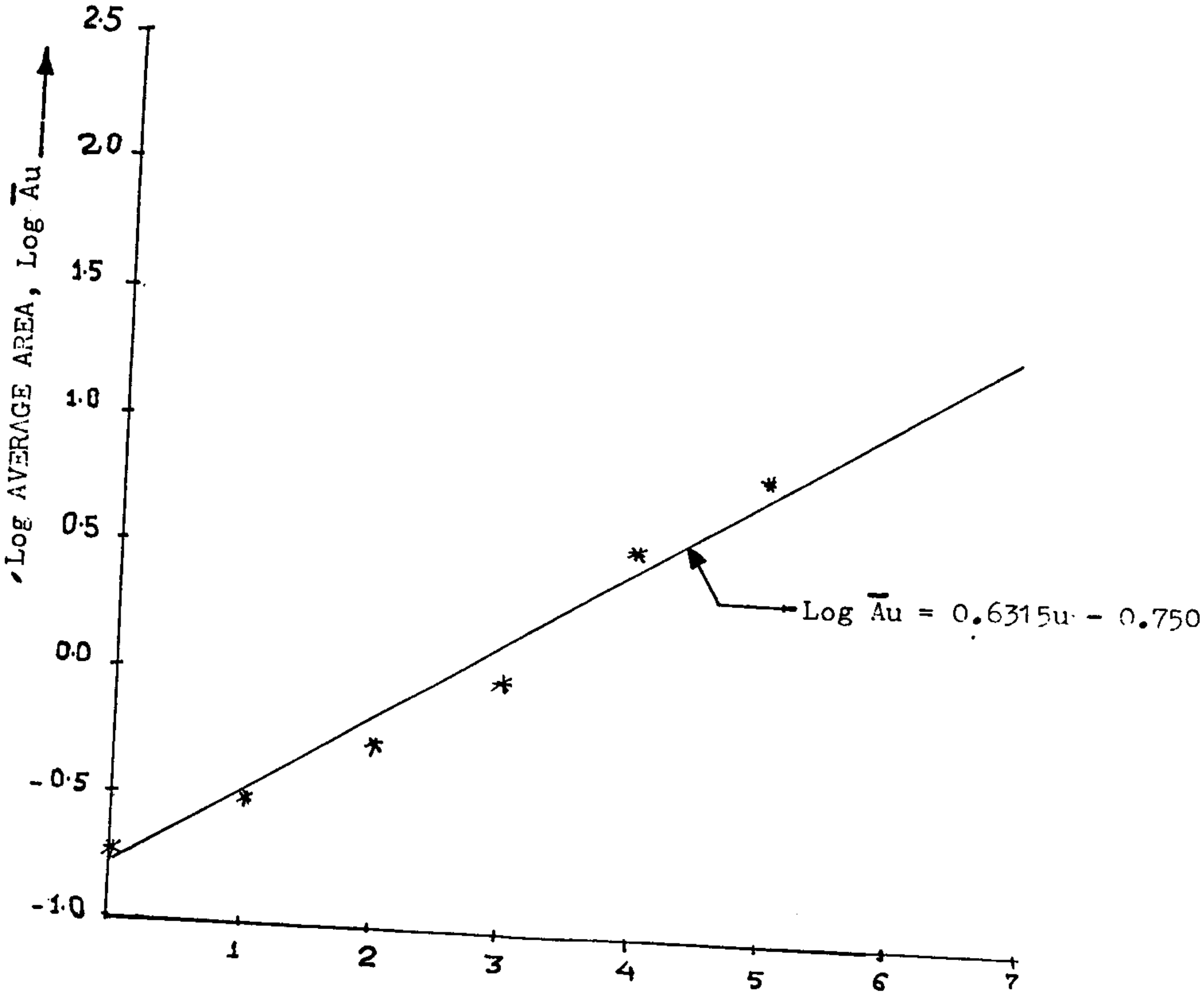

Fig. 15 MEAN AREA Vs STREAM ORDER

records are not available.

6.3 Relief Aspect of Tawi Basin:

The geomorphological parameters, of interest to hydrology, under this aspect has been described in clause 5.3 and accordingly these are estimated for Tawi Basin. The results are furnished in Table-5. The relief measures of the basin which are mostly non-dimensional have significant effect on overland flow governing the flow processes.

As discussed in Chapter-5, these areal descriptors are of great importance specially for a mountainous catchment like Tawi to understand the storage and flow characteristics, intensity of erosion processes operating on slope, comparison of basins for hydrograph synthesis etc.

Table-5

1. Basin Relief,H	3.780 km
2. Relief Ratio, Rh	0.0480
3. Relative Relief, Rhp	0.014
4. Ruggedness Number,Rn	0.2770
5. Taylor & Schawrtz Slope	0.378

Fig.16 shows a general slope map of the Tawi basin in the direction of basin mouth to the extreme point at basin divide on the upstream.

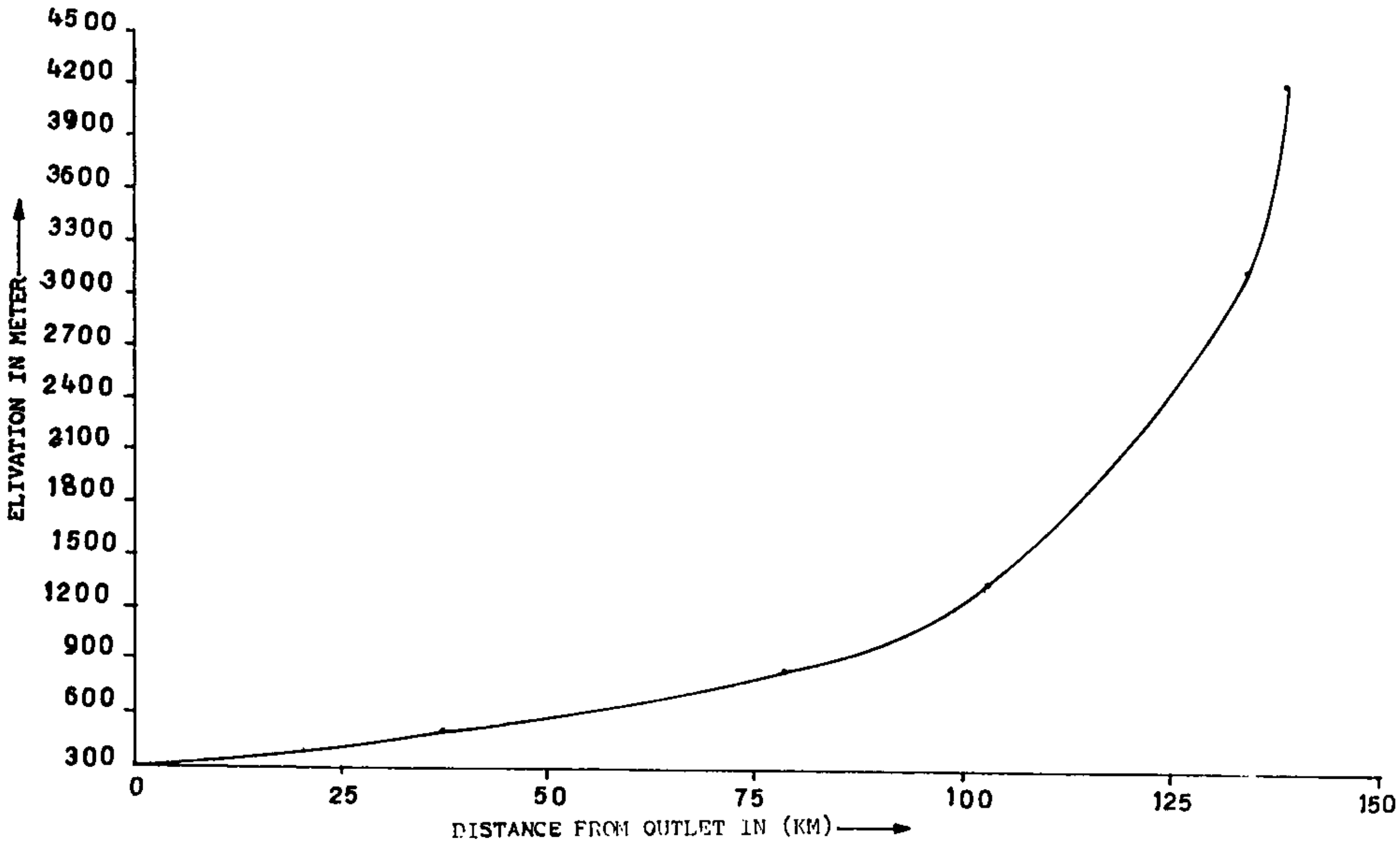

FIG. 16 APPROXIMATE SLOPE MAP OF TAWI BASIN

7.0 CONCLUDING REMARKS :

In the light of review and discussion on various elements on geomorphology of interest to hydrology in the previous chapters, it is seen that, in absence of adequate data, specially in ungauged basins, the measurable geomorphological properties can be applied to synthesize the run-off response of the basin. However, in India, not enough successful applications of geomorphological characteristics to specific hydrologic studies in a basin and then transforming the results to other basins have yet been documented. There are, therefore, many limitations in substituting the results of such applications for more traditional tools of hydrologic methods.

The hydrogeomorphological parameters as suggested by many investigators have been estimated for Tawi sub-basin from a toposheet manually which is very tedious, time consuming and prone to human error. It is felt that use of a digitiser where basic map data can be quickly, accurately and inexpensively converted into a form for automatic machine data processing would have been more helpful.

The estimated geomorphological parameters of Tawi basin covering linear, areal and relief aspects as presented in the report , will be helpful in estimating and modeling flows of the basin.

In the Tawi basin, the existing net work of hydrometeorological observation is not sufficient. The daily flow data are available for about 13 years (1977 to 1987) at Jammu site only. While long term daily rainfall data are available there are many gaps. Moreover hourly storm data are not available. Therefore, difficulty has been faced to develop reliable design flood hydrograph. Now with the estimated geomorphological parameters of the basin it may be possible to develop synthetic Geomorphological Instantaneous Unit Hydrograph or evaluate important hydrologic model parameters like that of Nash Model (Nash,1960).

The geomorphological characteristics of Tawi basin will provide a simple means to compare it with other basin to regionalise the experimental results.

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