QUANTITATIVE ANALYSIS OF RUNOFF PARAMETERS IN SELECTED RIVER BASINS OF KERALA

By

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THESIS

Submitted in partial fulfilment of
the requirement for the degree

Master of Science in Agricultural Engineering

Faculty of Agricultural Engineering
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1990

DECLARATION

I hereby declare that the thesis entitled "Quantitative Analysis of Runoff Parameters in Selected River Basins of Kerala" is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

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Tavanur,

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CERTIFICATE

Certified that this thesis, entitled "Quantitative Analysis of Runoff Parameters in Selected River Basins of Kerala" is a record of research work done independently by Kum. **Jayasree, S.** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship, or associateship to her.

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SYMBOLS AND ABBREVIATIONS

A	-	Drainage area
am	-	ante meridian
cm	-	centimetre
D_d	-	Drainage density
D_s	-	Stream frequency
et al.	-	And other people
KSEB	-	Kerala State Electricity Board
km	-	kilometre
L_u	-	Summed length streams of order 'u'
L_1, L_2, L_3, L_4 & L_5	-	Summed length of streams of order 1,2,3,4, and 5
$\overline{L}_u$	-	Average length of streams of order 'u'
$\overline{L}_1$, $\overline{L}_2$, $\overline{L}_3$, $\overline{L}_4$ & $\overline{L}_5$	-	Average length of streams of order 1,2,3,4 and 5
L	-	Total length of streams of all orders
L_m	-	Maximum straight length of sub-basin
L_s	-	Length of main stream
M	-	Constant of channel maintenance
Mm^3	-	Million metre cubed
N_u	-	Number of streams of order 'u'
N_{u+1}	-	Number of streams of order u + 1
N_1, N_2, N_3, N_4 & N_5	-	Number of streams of order 'u' 1,2,3,4, and 5
N	-	Total number of streams of all orders
P	-	Monthly rainfall
P_1	-	Monthly rainfall of the same month
P_2	-	Monthly rainfall or the previous month
pm	-	post meridian
PWD	-	Public Works Department
Q_{m1}	-	Average monthly monsoon discharge during 1976-'80
Q_{m2}	-	Average monthly monsoon discharge during 1981-'85
q_{m1}	-	Average monthly monsoon discharge per unit area during 1976-'80

q_{m2} - Average monthly monsoon discharge per unit area during 1981-'85

Q_1 - Monthly monsoon discharge during 1976-'80

Q_2 - Monthly monsoon discharge during 1981-'85

r - Correlation coefficient

r_b - bifurcation ratio

r_l - Average length ratio

R_c - Confluence ratio

R_L - Summed length ratio

R_e - Elongation ratio

R_f - Form factor

Vs - Versus

% - Per cent

S.R.O. - Surface Runoff

Introduction

INTRODUCTION

The drainage basin as a whole can be considered as a system unit having permanent exchanges of matter and energy with its surroundings. The inputs of the system are from precipitation, man's action, underground sources, wind and solar radiation. The outputs are runoff, evapotranspiration, output due to man's action, wind and underground water. The evolution of a drainage basin is the result of the interactions between the flow of matter and energy and the resistance of the topographical surface. Precipitation is the major source of matter and solar radiation, the source of energy.

Repeated rainfall with erosive effect creates embryonic drainage paths. Well formed channels are developed by the movement of precipitation in several stages. First comes direct action of rainfall on the soil, then surface runoff on the sloping ground. The two dimentional surface flow becomes linear where several streamlets join. Their combined energy carve the topographical surface. Repeated carving of the surface increases the depth and length of the stream.

The nature of stream flow in a region is a function of geomorphological and hydrological factors of the river basin. Geomorphology is the science dealing with measurements of the form of the earth's crust. Information necessary to this end can be obtained from three main sources, by the measurement about the form of the land and about the spatial distribution of land forms, from the information about the process responsible for the production of particular types of land forms and by the analysis of deposits indicating the processes which occurred in the past. Hydrological factors include precipitation, evapotranspiration, solar energy etc.

Satisfactory surface flow rate and quality are highly important to such fields as Municipal and industrial water supply, flood control, stream flow forecasting, reservoir design, navigation, irrigation, drainage, water quality control, water based recreation and fish and wild life management. Mathematical models can be used in the planning and development of water resources on a long term basis.

Rivers warrant geographical study for three main reasons Firstly, because of their existence in the physical landscape and their significant role in producing fluvial land forms. Secondly because of their relation to many other geomorphological processes and thirdly, because of their significance for human use.

The basic objective is to study the geomorphological and hydrological relation and to develop the required mathematical models. The selected river basins are Chaliyar and Kabbani. The specific factors to be studied are

1 Morphological factors

a. Linear aspects

(i) Stream order and the number of streams of each order

(ii) Stream lengths of each order

(iii) Bifurcation ratio

(iv) Length of overland flow

b Areal aspects

(i) River basin area

(ii) Basin shape

(iii) Drainage density

(iv) Constant of channel maintenance

(v) Stream frequency

(vi) Pattern of drainage

(vii) Vegetal cover

2. Climatic factor

Rainfall

3. Average annual runoff and peak runoff

The present study gives an insight into the runoff parameters of the basins considered. These are applicable to the river basins under similar conditions. The method helps to quantify the factors controlling runoff.

Review of Literature

REVIEW OF LITERATURE

To understand the morphological systems and to analyse the form process relationships, it is necessary to express the character of the drainage basin in quantitative terms. Any river network demands the adoption of a classification system for its analysis.

2.1 Classification of river network

The first attempt to classify the rivers was made by Gravelius (1914). He considered the largest river to be of first order, from source to mouth. The tributaries flowing directly into it are of second order, streams flowing into the second order stream was of third order and so on.

Horton (1945) proposed a classification system for channel networks in which fingertip channels were designated as order one and where two first order tributaries joined the channel segment was of order two etc.

Strahler (1952) continued the task of classification with the smallest fingertip tributary as the basic unit. He proposed the river segment of second order to appear when two first order segments join The new course had characterstics entirely different from the branches. A third order segment would appear at the junction of two second order stream segments. The third order segment might be receiving tributaries of lower orders The order of the river segment would change when it unites with a higher order one and so on. Horton-Strahler system of classification is now widely accepted

Panove (1962) attributed the first order to the smallest fingertip tributaries. Two second order streams would give one of the third order and so on upto the main stream. He found a relationship for determining class of the tributary, based on the regional parameters to determine runoff and the basin area.

$$cl = b + a \log A$$

Where

cl - class to which the tributary belongs

a & b - regional parameters

A - drainage area

Shreve (1966) found out a new system of classification, taking into account all tributaries and provided the size of the basin in terms of the number of stream segments. He designated the streams as exterior, if they end with a spring and as interior if their upstream end was connected to another two segments. Shreve proposed to divide the network into separate links at each junction and to allow the magnitude of each link to reflect the number of first order fingertips ultimately feeding it.

It had been verified for very many cases that rivers of the same order were generally similar in terms of drainage basin area, mean length of channel network, mean slopes, water discharge etc., if they had developed under similar physiographical conditions. Different systems of classification is shown in Fig.2.1.

2.1.2 Law of stream numbers

Horton (1945) stated, "the number of streams of different orders in a given drainage basin tend closely to approximate an inverse geometric progression in which the first term is unity and the ratio is the Bifurcation ratio".

The number N_o of streams of oder 'o', having the bifurcation ratio r_b and the order 'u' of the main stream.

$$N_o = r_b^{u-o}$$

The total number N of streams is given by

$$N = \frac{r_b^{u-1}}{r_b - 1}$$

Hirsch (1962) defined the term confluence ratio against the bifurcation ratio. Confluence ratio (R_c) was established in various ways.

Horton considered the last term of the geometric progression as unity. Later, Christofoletti (1970) studied the drainage network

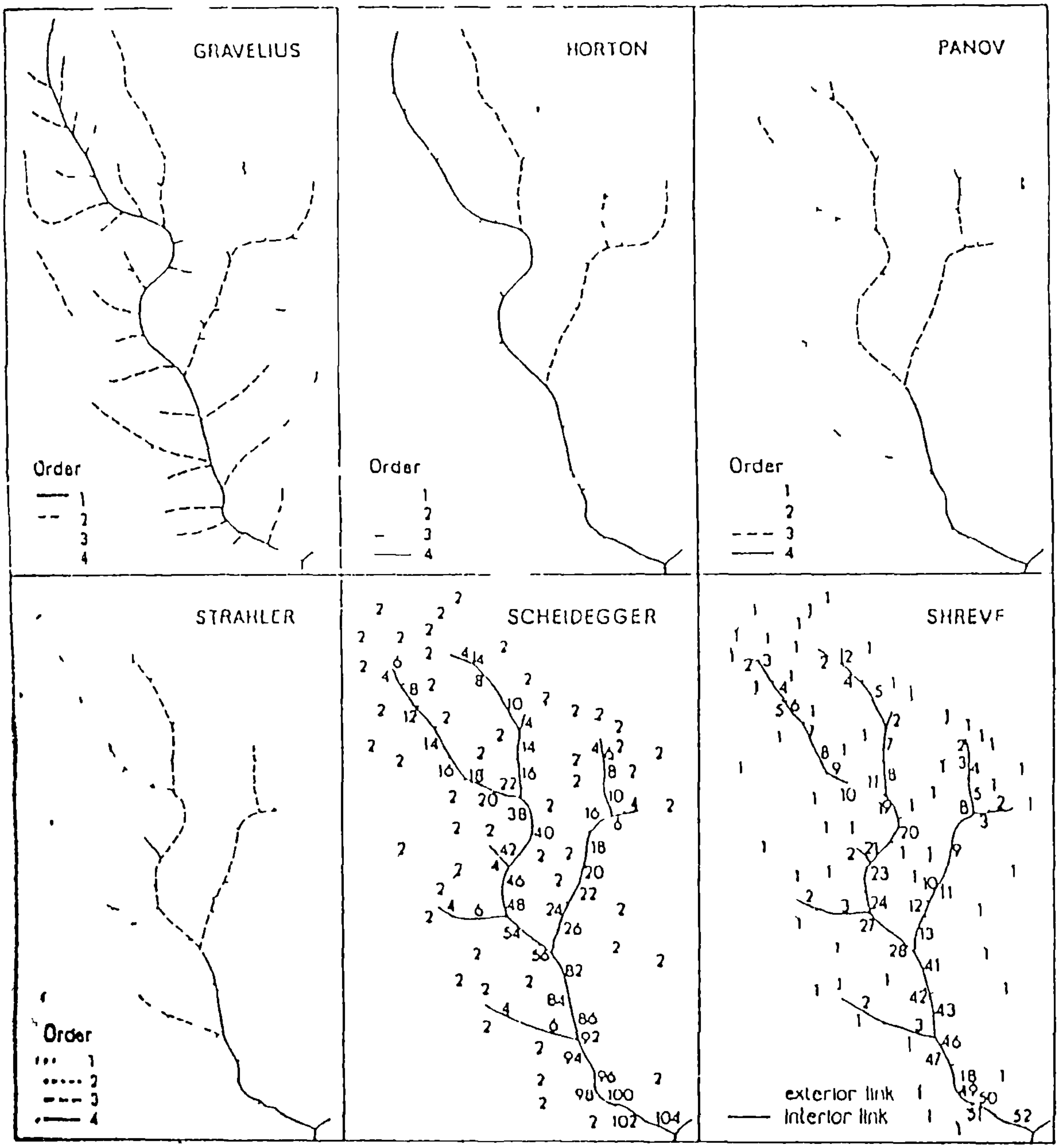


Fig.2.1 VARIOUS CLASSIFICATION SYSTEMS FOR RIVER NETWORKS

in the Brazilian Plateau. He found that the progression could not be good with the last term as unity. It was proved that local conditions might cause the transition to a higher order before the accumulation of all streams of lower orders. Generally, in elongated basins, the number of the highest order stream would not be equal to unity as the stream, was not fully developed under the given physiographical conditions. As such, the law was modified as, "the numbers of stream segments of successivel, higher orders in a given drainage basin tend to form a decreasing geometric progression in which the first term N_1 is the number of first order streams and the ratio is the confluence ratio R_c". The number of streams of a given order x was given by, $Nx = \frac{N_{x-1}}{R_c}$. The value obtained finally was an indication of the extent to which the main stream had developed.

A basin carved in friable rock could have a high confluence ratio because it would be complete for a certain order with more streams of lower orders compared with a basin of the same stage in a plain area. Besides influencing the landscape morphometry, the confluence ratio is an important control over the peakedness of the runoff hydrograph (Fig.2.2).

2.2 River length

The length of a stream is the distance measured along the stream channel from the source to a given point or to the outlet. The source is considered as the location at which a stream starts, which coincides with the place where the smallest perennial stream appears.

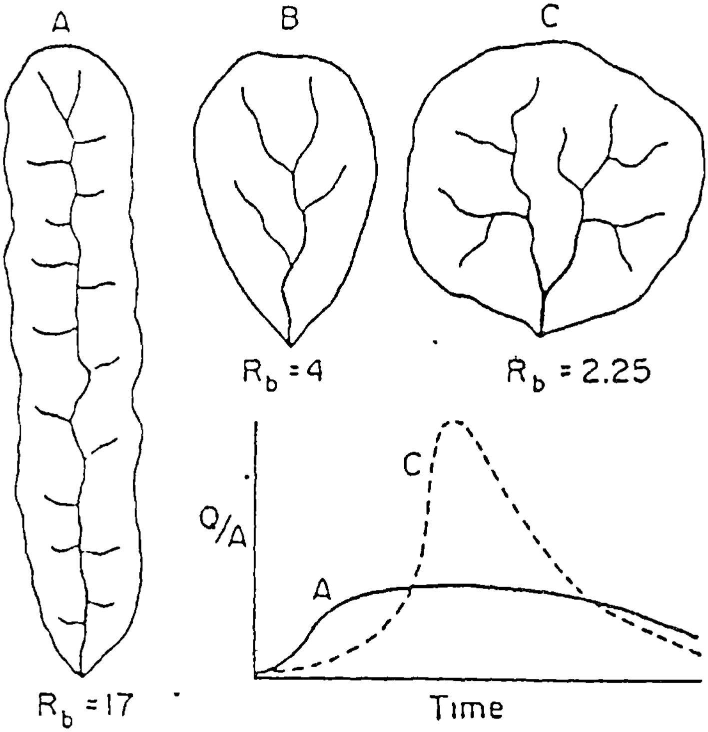


Fig.2.2 HYPOTHETICAL BASINS OF EXTREME AND MODERATE BIFURCATION RATIOS, WITH SCHEMATIC HYDROGRAPHS

2 2 1 Horton's law of summed lengths

The law stated, "the sums of the lengths of stream segments of successively higher orders tend to form a decreasing geometric series in which the first term is the summed length of first order streams (L_1) and the ratio (R_c) of successive summed lengths".

Total stream length of all orders could be calculated from the progression as,

$$L = L_u \frac{(1-R_c^{u})}{1-R_c}$$

2.2.2 Law of average stream length

The law stated, "the average lengths of stream segments of successively higher orders in a basin tend to approximate an increasing geometric series in which the first term l_1 is the average length of first order segments".

Schumm (1956) plotted frequency distribution histograms of first and second order channel lengths for the Perth Amboy Badlands, New Jersey. Distribution of lengths of streams of eachorder in a drainage basin were characteristically right-skewed (log - normal) Morisawa (1964) obtained straight line plots between the logarithm of mean stream segment length and order for four drainage basins in the Appalachian Plateau Province.

2.3 Length of overland flow

Overland flow length is the distance from the ridgeline or drainage divide, measured along the path of surface flow which is not confined in any defined channel, to the intersection of this flow path with an established flow channel. Overland flow depends on the length of the slope, nature of the surface, land use pattern and the type of cultivation, overland flow appears for an interval just after rainfall and then disappears as water is absorbed by the soil, retained by the plant cover or evaporated.

According to Horton (1945) this parameter was approximately half the average distance between the stream channels and hence is approximately equal to half the reciprocal of the drainage density.

2.4 Drainage basin area

Drainage basin area is bounded by the water divide and extends down to the end of the main stream. In some basins, areas in which surface flow collects in sinks or lakes not connected by surface channels to other streams in the basin are found. Such areas are designated as non-contributing to stream flow although ground water connections may exist.

Other factors being equal, the amount of rain intercepted and the peak discharge decreases with the area of the basin. This has been the basis for a large number of flood formulae in the general form $Q = cA^n$.

Where

Q - the peak discharge

A - the basin area

c - a constant that varies according to land use topography of the basin

n - a constant that has a range from 0.22 to 0.9

For many years the rational method has been used for obtaining the peak flood flow, i.e., $Q = k\,A\,i$

Where

A - the catchment area

k - the impermeable factor of area A

i - the design rainfall intensity on the catchment averaged over the time of concentration

Leopold and Miller (1956) by relating characteristic discharge to drainage area obtained an equation $Q_{2.33} = 12A^{0.79}$ for basins in Central New Mexico. An exponential relationship was found between order and discharge.

2 4.1 Relationship between basin area and length of main stream

River length and drainage basin area are directly related. Hack (1957) established the relation $L = 1.4A^{0.6}$

(L - the stream length measured in miles to the drainage divide, A - the drainage area in miles^2) for the streams of Virginea and Maryland. For the largest plain rivers in the USSR, the Peoples' Republic of China and the US, it was L = 2.9 A. Church and Mark (1975) found from the relationship $l = 1.09\ a^{0.55}$. (l - average lengths of stream segments of successive orders and a - the average basin area) that the stream length was positively allometric with respect to the basin area for 6 sixth order basins in the Ialomita basin.

2.5 Basin shape

A series of morphometrical parameters and the formation of floods depend on the basin shape. The geometry of stream network is controlled by the basin shape which is a function of geological structure. Floods and their erosive power is higher in elongated basins.

A number of indices were devised to express the shape of drainage basins. Horton (1941) concluded that a normally developed basin should be pear-shaped. It was a sign that the basin had resulted from erosion processes on an initially inclined surface. He introduced the ratio, form factor R_f which was the ratio of the area of a drainage basin (A_b) to the square of its maximum length (L_m).

$$R_f = \frac{A_b}{L_m^2}$$

Luchiseva (1950) introduced the compactness coefficient which was the ratio of the actual basin perimeter (P) to the perimeter of a circle of equal area (P^1).

$m = \frac{P}{P^1} = 0\ 282\ \frac{P}{A}$. This coefficient equalled unity when the basin shape was a perfect circle, increasing to 1.128 in the case of a square and would exceed 3 for a very elongated basin.

Miller (1953) represented the basin shape using the circularity ratio. The ratio was the quotient between the area (A) of a basin and the area A_c of a circle whose circumference equalled the basin perimeter, $R_c = \frac{A}{A_c}$. The ratio was found to range between one and 0.785 for a perfect circle and for a square it would decrease with the elongation of the basin. The circularity ratio was found to be influenced by the slope, relief, structure and tectonics of geological formations.

Schumm (1956) proposed elongation ratio, which was the ratio of the diameter D_c of a circle of area equal to that of the basin and the maximum basin length (L_b), $R_e = \frac{D_c}{L_b}$. The ratio varied from 1 275 for a circle, to one for a square and increased with elongation.

Chorley et al. (1957) noted that the pear shaped basins were closely resembled with Lemniscate curves. Based upon comparison of basin with lemniscate curve, lemniscate ratio, given by $K = \frac{L_b^2}{4A}$ was proposed. The ratio varied between 10-15 for very elongated basins whereas the value equalled unity for a circle. The small range of variation of the lemniscate and the more complicated calculations made this index inadoptable.

Singh (1970) in a case study of Hosharpur Kangra tract showed a negative correlation (-0.52) between the circularity ratio and stream occurrence. The circularity ratio provided a limited indication of the shape of a drainage basin, since most basins were elongated.

Seyhan (1975) found that rainfall and runoff were better correlated with the elongation ratio than with the form factor. For a given order, increases were noted in the length of the main stream, in the area and in other parameters of elongated basins, indicating the significance for the form factor in drainage basin evolution.

2.6 Drainage density and constant of channel maintenance

Drainage density is a term which had been defined in a number of ways. The commonly adopted form of the definition of drainage density is the ratio of the total stream length to the area of the basin. Constant of channel maintenance is the area necessary to maintain one kilometre of drainage channel. It is the reciprocal of drainage density.

Horton (1945) noted higher drainage densities in areas with higher precipitation and very low densities in basins with great permeability. He explained regional variations of drainage density by the differences in infiltration capacity. He deduced the following relationship for the calculation of drainage density from the laws of stream numbers and average lengths, $D_d = \frac{l_1 r_b^{u-1}(\rho - 1)}{A (\rho - 1)}$. Where D_d - drainage density, r_b - bifurcation ratio, u - order of stream, l_1 - average length of first order stream, ρ - average length ratio. He found an inverse relation of D_d with basin area when stream length was constant and direct relationship with the stream length at constant drainage area

Carlston (1963) studied thirteen basins in the central and eastern United States. The variation of drainage density was found to be due to the difference in permeability and transmissibility. He expressed the stream flow in terms of drainage density Maximum flood (return period 2 33 years) $Q_{2.33} = 1.3\ D_d^2$, Base flow $Q_b = 14\ D_d^{-2}$ A low drainage density was found in regions with high resistance to erosion on a highly permeable substratum forming a relief with gentle slopes covered by dense vegetation.

Strahler (1964) conducted studies for selected river basins of U.S.A. and classified the areas as low drainage density, medium drainage density, high drainage density and very high drainage density. The changes in drainage density with the geomorphological evolution of a region was attributed to climatic changes and as a consequence of man's action. Man, in order to satisfy his needs, had disturbed the equilibrium of the environment. Such actions would accelerate erosion

Orsborn (1970) related drainage density to mean annual floods and ground water flow, with the same amount of precipitation, high drainage densities were associated with larger floods and vice versa. He expressed S.R.O. as percentage of total runoff He expressed S.R.O. as $Q = 58\ D_d^{0.5}$.

Pethick (1975) found an inverse correlation between the drainage density D_c and area of basin. $D_c = 6.675A^{-0.3366}$ with a correlation coefficient of -0 77. He concluded that the low correlation coefficient and the great scatter of values were due to the length of streams which were not taken into account.

Kate and Pathak (1987) studied the geomorphology of an area using air-photo interpretation technique. Density of drainage towards rocky area was more than the areas away from rock outcrops. Thus, the degree of erodibility was more in high relief areas than the lower relief areas This was also an indication of the non-uniform drainage pattern.

2.7 Stream frequency

Stream frequency (D_s) is defined as the ratio of the total number of streams to the drainage area, $D_s = \frac{N}{A}$. Stream frequency can be calculated from the decreasing geometric progression of the numbers of stream segments of successively higher orders.

$$D_s = \frac{N_u(1-R_c^{\,u})}{A(1-R_c)}$$

Seyhan (1976) discovered that the relationship between stream frequency and drainage area was obviously inverse in nature when the number of streams remained constant for various values of areas though a direct relationship exists between the total number of stream segments and drainage areas.

Christofoletti and Oka-Fiori (1980) carried out researches in the Piracicaba and Sao Pedro areas (Brazil). For these regions, deep geological formations had no control over the spatial distribution of streams. Stream frequency was a hydrological phenomenon related to the characteristics of surface geological formations.

2 7 1 Relationship between drainage density and stream frequency

Melton (1957) studied 156 mature drainage basins and expressed the relationship between drainage density and stream frequeny. $D_s = 6.694\ D_d^2$ (correlation coefficient +0.97). The errors obtained in applying this formula to other basins indicating that the value of the constant differs from one region to another in relation to the extent to which the basin topography was adjusted to environment conditions.

Ion Zavoianu (1978) analysed the basins in Romania and noted that an important role in determining stream frequency and drainage density was played by rock type and in particular by differences in the degree of consolidation and resistance to erosion.

For consolidated rock with a geological resistance ranging from 4 to 9 both drainage density and stream frequency were inversely related to the degree of rock resistance. He expressed the relationship between stream frequency and drainage density as,

$$D_s = 1.71\ D_d^{1\ 44}$$

2.8 Basin slope

Slope may be defined as the tangent of the angle of inclination of a line or plane defined by a land surface. It is the result of a complex and continuous interaction between internal and external forces acting upon the earth's surface.

Chorley and Morgan (1962) formed regression equations for mean channel slope and order to streams in the Unaka mountains, England

Ebisemiju (1979) had shown that basin morphology could be almost completely quantified and studied by measurement of four morphometric parameters, drainage density, stream numbers, stream lengths and relief. These factors, together account for about 90% of the inter-relations of the several morphometric properties.

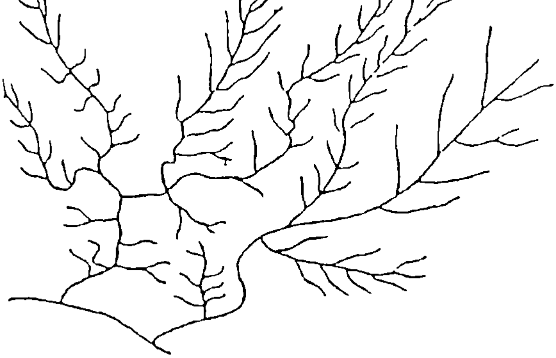
2.9 Pattern of drainage

Quantitative description of the drainage pattern had been approached by three methods, by the analysis of component directions and orders, by the analysis of junction angles or bifurcation ratios and by the deviation of generalised patterns. However, drainage patterns are usually expressed in qualitative terms and classifications. They are mainly designated as Dentritic, Parallel, Trellis and Rectangular patterns (Fig 2.3).

2.10 Vegetal cover

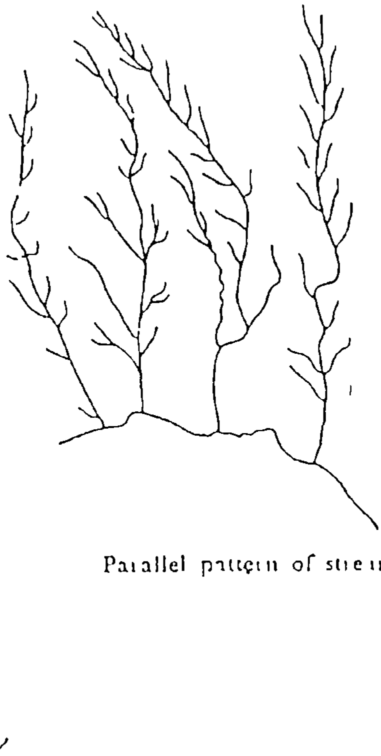
Vegetation of the basin surface depends on the soil, rocks and location of a basin and influence climatic conditions and hydrological processes The canopy and litter of a forest can diminish runoff and increase the quantity of water infiltrating into the soil. Vegetation also plays a considerable role in the water balance of a region, through evapotranspiration. Thus, the importance of vegetation in the transfer of mass and energy by various routes within a drainage basin is apparent.

The classical approach to study the effect of vegetation on runoff is to alter the land use on one of a pair of otherwise identical basins after an initial calibration period, then to ascribe differences in runoff patterns to the contrasting land usage. The original basin acts as a control, so that extraneous influences such as climatic change can be identified.

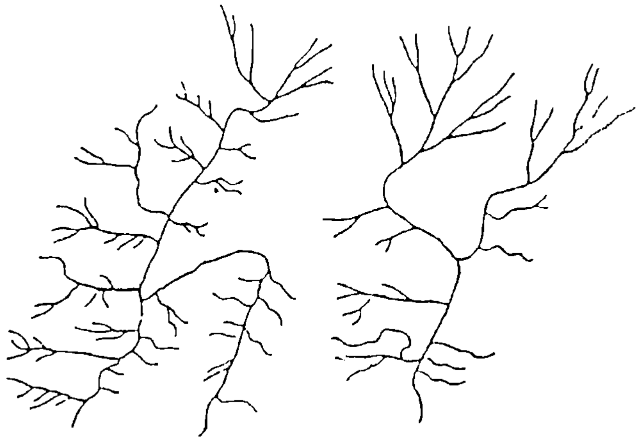


Dendrite pattern catchment

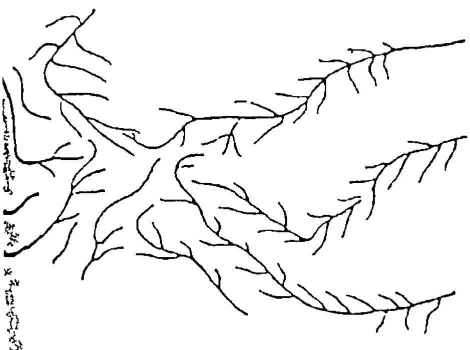
The Pinnate pattern drainage system



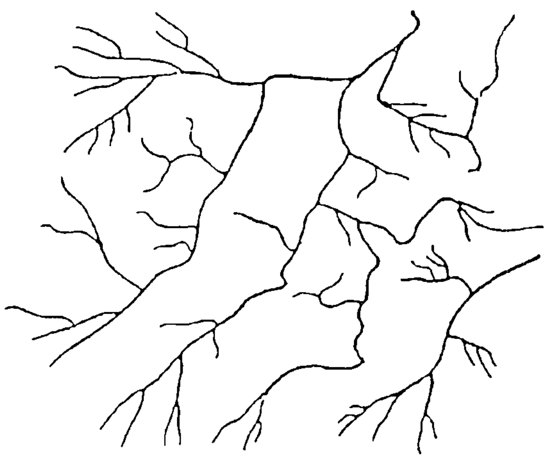
Parallel pattern of streams



Trellis pattern of streams in a drainage basin



Radial pattern of streams



Rectangular pattern drainage basin

Fig.2.3 PATTERNS OF DRAINAGE

Batts and Henry (1928) studied the effect of the removal of Douglas Fire trees from the eastern parts of Colorado on the stream flow. River flow rate was found to increase by 17% and during flood season, it increased by 50%. Periya (1962) found an increase of runoff rate by the substitution of large trees with tea in Eastern Africa.

Walter (1964) developed a linear function between the productivity of grass land in relation to dry weight and the average yearly rainfall for South West Africa.

Danis, a forest observation centre, Denmark reported a lowering of two meters in the water table level when the trees were destroyed in the coastal area when the deep rooted trees of Massatch Hills, Cuttak were cut and herbaceous plants were cultivated, water loss by evapotranspiration was reduced by a considerable extent. The sub-surface water level was raised considerably after that. On the other hand, when the trees of Belgaum area were largely cut down the water table of that area was lowered for a number of years

In Kerala, during 1960-70 forests were largely destroyed in Trivandrum and Palghat districts. The rainfall of these regions was above 2100 mm, before 1960. It was reduced to 900 mm in 1970. Annual rainfall increased to 1500 mm when rubber, cardomom, coffee and teak wood were cultivated in this region.

Brown (1988) studied storm runoff quantity and quality in three water sheds near St Paul in Ransey country from April 15 through September 15 of 1984, '85 and '88. Differences in storm runoff quantity between years in an urban watershed that was lacking lands appeared to be related to the precipitation. Watershed having largest amount of impervious area and smallest amount of wet land area had the largest amount of storm runoff Difference in storm runoff quality was related to the amount of wet land and lake area.

2.11 Composition of rocks and soil

Rocks act as a support for other morphometrical elements. The resistance offered by the rocks determined the relief of the basin. The type of rock influences the soil layer and vegetation Soil is an element which depends on the type of rock, on vegetation, on the spatial position of a basin and on climatic factors. The properties of soil are decisive factors in the processes of runoff, infiltration and erosion.

Bertrand et al. (1964) noted that an increase in the percentage of sand in a soil lowers surface runoff. The particle size distribution and texture of soils would play a very important role in infiltration and surface runoff processes. There was a close relationship between infiltration and runoff i e , the factors favouring runoff hinder infiltration and vice versa.

2.12 Rainfall

The magnitude of stream flow is related to the rainfall that provokes it as well as the storage capacity of the basin. A number of studies had been conducted to find this relationship and formulae were developed.

Benson (1962) developed the following equation for the peak discharge in the mean annual flood for 164 basins of New England

$$\dot{Q}_m = 0.009\ A^{0.85}\ R^{2.2}$$

Kerala P.W D. (1974) presented empirical formulae for estimating annual runoff for some river basins in Kerala. The formulae were linear including the rainfall of the year under consideration and the rainfall of the previous year.

Bandyopadhyay (1980) developed a non-linear mathematical model to simulate the response of an urban catchment for the city of Calcutta.

Chinnamani and Sakthivadivel (1980) analysed the decreasing trend in the annual rainfall of Katery river basin due to deforestation. Maximum flood flow had an upward trend from 1966-67 after the complete obliteration of the soil conservation works.

Sen (1986), quoted Chinese Engineers that, the rainfall intensity had appreciable effect on runoff for the humid regions of their country Soil moisture at the beginning of rainfall could have a marked influence over the rainfall-runoff correlation

2.13 Runoff

Runoff depends on a number of factors of the drainage basin most of which are inter-related It is impossible to incorporate all the variables in a single equation. Runoff parameters are still, a field requiring major research works.

Pillai, N.N. (1964) developed a correlation graph for Kallada Basin to estimate the monthly runoff from the catchment of the basin. Later it was applied to compute the yield of Achencoil (basin are 847 km^2) and Pamba (basin area 1700 km^2) within $\pm$ 40% of the observed yield

Shallash and Starmans (1969) developed a formulae

$Q = 0\ 00135 \frac{R^{3/2}}{D}$ Where R - total annual rainfall over the catchment (inches) and D - drainage density (miles/$miles^2$). The formulae had been based on observations in the Kafue river basin, Zambia.

Hann and Read (1970) devoted a part of their study to develop a prediction equation for the mean annual runoff for small watersheds of Kentucky. The prediction equation was

$$RO = -9\ 65 + 0.43\ Prec + 0\ 62\ P + 0\ 010\ R_r$$

Where

RO – mean annual runoff (inches)

Prec – mean annual precipitation (inches)

P – perimeter (miles)

R_r – Relief ratio

Ratio of total relief to largest dimension of basin, generally parallel to main stream (feet per mile)

Gregory and Walling (1971) stated that in the drainage basin open system input of energy occurs from the climate over the basin and from endogenetic forces under the basin, transport of water and sediment takes place within the system over slopes and in stream channels and below the surface, and loss takes place principally by evaporation and transpiration to the atmosphere and by outflow of water and sediment from the mouth of the basin (Fig.2.4).

Irina Cech and Kaun Assaf (1976) analysed the runoff variations due to urban developments. The highest peak flow was found to occur in regions of most intense urbanization and industrialization Local topography and physiographic characteristics being the same, the abrupt increase in inflow should be due to man induced changes.

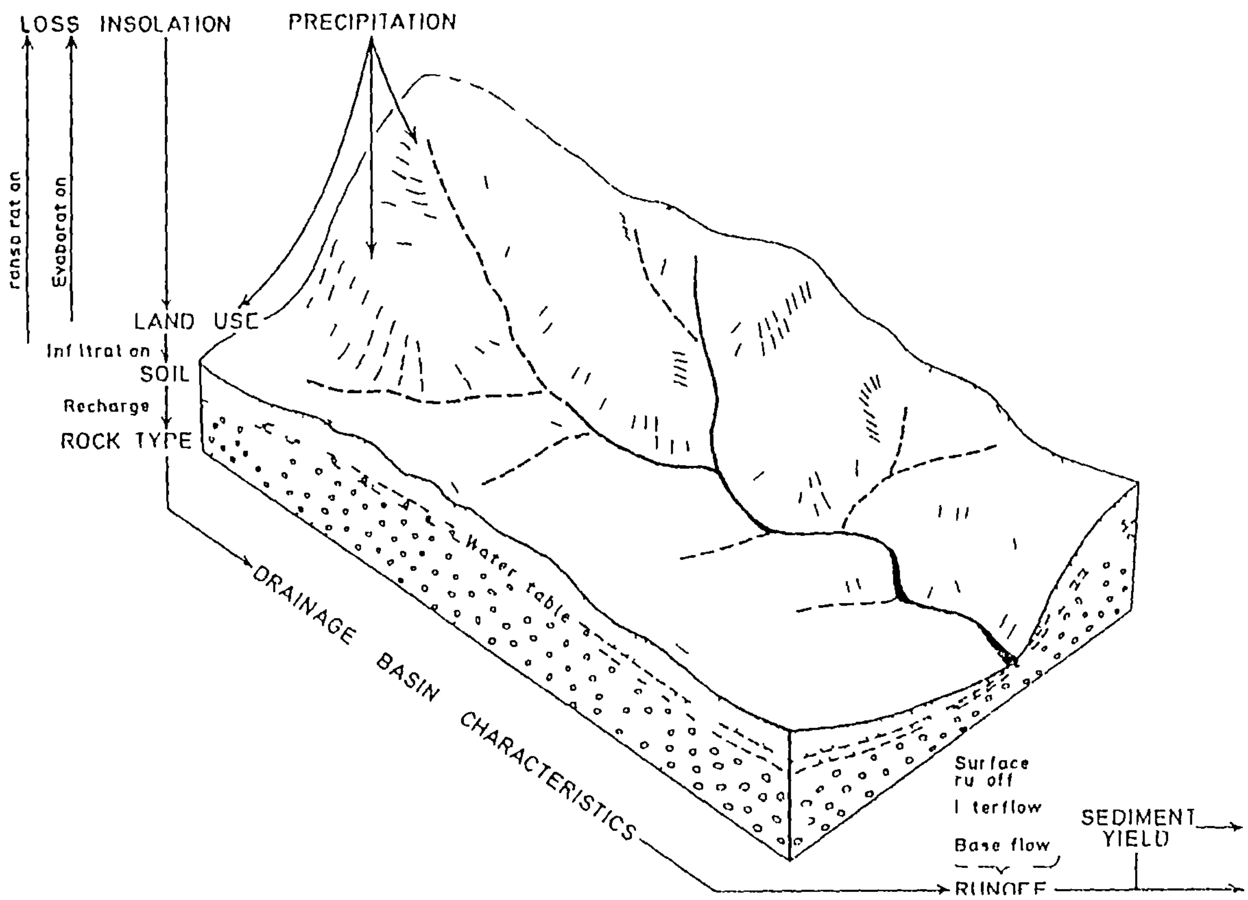


Fig.2.4 A GEOMORPHOLOGICAL VIEW OF THE DRAINAGE BASIN

Robert Milhous (1976) attempted to express the flood flow and low flow of Western Washington in terms of the geomorphic parameters Low flows would be controlled by microfeatures including the vegetation and specific geological details A rivergauge would give some information about the flows, downstream of the gauge, if some additional facts of the latter was also available. However, the use of geomorphic parameters was acceptable only for flood flows, not the low flows

Cech and Assaf (1978) emphasises that the highest peak flow occurs in regions of most intense urbanization and industrialisation Such an abrupt increase in flow in urban localities would be the result of man induced changes.

Kalyan Rudra (1979) found that the retardation of the flow by dams, deforestation in the upper catchment areas of the tributaries of Bhagirathi and human interference increased the possibility of flood The constructions like embankments and dams, topography, evapotranspiration and underground water table were found to have pronounced effect on the flood.

Hanumantha Rao (1983) computed runoff from catchments in South India. The prediction of yields would depend not only on rainfall but also on basin characteristics, especially soil cover, anticipated precipitation index and other methodological data of the basin

Rao (1985) showed a hydrograph pip and a definite effect on flow hydrograph, by interceptors. Hydrograph pip was noticed mainly for a thickly populated sector areas with large open spaces and long buildings oriented towards the outlet. The runoff coefficient and time of concentration depend upon the percentage of impervious area and characteristic impervious length factor.

Subramanyam (1986) assessed the development of the water sources of Krishna river basin and concluded that the Western Ghats were vitally important in providing the Krishna river system with enormous amount of water surplus.

Materials and Methods

MATERIALS AND METHODS

3.1 Definitions

1 Average stream length

Average stream length of a given order in a river basin is the average length of streams of that order, belonging to the river basin.

2 Bifurcation ratio (Confluence ratio)

Bifurcation ratio (Confluence ratio) is the ratio of the number of stream segments of a given order N_u to the number of segments of the next higher order N_{u+1}.

3 Constant of channel maintenance

Constant of channel maintenance is the drainage area required to maintain one kilometer of the channel.

4. Drainage density

Drainage density is the length of stream segments per unit drainage area.

5 Elongation ratio

Elongation ratio is the ratio of the diameter of a circle of area equal to that of sub-basin and the maximum sub-basin length.

6. Form factor

Form factor is the ratio of drainage area to the square of the maximum length of sub-basin.

7. Geomorphology

Geomorphology is the science dealing with the measurements of the form of the earth's crust.

8. Order

Order of a stream segment is the number designated to it after classification of river network

9. Sub-basin

Sub-basin is the drainage area contributing to a given river-gauge station.

10. Stream frequency

Stream frequency is the number of stream segments per unit drainage area.

11. Summed stream length

Summed stream length of a given order in a river basin is the total length of streams of that order, belonging to the river basin

3.2 Objectives

The main objective of this study was a quantitative analysis of runoff parameters for Chaliyar and Kabbani river basins. The specific objectives were to study the inter-relationships between the geomorphological parameters and the effect of these parameters and the climatic factors (rainfall) on the stream flow. The river basins were divided into sub-basins, with each sub-basin containing a rivergauge station (Fig.3.1 and 3.2). Geomorphological parameters suggested for the analysis were

1. Stream order and the number of streams of each order
2. Summed stream length and the average stream length of all orders
3. Bifurcation ratio (Confluence ratio)
4. Length of overland flow
5. Sub-basin area
6. Basin shape
7. Drainage density
8. Constant of channel maintenance
9. Stream frequency
10. Pattern of drainage

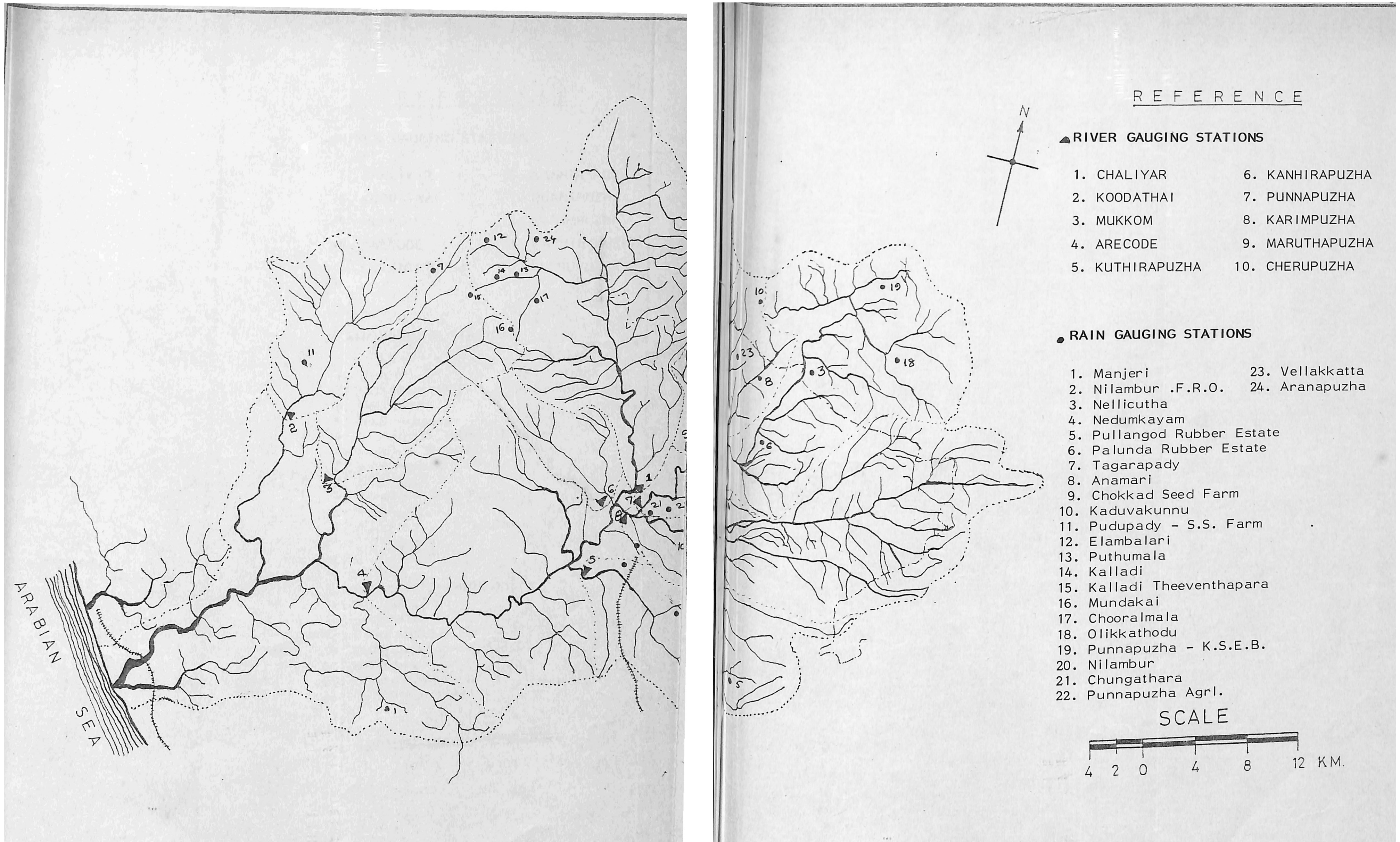


Fig. 3·1 MAP OF CHALIYAR RIVER B… N SHOWING HYDROLOGICAL STATIONS

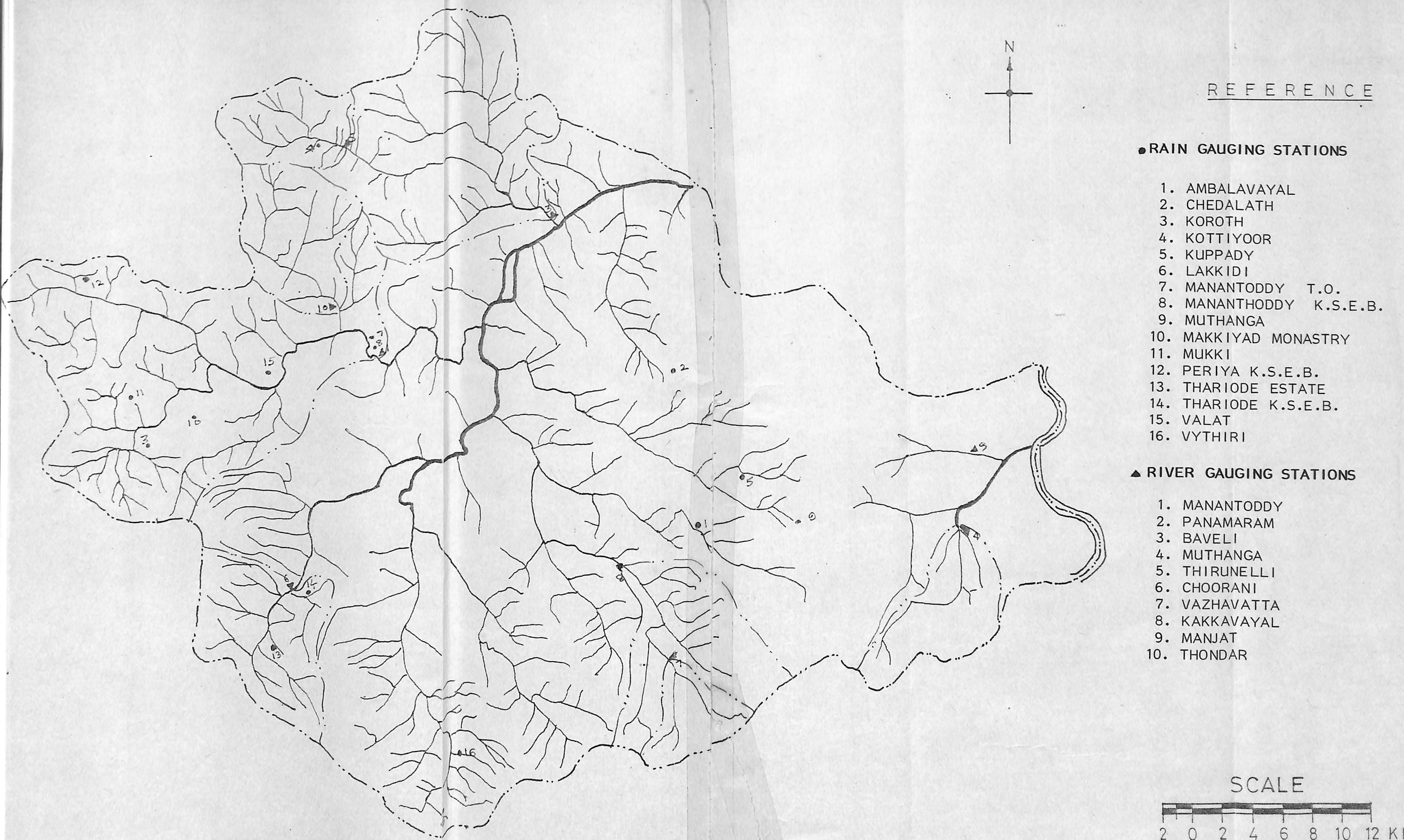


Fig. 3·2 MAP OF KABBANI RIVER BASIN SHOWING HYDROLOGICAL STATIONS

Vegetal cover and the composition of rocks and soil were the other factors considered. Stream order, stream lengths, bifurcation ratio and the length of overland flow were the linear aspects Sub-basin area, basin shape, drainage density, constant of channel maintenance, stream frequency and the pattern of drainage were the areal aspects. These parameters were expressed quantitatively and analysed

3.3 Morphological factors

Morphological factors were collected from the topographical map of the river basins. Each river basin was divided into sub-basins, each containing a stream flow gauging station and the tributaries contributing to it. The sub-basins were treated as separate basins Morphological factors were measured for each sub-basin. Other factors like vegetation and nature of soil were noted for the river basins.

The sub-basins of Chaliyar basin were

1. Chaliyar
2. Maruthapuzha
3. Punnapuzha
4. Karimpuzha
5. Kanhirapuzha
6. Mukkom
7. Koodathai
8. Kuthirapuzha
9. Arecode

The sub-basins of Kabbani basin were

1	Thondar	2	Thirunelli
3	Manantoddy	4.	Choorani
5.	Panamaram	6.	Vazhavatta
7	Muthanga	8	Manjat
9	Kakkavayal	10.	Baveli

3 3.1 Linear aspects

Horton-Strahler system of classification of river network was adopted. The fingertip tributaries were designated as a first order, two first order stream segments meet to form a second order one and so on Lower order tributaries joining the stream do not change the order The highest order which designates the main stream was considered as the order of the sub-basin. The sub-basins with the ordered stream segments are shown in Fig.3.3 and 3.4. The number of stream segments of each order was found from the map, for all sub-basins.

Confluence ratio was calculated using the relationship

$$R_c = \frac{N_u}{N_{u+1}} \qquad \ldots \quad \ldots\ldots \quad 3\ 1$$

It was calculated by three methods, viz., the method of weighted means, from regression equation and from the graph.

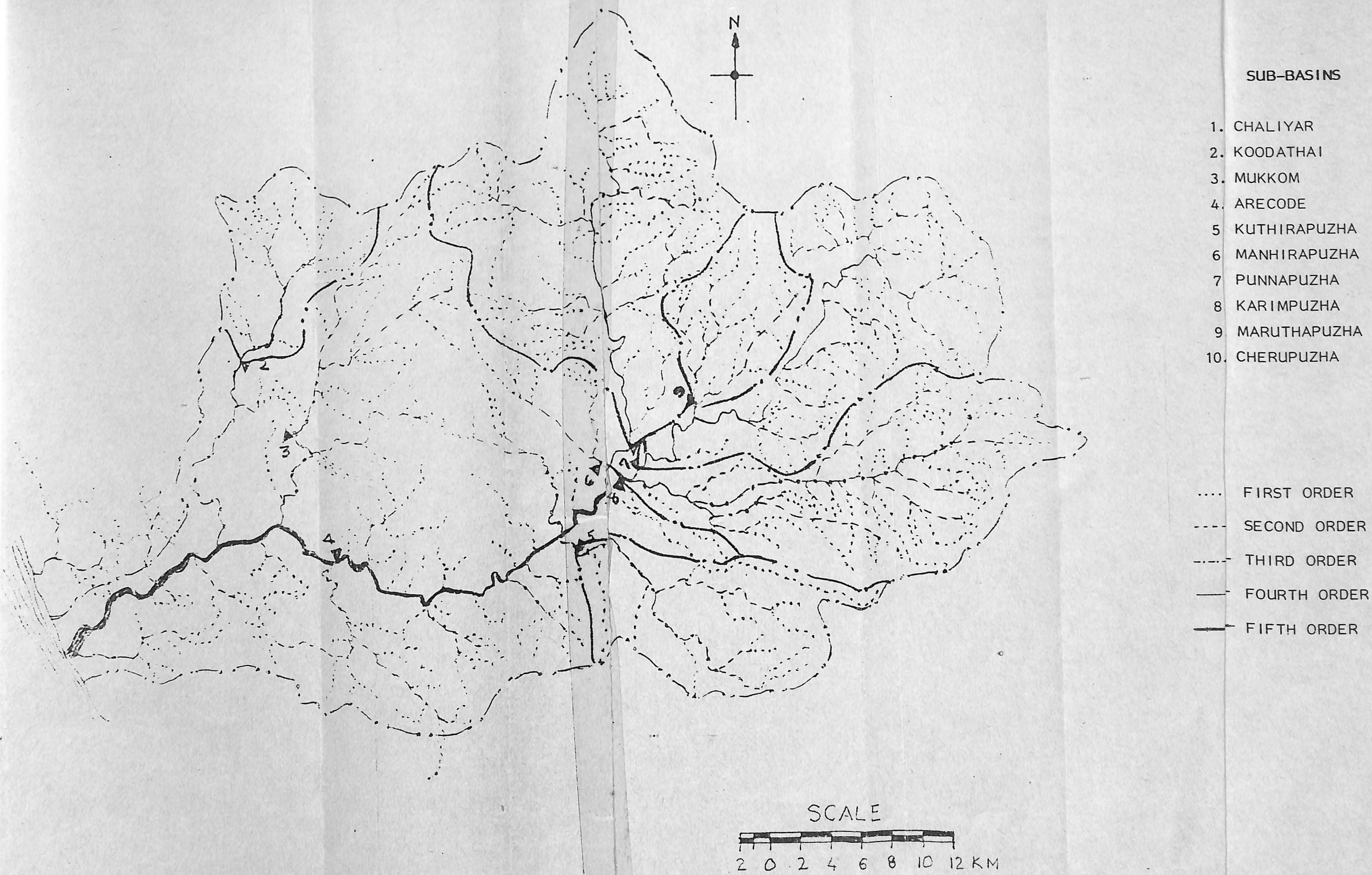


Fig.3.3 SUB-BASINS AND THE CLASSIFICATION OF RIVER NETWORK IN CHALIYAR RIVER BASIN

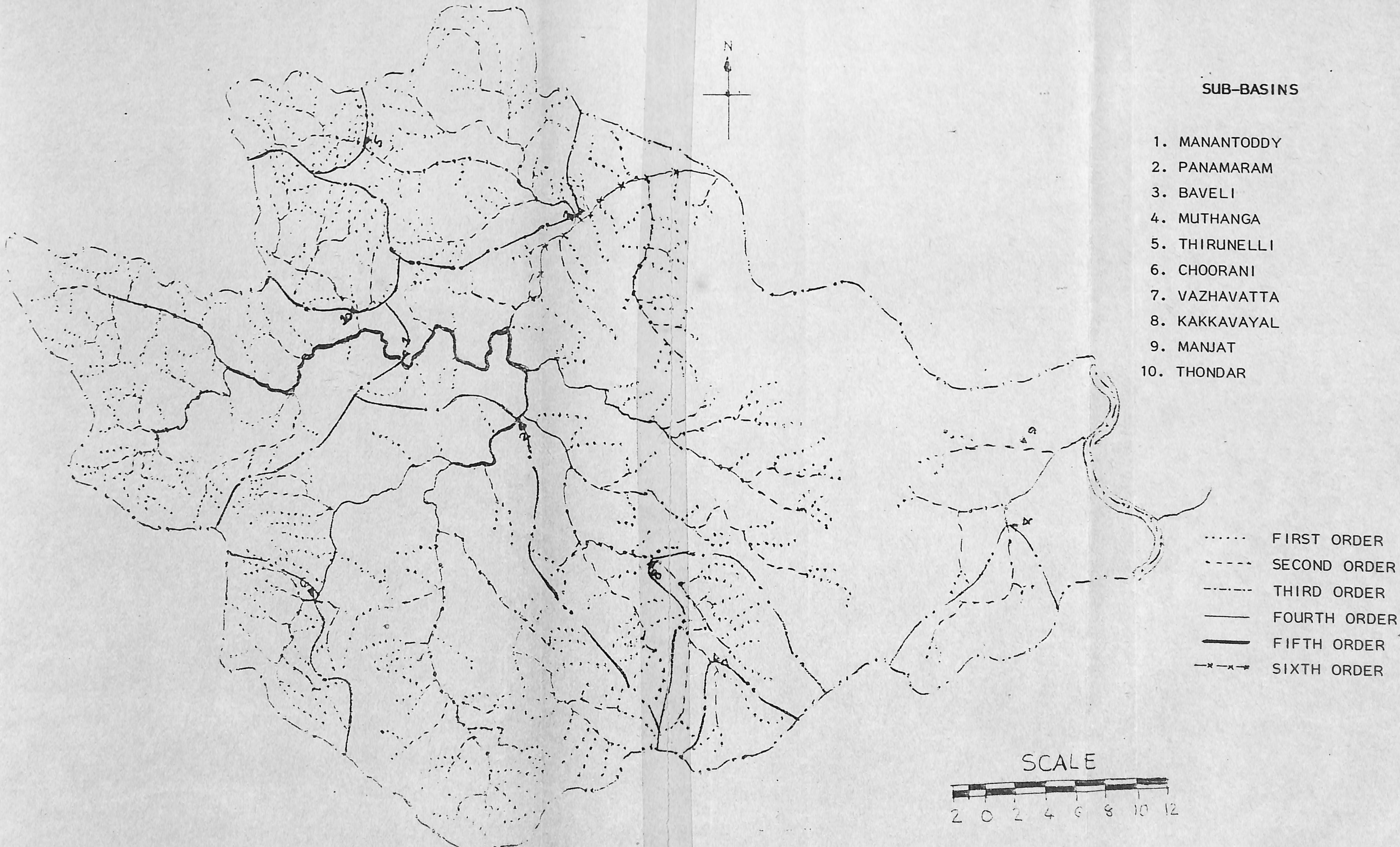


Fig.3.4 SUB-BASINS AND THE CLASSIFICATION OF RIVER NETWORK IN KABBANI RIVER BASIN

a Method of weighted means

If N_1, N_2, N_3 ----- N_u are the number of streams of order 1, 2, 3, ------- u, $R_{c1} = \frac{N_1}{N_2}$

$R_{c2} = \frac{N_2}{N_3}$, $R_{c3} = \frac{N_3}{N_4}$ ---------- $R_{ci} = \frac{N_i}{N_{i+1}}$

$N_1 + N_2 = a_1$, $N_2 + N_3 = a_2$ ---------- $N_i + N_{i+1} = a_1$

$\frac{N_1}{N_2} = b_1$, $\frac{N_2}{N_3} = b_2$ ---------- $\frac{N_i}{N_{i+1}} = b_i$

$$R_c = \frac{a_1b_1 + {}_2b_2 + a_3b_3 + \text{---------} a_ib_i}{a_1 + a_2 + \ldots + a_i} \qquad \ldots\ldots 3\ 2$$

Confluence ratio is given by,

$$R_c = \frac{\Sigma a_ib_i}{\Sigma a_i} \qquad \text{(Appendix I)}$$

b. Method of regression equations

According to Horton's law, the number of stream segments of each order form a decreasing geometric progression. Order and stream numbers of each order were thus plotted on a semilogarithmic graph The regression equations for the best fit regression lines were found The anti-logarithm of the regression coefficient was calculated, as the confluence ratio. The regression equations were of the form N_u = a-bu Anti-logarithm of b was the confluence ratio. However, due to lack of data this method was not used for further calculations.

c Graphical method

It is also based on Horton's law of stream numbers The order and the number of streams of each order was plotted on a semi-logarithmic graph. The slope of the line of best fit was calculated for each sub-basin. The anti-logarithm of this slope represented confluence ratio.

Confluence ratio by the method of weighted means was used for further calculations and the verification of the law of stream numbers The number of streams of order u was calculated using the equation,

$$N_u = \frac{N_1}{R_c^{u-1}} \quad \ldots\ldots\ldots\ldots\ldots 3.3$$

Since the number of streams of successive orders form a geometric progression, N_u denotes the general term of the progression with N_1 as the first term and R_c as the common ratio. The value obtained for the highest order is an indication of the degree of accumulation of lower order streams. It gives an account of the development of the sub-basin with reference to the order assigned to it. Total number of streams was obtained from the relationship,

$$N = \frac{N_u\ (1-R_c^{\ u})}{1-Rc} \quad \ldots\ \ldots\ .\ 3.4$$

It has been illustrated in Appendix II.

The number of streams were calculated using equations 3.3 and 3.4 to verify Horton's law of stream numbers. The number of streams of each order and the total number of streams of all orders were, thus obtained. Number of streams of each order form a certain fraction of the total number of streams. The percentage number of streams of each order was calculated for each sub-basin as equal to

$$\frac{N_u}{N} \times 100 \quad \ldots\ldots\ldots\ldots \quad 3\ 5$$

Order and logarithm of the number of streams were plotted graphically. Regression equations were obtained for each sub-basin with the number of streams of order 'u' as the dependent variable and the order of streams as the independent variable. Confluence ratios obtained by the three methods were compared.

Length of streams were measured from the topographic map of the river basins using a thread. The length, multiplied with the scale was the actual length. The total length of streams of each order, which gives the summed stream length was calculated for each sub-basin. The average stream length was obtained by dividing the summed stream length with the number of streams of each order. The length ratio R_L is the ratio of the summed length of streams of a given order to that of the streams of successive order. The ratio was obtained as the weighted mean of the measured ratios.

$$\frac{L_1}{L_2} = q_1 \quad \frac{L_2}{L_3} = q_2 \quad \frac{L_3}{L_4} = q_3 \text{ --------- } \frac{L_{u-1}}{L_u} = q_{u-1}$$

$$L_1 + L_2 = p_1 \quad L_2 + L_3 = p_2 \quad L_3 + L_4 = p_3 \text{ ----} L_{u-1} + L_u = p_{u-1}$$

$$R_L = \frac{(p_1 q_1 + p_2 q_2 + p_3 q_3 + \text{-----------} + p_{u-1} q_{u-1})}{p_1 + p_2 + p_3 + \text{-----------} + p_{u-1}}$$

$$R_L = \frac{\sum p_{u-1} \; q_{u-1}}{\sum p_{u-1}} \quad \ldots\ldots\ldots\ldots\ldots\ldots \; 3.6$$

Summed length of streams of order 'u' is

$$L_u = \frac{L_1}{R_L^{\,u-1}} \quad \ldots\ldots\ldots\ldots\ldots\ldots \; 3.7$$

Total length of streams of all orders in a sub-basin

$$L = L_u \; \frac{(1 - R_L^{\,u})}{1 - R_L} \quad \ldots\ldots\ldots\ldots \; 3.8$$

Similarly, the average length of streams was also calculated. Average length ratio r_l was given by

$$r_l = \frac{R_c}{R_L} \quad \ldots\ldots\ldots\ldots\ldots \; 3.9$$

Average length of streams of order 'u' is

$$l_u = \frac{L_u}{N_u} \quad \ldots\ldots\ldots\ldots\ldots \; 3.10$$

If l_1 is the average length of first order streams, average length of streams of order 'u' is

$$l_u = l_1 \; r_l^{\,u-1} \quad \ldots\ldots\ldots\ldots\ldots \; 3.11$$

The geometric progression of average length is l_1, $l_1 r_l$, $l_1 r_l$, -- $l_1 r_l^{u-1}$ The summed length ratio R_L and the average length ratio r_l were calculated by the method of weighted means. The summed lengths were calculated using equations 3.7 and 3.8. The average lengths were calculated using equations 3.10 and 3.11 (Appendix III & IV). Horton's law of summed stream length as well as the law of average stream length was studied for the sub-basins.

3.3.2 Areal aspects

Area, being one of the most important morphological factors, was related to most of the other parameters. The relationship of area with the length of the main stream and the maximum length of the sub-basins was examined. Length of main stream (L_s) was measured from the starting of the stream to the rivergauge station. The path which has the maximum angle of deviation was followed. Since the two factors are related in an exponential function with order, the relationship was studied using a power function, with the area as the dependent variable and log (L_s) as the independent variable.

Basin shape was expressed using elongation ratio, form factor, the maximum straight length of sub-basin and the length of main stream. Form factor and elongation ratio were calculated from the formulae,

$$\text{Form factor } R_f = \frac{A}{L_m^2} \qquad \ldots\ldots\ldots\ldots 3.12$$

Elongation ratio $R_e = \frac{D_c}{L_m}$

i.e., $R_e = 1.129 \frac{A}{L_m}$ 3.13

The maximum straight length of the sub-basins were measured from the topographical maps and multiplied with the scale. It was analysed with respect to the other parameters.

Stream frequency is the number of stream segments per unit area of the drainage basin. It was obtained as the ratio of the total number of stream segments of all orders to the drainage area of the sub-basin.

$D_s = \frac{N}{A}$ 3.14

Drainage density is the stream length per unit area of the sub-basin. The total length of the streams of all orders (ΣL) was found and drainage density was calculated as the ratio of the total length to the drainage area of the sub-basin.

$D_d = \frac{L}{A}$ 3.15

Constant of channel maintenance (M) is the reciprocal of drainage density. It is the area required to maintain one kilometre length of the stream. Constant of channel maintenance, stream frequency and drainage density were studied for their inter-relationship as well as their relationship with the morphological factors and stream flow, using regression analysis.

Correlation and regression studies made for the morphological parameters are as follows

1. Confluence ratio and maximum straight length of the sub-basin
2. Confluence ratio and the average monthly monsoon discharge for the periods 1976-1980, 1981-1985 and 1976-1985
3. Confluence ratio and the average annual discharge during 1976-80, 1981-85 and 1976-'85
4. Maximum straight length of the sub-basin and the average annual discharge of each sub-basin
5. Form factor and the average monthly monsoon discharge for the periods 1976-1980, 1981-1985 and 1976-1985
6. Form factor and the average annual discharge for the period 1976-'80, 1981-'85 and 1976-'85
7. Elongation ratio and the average monthly monsoon discharge for the periods 1976-1980, 1981-1985 and 1976-1985
8. Elongation ratio and the average annual discharge for the period 1976-'80, 1981-'85 and 1976-'85
9. Area of sub-basin and drainage density
10. Area of the sub-basin and stream frequency

11. Average annual monsoon discharge and drainage density

12 Average annual monsoon discharge and stream frequency

13. Average monthly monsoon discharge and drainage density

14. Average monthly monsoon discharge and stream frequency

15. Number of stream segments and order, for each sub-basin

16. Confluence ratio and the average annual discharge per unit area

17 Confluence ratio and the average monthly monsoon discharge per unit area during 1976-1980, 1981-1985 and 1976-1985

18. Maximum straight length of the sub-basin and the average monthly monsoon discharge for the periods 1976-1980, 1981-1985 and 1976-1985

19. Maximum straight length and the average monthly monsoon discharge per unit area for the three periods

20. Maximum straight length and drainage area of the sub-basin

21. Length of main stream and drainage area of the sub-basin

22. Confluence ratio and the average monthly monsoon discharge per unit area, during the periods 1976-1980, 1981-1985 and 1976-1985

23. Drainage density and the average monthly monsoon discharge per unit area

24. Form factor and the average monthly monsoon discharge per unit area for the three periods

25. Elongation ratio and the average monthly monsoon discharge per unit area for the three periods

26. Drainage density and stream frequency

27. Average annual monsoon discharge and monthly monsoon discharge with slope Relations from No.13 to 21 had been considered for the final analysis as they were found significant

3.3.3 Climatic factor

Precipitation is the major input of a drainage basin. As such, rainfall data was collected for the analysis. Rainfall records from all the raingauge stations within the limits of each sub-basin were collected for a period 1976-'85. Arithmetical average of the rainfall was considered to be the average rainfall of the sub-basin. The raingauge stations for each sub-basin are given in Table 3.1. The relationship of rainfall with stream flow was studied using linear and exponential models However, linear models were used for final analysis, as the other forms were found insignificant.

3.3.4 Stream flow

The position of raingauge stations and rivergauge stations of Chaliyar and Kabbani river basins are given in Fig.3.1 and 3 2. Data

Table 3.1 Rivergauge stations and representative raingauge stations

River basin	Sl.No.	Sub-basin	Raingauge station
	1	Chaliyar	Elambalari, Puthumala, Kalladi, Kalladi Theevanthapara, Mundakai, Chooralmala, Aranapuzha.
	2	Koodathai	Pudupady - S.S. Farm
	3	Mukkom	Tagarapady, Kalladi Theevanthapara, Mundakai.
Chaliyar	4	Arecode	Manjeri, Nilambur, Nellicutha, Nedumkayam, Pullangode rubber estate, Palunda, Anamari, Chokkad, Kaduvakunnu, Pudupady, Elambalari, Puthumala, Kalladi, Kalladi Theevanthapara, Mundakai, Chooralmala, Olikkathodu, Punnapuzha - KSEB, Chumathara, Vellakkatta, Aranapuzha, Punnapuzha - Agrl.
	5	Kanhirapuzha	Nil
	6	Pumapuzha	Anamari, Kaduvakunnu, Punnapuzha - Agrl., Palunda, Nellicutha, Olikkathodu, Punnapuzha - KSEB.
	7	Kuthirapuzha	Pullangode rubber estate, Chokkad Seed Farm.
	8	Karimpuzha	Nellicutha, Nedumkayam, Palunda, Anamari, Kaduvakunnu, Olikkathodu, Punnapuzha - KSEB, Chungathara, Pumapuzha - Agrl., Vellakkatta.
	9	Maruthapuzha	Anamari, Kaduvakunnu, Vellakkatta.

Table 3.1 (Contd.)

River basin	Sl.No.	Sub-basin	Raingauge station
	1	Manantoddy	Koroth, Manantoddy TO, Manantoddy - KSEB, Makkiyad Monastry, Mukki, Periya KSEB, Valat.
	2	Panamaram	Nil
	3	Baveli	Nil
	4	Muthanga	Nil
Kabbani	5	Thirunelli	Kottiyoor
	6	Choorani	Thariode estate, Thariode KSEB.
	7	Vazhavatta	Nil
	8	Kakkavayal	Nil
	9	Manjat	Nil
	10	Thondar	Nil

regarding the rainfall at various raingauge stations and the streamflow at different rivergauge stations were collected from the Water Resources Divisional Office, Kerala P W.D., Trichur. Records were available for daily average discharge and the weighted monthly discharges. The computation of weighted discharges is shown in Appendix V & VI. Annual monsoon, non-monsoon and total discharges were computed. All the quantitative parameters were studied with reference to the monthly discharge, annual discharge and the discharge contributed by unit area of the sub-basin.

Runoff - rainfall relationship was assessed in 19 stages. Correlation and regression studies were made for the following.

1. Monthly discharge and monthly rainfall of the same month and the preceding two months for the period 1976-85, for all the sub-basins, with each year taken separately.

2. Monthly discharge and the monthly rainfall of the same month and the previous month, with each year taken separately.

3. Monthly discharge and monthly rainfall of the same month and the preceding two months, for five years, i.e., 1976-1980 and 1981-1985 for each sub-basin.

4. Monthly discharge and monthly rainfall of the same month and the preceding two months for 10 years, 1976-1985 for each sub-basin.

5 Monthly discharge and monthly rainfall of the same month and the previous month for five years, i.e., 1976-'80 and 1981-'85 for each sub-basin.

6. Monthly discharge and monthly rainfall of the same month and the previous month for ten years, 1976-85 for sub-basin.

7. Monthly monsoon discharge and monthly monsoon rainfall for the periods 1976-'80, 1981-'85 and 1976-1985, for each sub-basin.

8. Average monthly monsoon discharge with average monthly monsoon rainfall and area for the periods 1976-'80 and 1981-'85 for all the sub-basins of Chaliyar, taken together.

9. Average monthly monsoon discharge with average monthly monsoon rainfall for all the sub-basins of Chaliyar and taken together for the periods 1976-'80 and 1981-'85.

10. Average monthly monsoon discharge with average monthly monsoon rainfall and area for the period 1976-'85 for all sub-basins of Chaliyar, taken together.

11. Average monthly monsoon discharge with the average monthly monsoon rainfall for the perioa 1976-1985 for all sub-basins of Chaliyar.

12. Average monthly monsoon discharge per unit area with the average monthly monsoon rainfall and area for all sub-basins, for the periods 1976-'80 and 1981-'85.

13. Average monthly monsoon discharge per unit area with the drainage area and the average monthly monsoon rainfall for all the sub-basins of Chaliyar taken together for 1976-'80, 1981-'85 and 1976-'85.

14 Average monthly monsoon discharge per unit area with the average monthly monsoon rainfall for all the sub-basins of Chaliyar, for 1970-'80, 1981-'85 and 1976-'85.

15 Annual monsoon discharge and annual monsoon rainfall for 1976-'85 to each sub-basin

16. Annual monsoon discharge with annual non-monsoon and total rainfall of 1976-'85 for each sub-basin.

17 Annual non-monsoon discharge and annual non-monsoon, monsoon and total rainfall of 1976-'85 for each sub-basin.

18. Total annual discharge to annual monsoon, non-monsoon and total discharges of 1976-'85 for each sub-basin.

19. Annual monsoon discharge to annual monsoon, non-monsoon and total rainfall of the previous year.

Non-monsoon discharge contributed only a small fraction of the total discharge and it was found to have no significant correlations Non-monsoon discharge were thus, not taken into account for final analysis. In the case of Kabbani basin the discharge and rainfall data were obtained only for three sub-basins, Manantoddy, Thirunelli and Choorani. A comparative study of the parameters of these sub-basins had been made. The data of 1986-1987 and 1988 was available for examining the final equation.

Graphs were plotted connecting,

1. Order and number of streams
2. Order and summed length of streams
3. Order and average length of streams
4. Order and average drainage area
5. Order and maximum straight length
6. Order and average monthly monsoon discharge of 1976-'80 and 1981-'85 for Chaliyar basin
7. Confluence ratio and the maximum straight length
8. Drainage area and average monthly monsoon discharge for Chaliyar river basin
9. Elongation ratio and form factor
10. Stream frequency and drainage density
11. Length of main stream and the average monthly monsoon discharge of 1976-'80 and 1981-'85 for Chaliyar river basin

Limitations

Limitations of the study are given below.

Horton-Strahler system of classification of stream was adopted. Fingertip tributaries were designated as of first order stream, second order streams were formed when two first order streams join and so on.

But the second order streams or first order streams joining a third order stream were not taken into account. Thus the lower order streams joining a higher order stream were neglected. Drainage area of streams of successive order in a sub-basin was not considered due to lack of contour maps. As such the drainage area of lower order streams was not available in a sub-basin. The highest order of the stream was considered as the order of the sub-basin. Hence, the relationship between the drainage area of lower order streams and the other parameters have not been studied for each sub-basin.

Slope was found to have very low correlation with the discharge, unless associated with area. An exact measurement of slope and the length of overland flow were not possible due to lack of contour map Drainage density and stream frequency of each order also, were not calculated for the same reason. Drainage density was calculated from the summed length of streams of all orders and stream frequency from the total number of streams of all orders. Some of the streams, especially first order streams get dried up during non-monsoon period. This effect was not taken into account.

Stream flow data from nine river gauge stations of Chaliyar basin was collected. Gauging station at Cherupuzha was eventually stopped after 1979 and the data was not obtained. Rainfall readings from many of the raingauge stations were not available. Also representative raingauge stations were not sufficient for some of the sub-basins. There are no raingauge stations within the limits of the rivergauge station of Kanhirapuzha and rivergauge readings were not available for the entire period. Raingauge stations of Chaliyar and Mukkom are situated near the boundaries of the sub-basins. Koodathai has only one raingauge station, Pudupady - S.S. Farm. Many of the raingauge stations were out of order and were not recording.

Raingauge stations have not been established within the drainage area of the sub-basins of Kabbani, except for Manantoddy, Thirunelli and Choorani. Kottiyur is the only raingauge station available within the station at Thirunelli. The two raingauge stations available for Baveli and Panamaram were not representative to it and also, the data for the ten years of study was not available. Stream flow records of Choorani after 1982 was not available. However, Kabbani basin has got significance as it is east flowing. Baseflow has not been separated in finding the discharge.

The equation of discharge was developed from the data corresponding to the eight sub-basins of Chaliyar. The number of observations are a few and hence the equation must be used with caution. The data for checking the equation was available only for 1986-'87 and 1988. The rainfall readings of 1988 is a rough estimate.

Results and Discussion

RESULTS AND DISCUSSION

The results of the study of runoff parameters of Chaliyar and Kabbani basins are discussed in the following sections.

4.1 Physical features

Chaliyar (Beypore) river flows towards the west aand Kabbani, towards the east. The physical features of the two basins are described below

4.1.1 Chaliyar river basin

The chaliyar river is one of the major rivers in the state. The main river starts from the Elambalari Hills at an altitude of 26,000 meters above M S.L This river is formed by the confluence of numerous streams and rivers. The important tributaries are Cherupuzha, Iringapuzha, Karumbanpuzha, Kanhirapuzha, Punnapuzha, Karimpuzha, Chaliyarpuzha and Vadapurampuzha. The parent river flows through Cholamala Estate, Kanthapara, Kurumbanmala, Mannathiambalam, Mambad, Edavanmala, Arecode, Vazhakade, Feroke and finally joins the sea at Beypore. Except for a narrow belt of arenaceous soil on the sea coast, the soils in the plains are for the most part composed of an admixture of clay and sand. The soil in the basin can be broadly classified as red clay, loam and red sand The climate in the basin is never uniform and varies from intense cold near the source to tropical climate in the plains and midlands. The two monsoons control the climate of the basin.

The upper reaches of the basin are very famous for their timber resources. Teak, Ebony, Blackwood etc. are grown in abundance in this area. The river basin is noted for its tile factory at its lower reaches. Stoneware, ceramic, plywood, match factories etc. also exist in this river basin. Paddy is the important wet crop in this valley though coconut, cashewnut, ginger, tapioca, arecanut etc. are grown in large areas as cash crops. In the upper reaches of the valley plantation crops such as coffee, tea, pepper, rubber etc. are cultivated on a large scale. There are about 17,500 hectares of wet lands, 18,000 hectares of dry land and 2,46,200 hectares of garden lands in the basin. Generally three crops of paddy are grown. The first crop depends mainly on south-west monsoon for its water requirements, which for the small areas of second and third crops, water is supplied from nearby ponds, wells or streams. The river basin is connected by good motorable roads.

4.1.2 Kabbani river basin

Kabbani river, one of the important tributaries of Cauvery river, has its origin in the Wynad taluk of Kerala State and flows towards east of western ghats to join the main river. This river is formed by the confluence of two main tributaries, Panamaram and Manantoddy. Panamaram river has its source in the western ghats near Lakkidi at an altitude of about 1,370 metres above M S L. Manantoddy river takes its origin in the Tondarmudi malai at an elevation of about 1,500 metre. These two rivers join together about 6.5 kilometre north of Panamaram. From this confluence point, the combined river known as Kabbani flows for a distance of about 8 kilometres through Kerala State and for another 11 kilometres along the boundary limits of Kerala and Mysore. At Kalvalli, the river takes a northern direction and flows through Mysore State.

About 16,200 hectares of paddy lands are available in this basin in Wynad taluk. Only single crop cultivation is practised in more than 75% of the above mentioned lands for want of irrigation facilities. In addition to these wet lands, about 81,000 hectares of dry lands and 40,500 hectares of poramboke lands are available in this basin

4.2 Law of stream numbers

According to the law of stream numbers the number of stream segments of successive orders follow a geometric progression. The number of stream segments of successive orders and the total number of streams of the sub-basins belonging to Chaliyar and Kabbani river basins are given in Table 4.1 and 4.2 respectively The calculated and observed number of streams verifies Horton's law of stream

Table 4 1 Verification of Horton s law of stream numbers Chaliyar bas n

Sl No	Sub basin	Order	Number of stream segments		Total number of segements	
			Observed	Calculated	Observed	Calculated
1	Kanhirapuzha	1	7		7 00	
		2	3	2 24	10	9 96
		3	1	0 72		
2	Kuthirapuzha	1	11	12 32		
		2	3	3 15	15	15 11
		3	1	7 00		
3	Mukkom	1	20	20 00		
		2	3	3 30	23	23 02
		3	1	0 53		
4	Maruthapuzha	1	18	18 00		
		2	4	4 03	23	23 09
		3	1	0 93		
5	Chaliyar	1	59	59 00		
		2	14	13 92	77	76 97
		3	3	3 28		
		4	1	0 77		
6	Koodathai	1	14	14 00		
		2	5	5 82	23	23 22
		3	2	1 99		
		4	1	1 01		
7	Punnapuzha	1	66	66 02		
		2	17	15 76	87	86 50
		3	3	3 78		
		4	1	0 90		
8	Arecode	1	228	226 95		
		2	57	55 63		
		3	5	13 63	304	300 37
		4	3	3 34		
		5	1	0 82		
9	Kar mpuzha	1	115	114 50		
		2	32	29 14		
		3	7	7 41	155	153 42
		4	2	1 89		
		5	1	0 48		

Table 4 2 Ver f cation of Horton s law of stream numbers Kabban basin

Sl No	Sub-basin	Order	Number of stream segements Observed	Number of stream segements Calculated	Total number of streams Observed	Total number of streams Calculated
1	Manjat	1	3	3 00	4	4 00
		2	1	1 00		
2	Vazhavatta	1	3	3 00	4	4 00
		2	1	1 00		
3	Kakkavayal	1	13	13 00		
		2	5	4 06	18	18 33
		3	1	1 27		
4	Muthanga	1	5	5 00		
		2	2	2 13	8	2 03
		3	1	0 91		
5	Thirunell	1	17	17 00		
		2	3	3 12	21	20 69
		3	1	0 57		
6	Thondar	1	16	16 00		
		2	3	3 24	20	19 90
		3	1	0 66		
7	Bavel	1	57	57 00		
		2	9	10 04	66	69 11
		3	2	1 77		
		4	1	0 31		
8	Choorani	1	17	17 00		
		2	6	6 07	26	26 01
		3	2	2 17		
		4	1	0 77		
9	Manantoddy	1	81	81 00		
		2	20	21 26		
		3	6	5 58	110	109 69
		4	2	1 47		
		5	1	0 38		
10	Panamaram	1	91	91 00		
		2	25	23 83		
		3	5	6 24	124	123 12
		4	2	1 63		
		5	1	0 43		

numbers, having the first term of the geometric progression as the number of first order streams and the ratio as the confluence ratio The last term of the progression, in most of the sub-basins is less than one, which means that under the physiographical conditions of the basin and for the existing confluence ratio, the number of streams of lower orders should be much larger for the basin to be considered as of the given order. The law is expressed using regression equations in Table 4.3 and graphically in Fig.4.1 to 4.4. The number of observations used for the regression equations is so small that these equations have not been used for calculations.

Table 4.4 shows that the degree of accumulation of lower order streams is not sufficient in most of the sub-basins for the order assigned to it. Koodathai, Vazhavatta and Manjat are completely developed (100%) Karimpuzha, Manantoddy, Panamaram and Baveli require more streams to be considered as of fourth or fifth order (degree of accumulation of lower order streams is less than 50 per cent). Mukkom has the lowest degree of accumulation of first and second order streams to be considered as of a third order sub-basin (24.5%). As a whole, the evolution of most of the sub-basins of Chaliyar river basin is more advanced as compared to sub-basins of Kabbani river basin.

The confluence ratio computed from the regression equation, by the method of weighted means and graphically are compared in Table 4.5. The three methods give more or less the same values. The

Table 4.3 Law of stream numbers expressed as regression equations

River basin	Sl.No.	Sub-basin	Regression equation
	1	Kuthirapuzha	$N_u = 1.289 - 0.423\ u$
	2	Kuthirapuzha	$N_u = 1.547 - 0.521\ u$
	3	Mukkom	$N_u = 1.894 - 0.651\ u$
	4	Maruthapuzha	$N_u = 1.874 - 0.628\ u$
Chaliyar	5	Chaliyar	$N_u = 2.342 - 0.598\ u$
	6	Koodathai	$N_u = 1.761 - 0.573\ u$
	7	Punnapuzha	$N_u = 2.435 - 0.621\ u$
	8	Arecode	$N_u = 2.952 - 0.560\ u$
	9	Karimpuzha	$N_u = 2.540 - 0.533\ u$
	1	Manjat	------
	2	Vazhavatta	-------
	3	Kakkavayal	$N_u = 1.718 - 0.557\ u$
	4	Muthanga	$N_u = 1.032 - 0.350\ u$
Kabbani	5	Thirunelli	$N_u = 1.800 - 0.615\ u$
	6	Thondar	$N_u = 1.764 - 0.602\ u$
	7	Baveli	$N_u = 2.233 - 0.592\ u$
	8	Choorani	$N_u = 1.620 - 0.417\ u$
	9	Manantoddy	$N_u = 2.303 - 0.482\ u$
	10	Panamaram	$N_u = 2.376 - 0.502\ u$

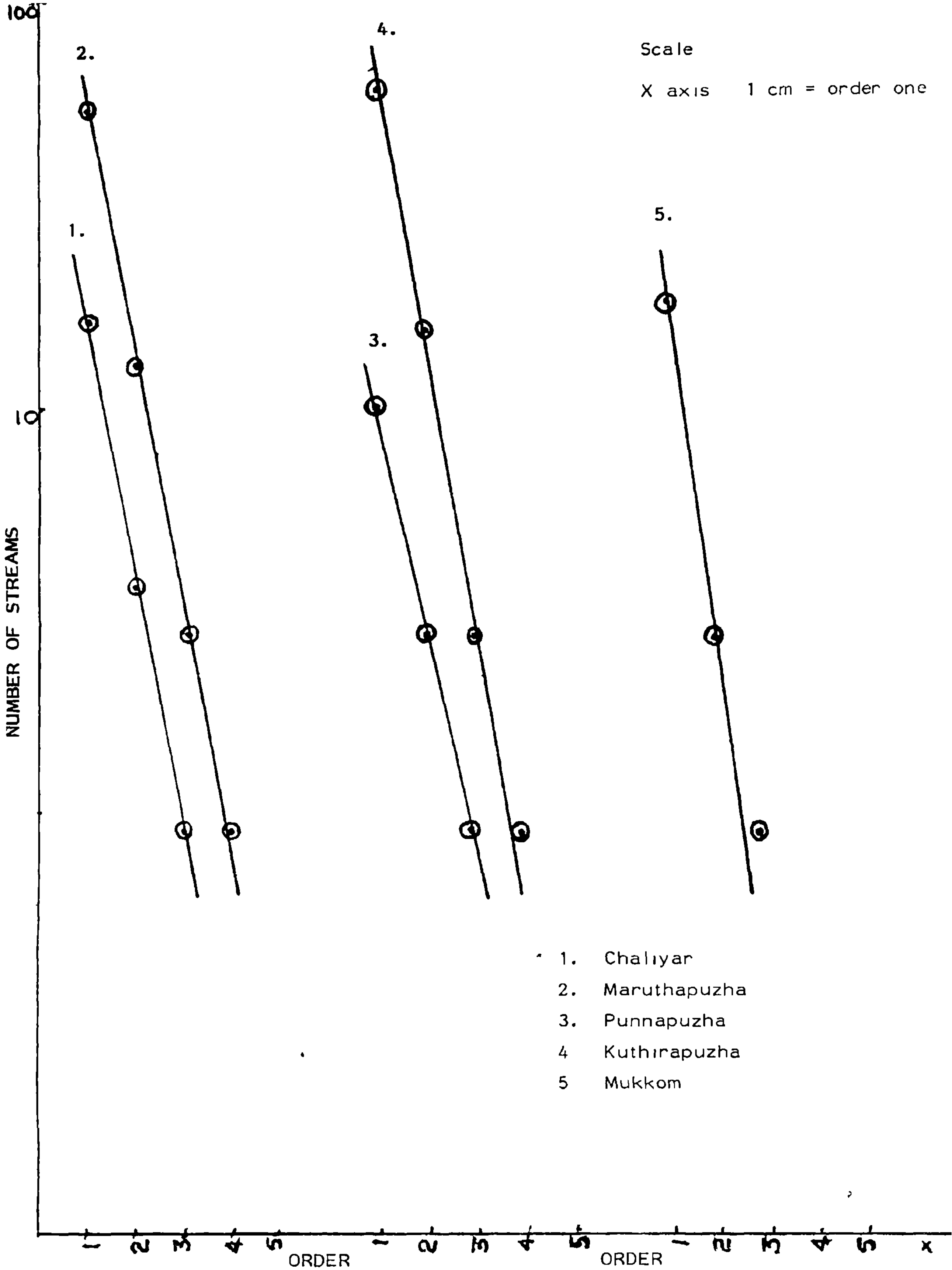


Fig.4.1 ORDER Vs NUMBER OF STREAMS – CHALIYAR RIVER BASIN

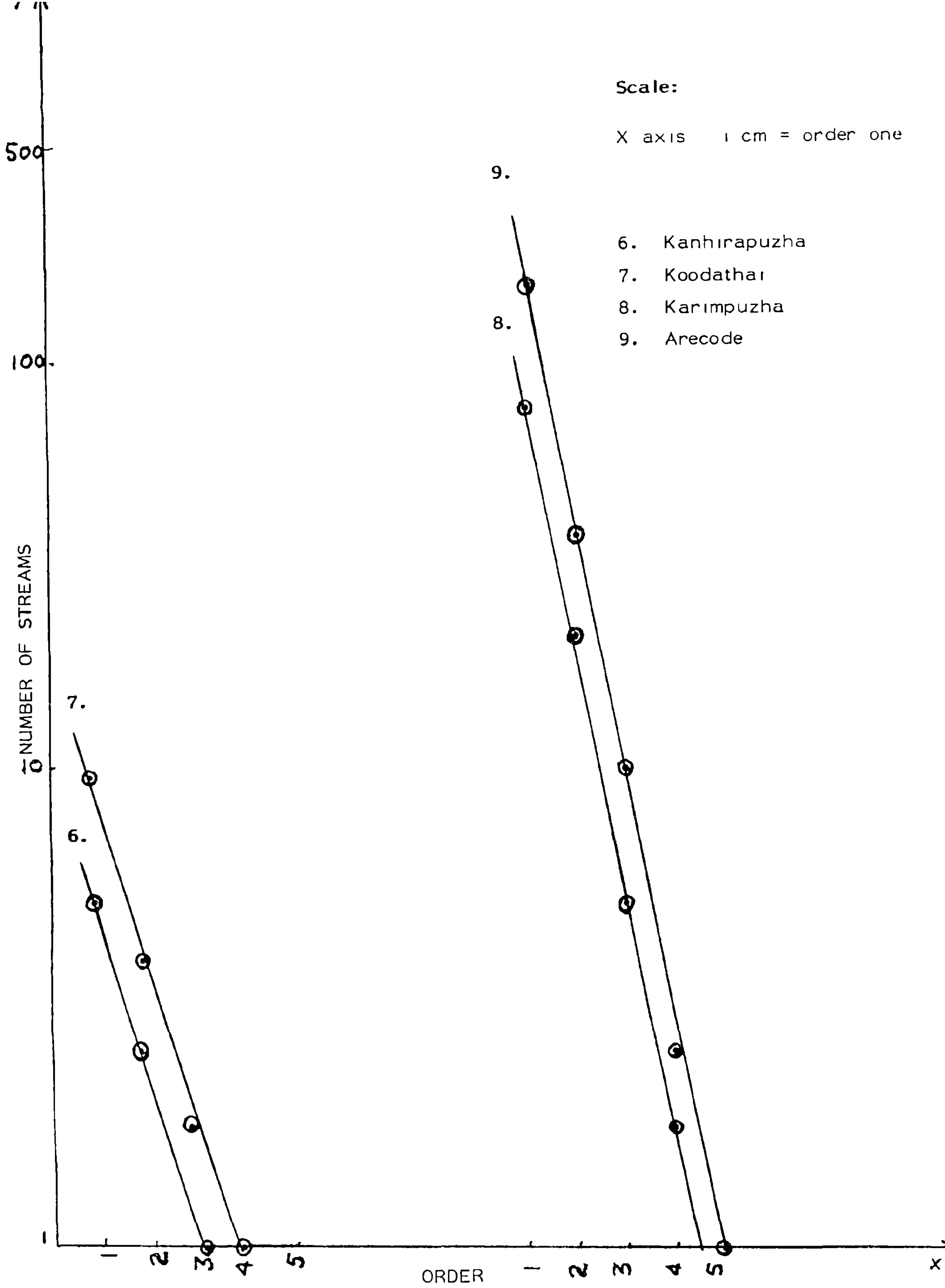


Fig. 4.2 ORDER V. NUMBER OF STREAMS

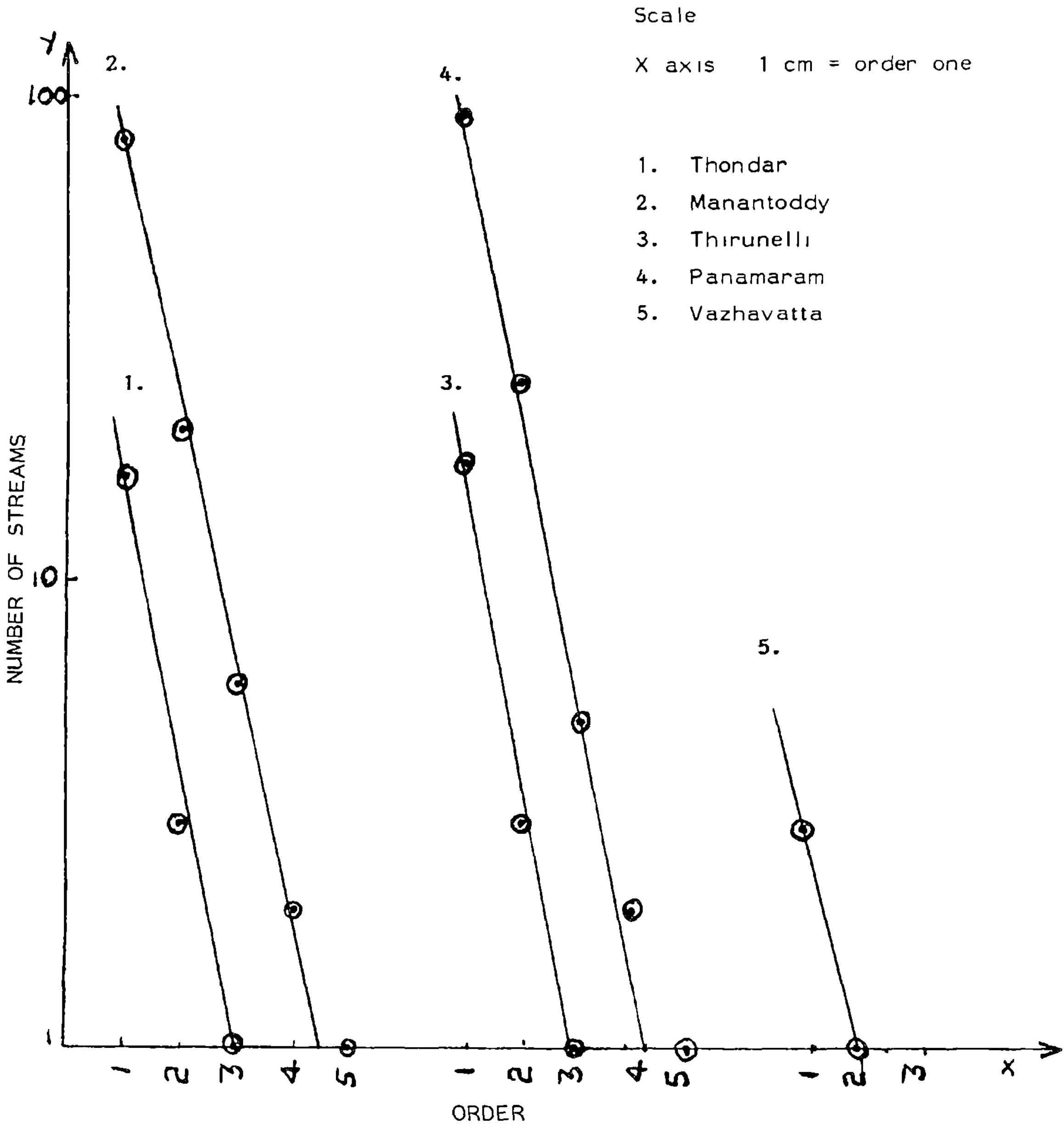


Fig.4.3 ORDER Vs NUMBER OF STREAMS - KABBANI RIVER BASIN

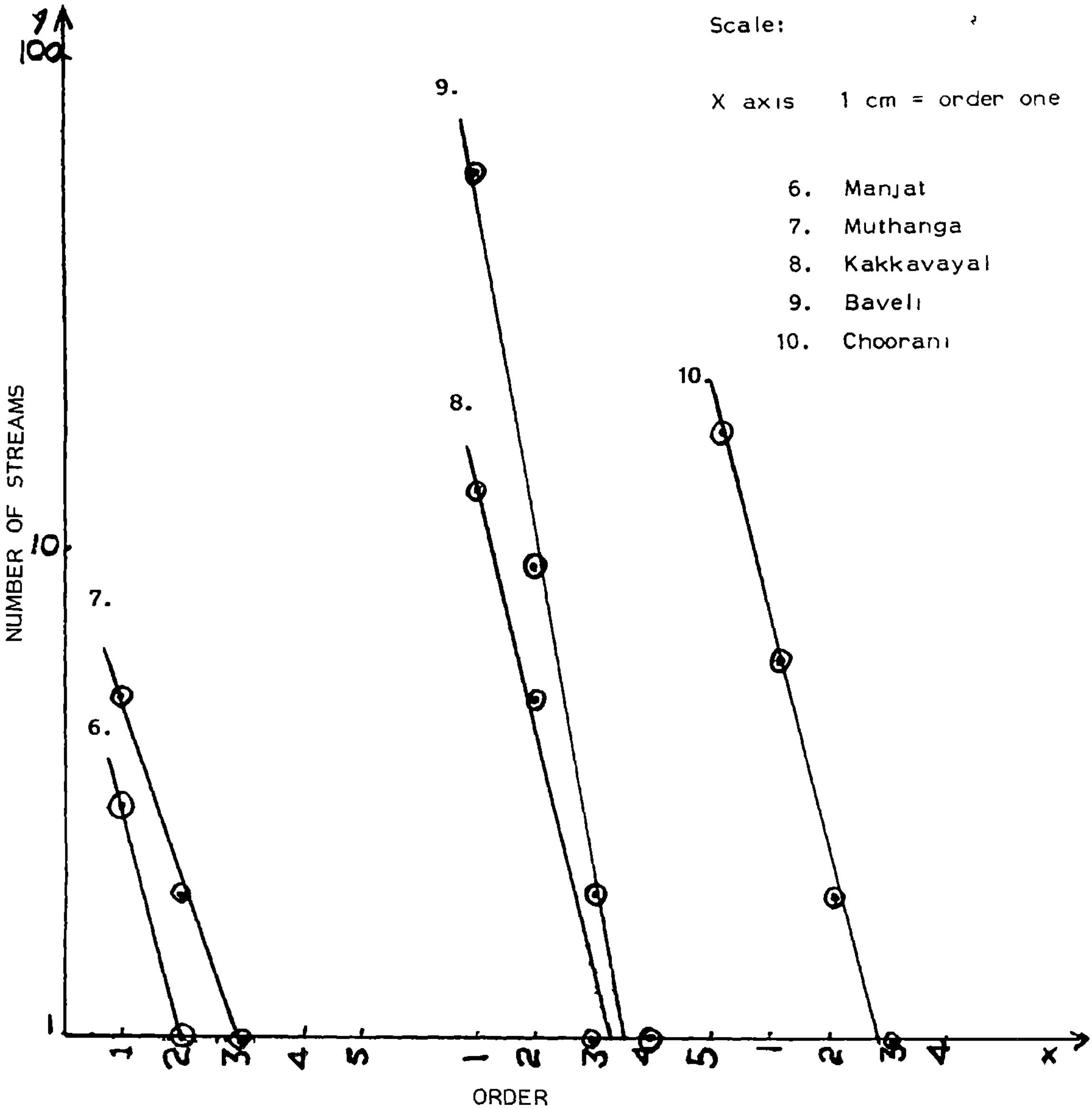


Fig.4.4 ORDER Vs NUMBER OF STREAMS - KABBANI RIVER BASIN

Table 4.4 Relationship between order, confluence ratio and degree of accumulation of lower order streams

River basin	Sl.No.	Sub-basin	Order	Confluence ratio	Degree of accumulation of lower order streams (%)
	1	Knhirapuzha	3	3.13	71.68
	2	Kuthirapuzha	3	3.51	89.80
	3	Mukkom	3	6.12	24.50
	4	Maruthapuzha	3	4.41	93.00
Chaliyar	5	Chaliyar	4	4.24	77.40
	6	Koodathai	4	2.41	100.55
	7	Punnapuzha	4	4.18	90.40
	8	Arecode	5	4.08	81.90
	9	Krimpuzha	5	3.93	48.00
	1	Manjat	2	3.00	100.00
	2	Vazhavatta	2	3.00	100.00
	3	Kakkavayâl	3	3.20	126.95
	4	Muthanga	3	2.35	90.54
Kabbani	5	Thirunelli	3	5.45	57.23
	6	Thondar	3	4.93	65.80
	7	Baveli	4	5.68	31.11
	8	Choorani	4	2.80	77.44
	9	Manantoddy	5	3.81	38 44
	10	Panamaram	5	3.82	42.74

Table 4.5 Confluence ratio of the sub-basins obtained by different methods

River basin	Sl.No.	Sub-basin	Confluence ratio obtained from		
			weighted means	Regression equation	Graph
	1	Kanhirapuzha	3.13	2.65	3.24
	2	Kuthirapuzha	3.51	3.32	3.16
	3	Mukkom	6.12	4.47	3.80
	4	Maruthapuzha	4.41	4.24	4.08
Chaliyar	5	Chaliyar	4.24	3.96	4 17
	6	Koodathai	2.41	3.74	2.61
	7	Punnapuzha	4.18	4.18	3.89
	8	Arecode	4.08	3.98	3.98
	9	Karimpuzha	3.93	4.18	3.98
	1	Manjat	3.00	--	--
	2	Vazhavatta	3.00	--	--
	3	Kakkavayal	3.20	3.61	2.56
	4	Muthanga	2 35	2.24	2 19
Kabbani	5	Thirunelli	5.25	4.12	4.69
	6	Thondar	4.93	4.00	4.69
	7	Baveli	5.90	3.91	4.20
	8	Choorani	2.80	2.61	2.82
	9	Manantoddy	3.81	3.03	3.31
	10	Panamaram	3.82	3.17	3.40

confluence ratio ranges between 2 4-4 8 for Chaliyar and 2.3-5 7 for Kabbani The percentage number of streams of successive orders are shown in Table 4 6 First order streams constitute the largest portion of the stream segments. For the sub-basins of Chaliyar it comprises about 75 per cent of the total number of stream. Percentage number of second order streams is about 20 and for the third order, it is about 4% In the case of the sub-basins of Kabbani river basin, first order stream segments form the major portion but the percentage varies from 62 5-86.4, the second order streams come to 20%-25% and the third order streams near to 5%.

Table 4.7 gives the relationship between the confluence ratio, maximum straight length of the sub-basin, degree of accumulation of lower order streams and annual monsoon discharge per area. The confluence ratio bears a direct relationship with the maximum straight length of the sub-basin (Correlation 0.48 for Chaliyar and 0.27 for Kabbani). The more elongated form of the sub-basins of Chaliyar helps to accumulate more number of lower order streams. The sub-basins of Chaliyar are thus, more developed than that of Kabbani basin. Hence, the confluence ratio is comparatively high for the sub-basins for Chaliyar. Confluence ratio is related to the annual monsoon discharge of the sub-basins. The correlation coefficients are -0 77 and -0.78 with the average annual monsoon discharge per unit area of the sub-basins of Chaliyar during 1976-'80 and 1981-'85. Average annual monsoon discharge per unit area has a correlation

Table 4.6 Number of stream segments expressed as percentage of total number of streams

River basin	Sl.No.	Sub-basin	Number of stream segments of order (%)				
			1	2	3	4	5
	1	Kanhirapuzha	70 00	20.00	10 00		
	2	Kuthirapuzha	73.00	20.00	6.70		
	3	Mukkom	83.00	12 50	4.20		
	4	Maruthapuzha	78 00	27.40	4.00		
Chaliyar	5	Chaliyar	77 00	18.00	4.00	1.30	
	6	Koodathai	64.00	23.00	4.50		
	7	Punnapuzha	76 00	19 50	3.50	1.20	
	8	Arecode	75.00	18 80	4 90	0.99	0.33
	9	Karimpuzha	73.00	20.00	4.50	1 30	0 64
	1	Manjat	75 00	25.00			
	2	Vazhavatta	75.00	25 00			
	3	Kakkavayal	68 40	26 30	5.30		
	4	Muthnaga	62.50	25.00	12.50		
Kabbani	5	Thirunelli	81.00	14.00	4 80		
	6	Thondar	80.00	15 00	5.00		
	7	Baveli	86 40	14 00	3.00	6.10	
	8	Choorani	65.00	23.00	7.60	3.80	
	9	Manantoddy	74.00	18.20	5.50	1.80	0.91
	10	Panamaram	73.00	20.20	4.00	1.60	0.81

Table 4 7 Relationship between confluence ratio, maximum straight length, degree of accumulation of lower order streams and discharge

River basin	Sl No	Sub-basin	Confluence ratio	Maximum straight length of sub-basin (km)	Degree of accumulation of lower order streams (%)	Annual monsoon discharge per area (Mm^3/km^2)	
						1976- 80	1981-'85
	1	Kanh rapuzha	3 13	18 80	71 68	2 68	2 25
	2	Kuthirapuzha	3 51	27 60	89 80	2 58	2 53
	3	Mukkom	6 12	29 60	24.50	5 57	4 38
	4	Maruthapuzha	4 41	20 40	93 00	1 77	1 12
Chaliyar	5	Chaliyar	4 24	42 40	77 40	3 09	1 71
	6	Koodathai	2 45	20 00	100 55	7 27	3 54
	7	Punnapuzha	4 18	40 80	90 40	1 82	1 53
	8	Arecode	4 08	76 00	81 90	1 92	1 74
	9	Kar mpuzha	3 93	45 20	48 00	2 11	1 83
	1	Manjat	3 00	-	100 00	0 98	0 68
	2	Vazhavatta	3 00	10 80	100 00	1 80	0 78
	3	Kakkavayal	3 20	21 20	126 95	1 08	1 87
	4	Muthanga	2 35	18 40	90 54	1 10	1 12
Kabban	5	Thirunelli	5 45	14 00	57 23	5 73	3 58
	6	Thondar	4 93	18 80	65 80	4 95	3 59
	7	Bavel	5 68	36 80	31 11	1 42	1 09
	8	Choorani	2 80	15 60	77 44	9 69	4 30
	9	Manantoddy	3 81	38 80	38 44	3 33	0 91
	10	Panamaram	3 82	42 00	42 74	0 19	0 17

of -0.75 with the confluence ratio for the period 1976-'85 But the relationship is not significant for the Kabbani basin. The discharge per area mainly depends on higher order streams which are larger than the lower order streams. The order and the number of larger streams are more significant than the number of small tributaries For a given order, the peak discharage is lower for a higher confluence ratio.

4.3 Law of summed lengths

According to the law of summed lengths, the length of streams of successive orders follow a decreasing geometric progression The summed lengths of streams of successive orders are expressed in Table 4.8 and 4.9. The law deviates for higher order streams, the value being higher than those predicted by the length ratio (R_L). As a stream enters flat land, lateral erosion prevails due to the decrease of slope, followed by braiding and meandering of the water course and thus, the length of streams increases considerably Most of the streams acquire a higher order in this course of flow An increase of stream length results for these orders, deviating the law established for the drainage system in the mountainous and hilly areas It can be seen from Fig.4.5 to 4.8 that the graphical plot of order and summed stream length has two straight line portions. The law deviate for the higher orders of Punnapuzha, Karimpuzha, Koodathai, Muthanga.

Table 4.8 Horton's law of summed stream length - Chaliyar basin

Sl. No.	Sub-basin	Summed length ratio R_L	Observed length of streams (kg)						Calculated length of streams (km)					
			L_1	L_2	L_3	L_4	L_5	L	L_1	L_2	L_3	L_4	L_5	L
1	Kanhirapuzha	10.45	31.20	19.60	0.60	-	-	51.40	31.20	2.99	0.29	-	-	34.47
2	Kuthirapuzha	2.73	82.80	23.60	24.00	-	-	130.40	82.80	30.35	11.13	-	-	124.28
3	Mukkom	3.21	100.40	39.40	7.60	-	-	147.40	100.40	31.26	9.73	-	-	141.42
4	Maruthapuzha	2.91	64.60	35.20	6.40	-	-	106.20	64.60	22.17	7.60	-	-	94.39
5	Chaliyar	3.20	262.60	67.00	33.20	26.80	-	389.60	262.60	82.04	25.63	8.01	-	378.28
6	Koodathai	5.00	67.52	17.40	7.60	10.00	-	93.44	67.52	13.51	2.71	0.54	-	82.77
7	Punnapuzha	2.75	237.80	102.72	20.00	44.00	-	404.52	237.80	86.61	31.50	11.49	-	367.42
8	Arecode	2.72	953.20	304.67	122.00	80.00	56.00	1515.87	953.20	350.32	128.75	44.32	17.39	1497.26
9	Karimpuzha	2.89	433.00	181.00	39.60	50.00	10.00	713.60	433.00	149.68	51.71	17.87	6.17	658.36

Table 4 9 Horton s law of summed stream length - Kabbani basin

Sl No	Sub basin	Summed length ratio R_L	Observed length of streams (km)						Calculated length of streams (km)					
			L_1	L_2	L_3	L_4	L_5	L	L_1	L_2	L_3	L_4	L_5	L
1	Manjat	1 30	10 40	8 00	-	-	-	18 40	10 40	8 00	-	-	-	18 40
2	Vazhavatta	3 59	24 40	6 80	-	-	-	31 20	24 40	6 80	-	-	-	31 20
3	Kakkavayal	2 69	63 64	20 84	12 00	-	-	96 48	63 64	23 70	8 83	-	-	96 17
4	Muthanga	1 41	9 44	4 88	6 00	-	-	20 32	9 44	6 69	4 74	-	-	20 86
5	Thirunelli	3 15	41 48	14 00	4 60	-	-	60 08	41 48	13 15	4 17	-	-	58 80
6	Thondar	2 32	49 44	10 40	-	-	79 84	49 44	21 34	9 20	-	-	-	79 99
7	Baveli	3 91	172 72	49 60	8 00	6 00	-	236 32	172 72	44 40	11 28	2 88	-	231 02
8	Choorani	3 11	56 48	19 44	8 56	1 20	-	85 68	56 48	18 15	5 83	1 87	-	82 34
9	Manantoddy	2 45	222 96	98 68	23 40	28 00	25 68	398 72	222 96	91 11	37 24	15 22	6 22	372 75
10	Panamaram	3 57	363 09	70 64	67 56	36 92	11 40	531 08	363 09	96 65	27 11	9 04	2 13	478 06

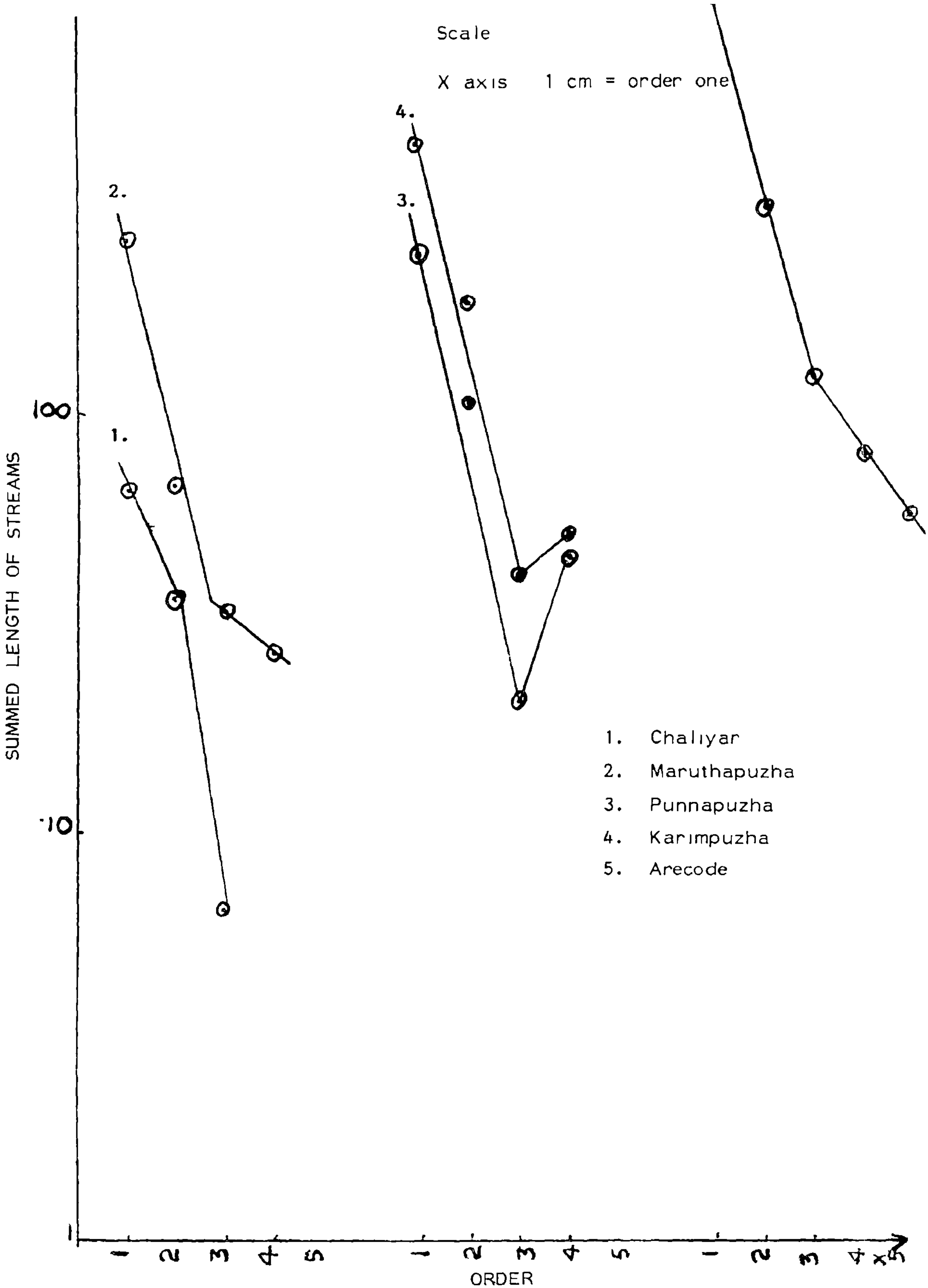


Fig.4.5 ORDER Vs SUMMED LENGTH OF STREAMS - CHALIYAR RIVER BASIN

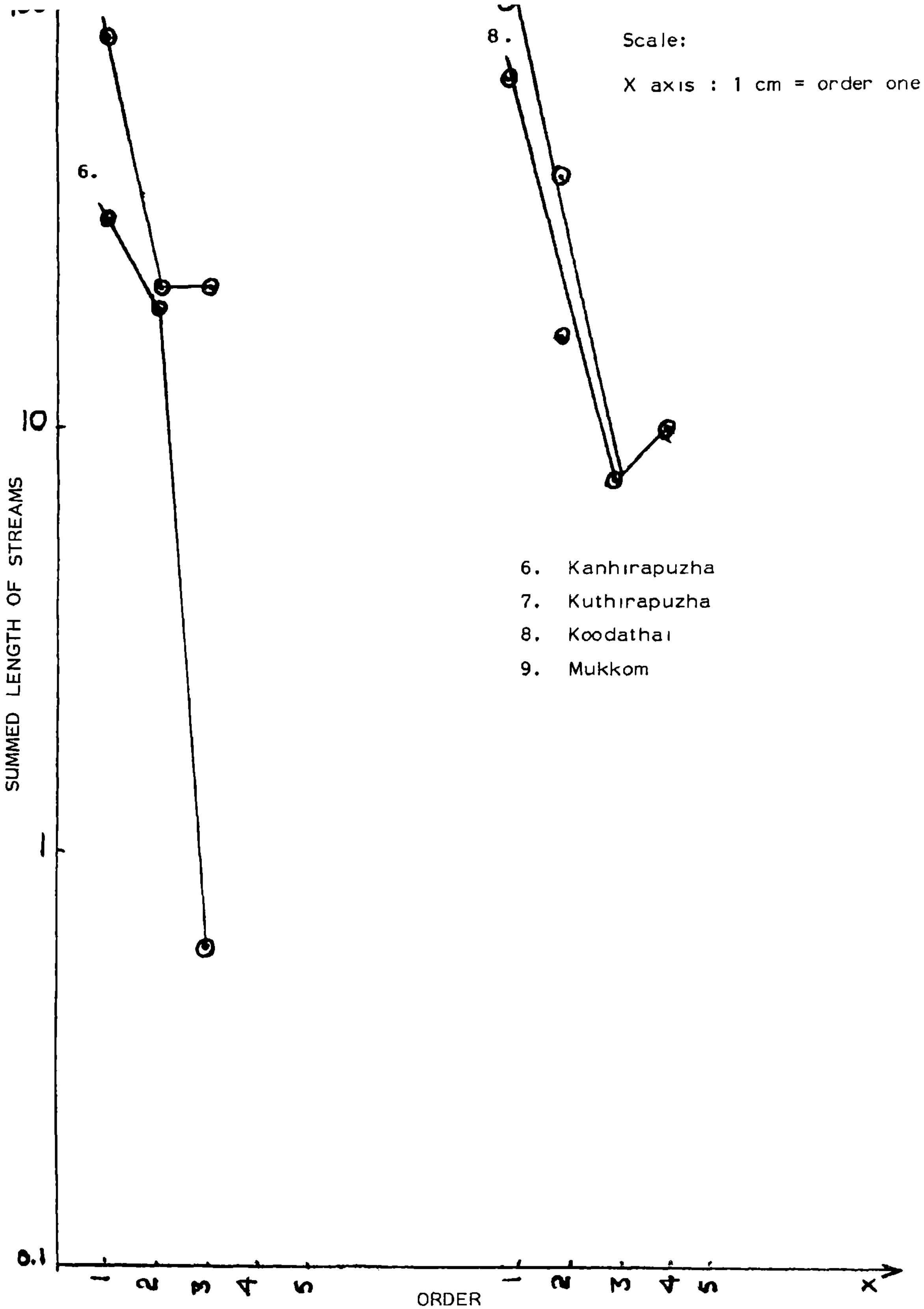


Fig.4.6 ORDER Vs SUMMED LENGTH OF STREAMS - CHALIYAR RIVER BASIN

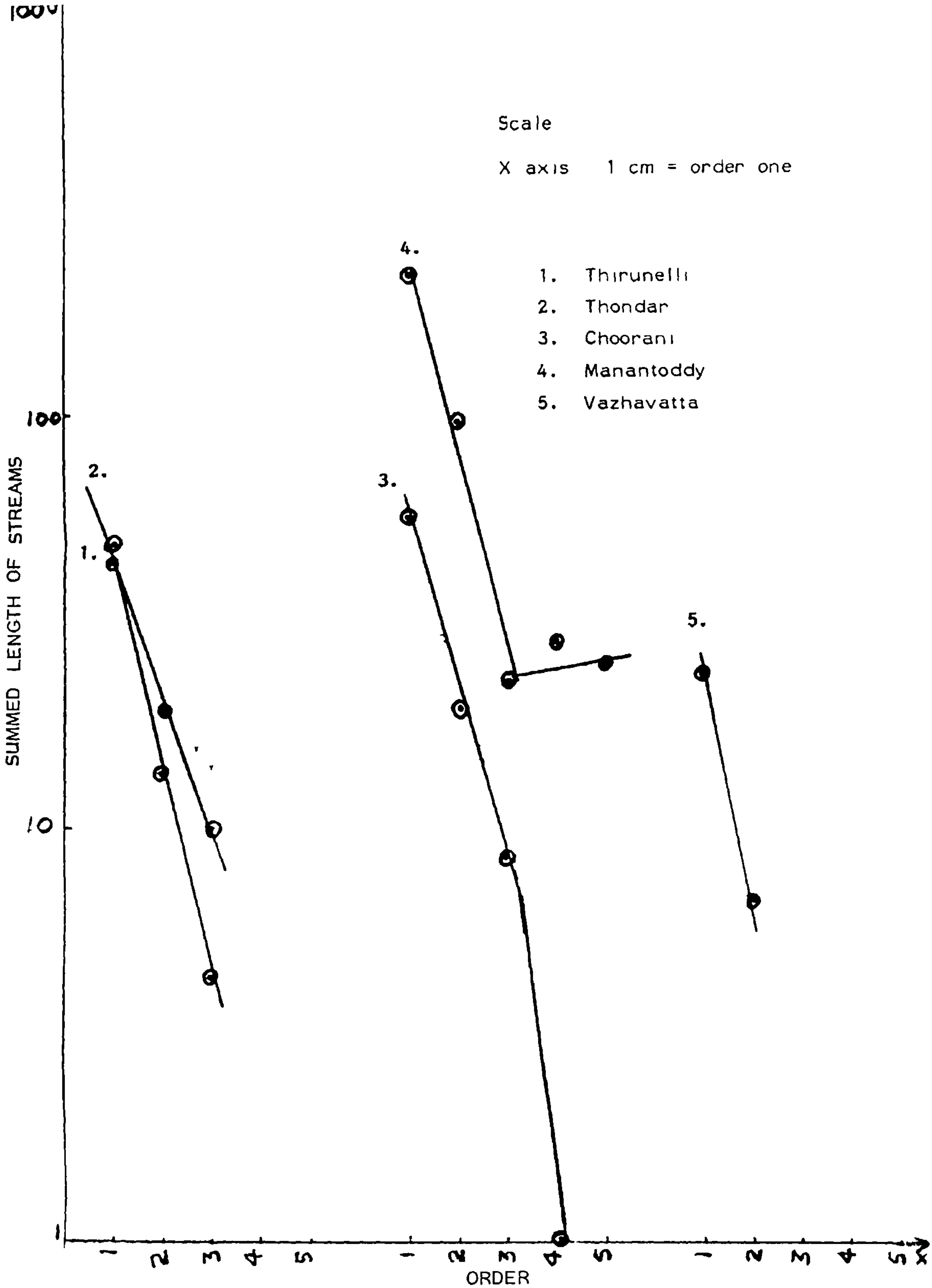
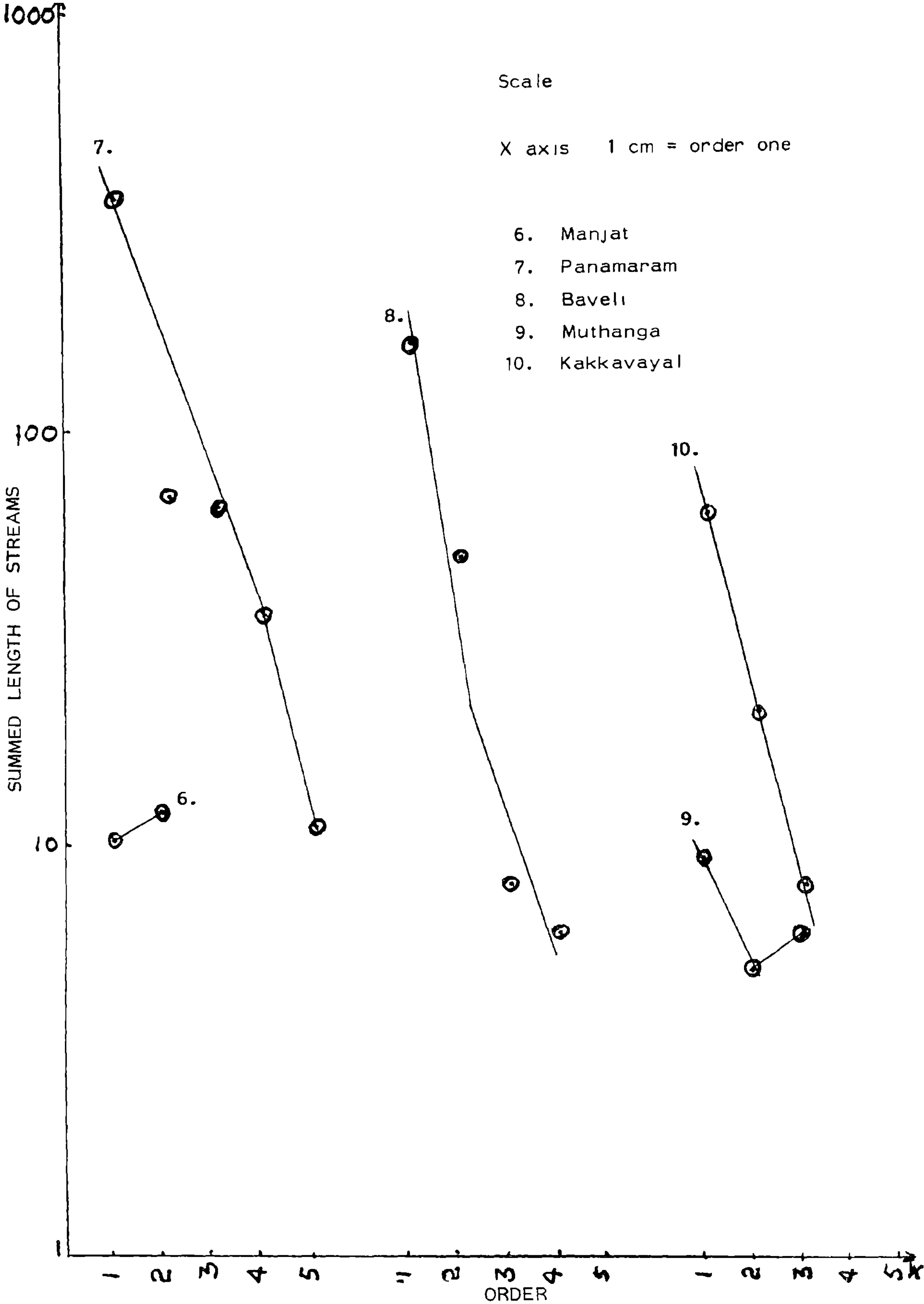


Fig.4.7 ORDER Vs SUMMED LENGTH OF STREAMS - KABBANI RIVER BASIN



Scale
X axis 1 cm = order one
6. Manjat
7. Panamaram
8. Baveli
9. Muthanga
10. Kakkavayal
SUMMED LENGTH OF STREAMS
ORDER
1000
100
10
1

Unlike the law of stream numbers of successive orders, the law of summed stream length form a decreasing progression. The length ratio R_L, therefore, is always less than the confluence ratio

4.4 Law of average stream length

According to the law, the average lengths of streams form a geometric progression. The average length of streams of successive orders are shown in Table 4.10 and 4.11. The law does not hold good, for higher orders. The graphical representation of the law is shown in Fig.4.9 and 4.10.

The graphical representations of the law of summed length of streams and the law of average length of streams have two straight line portions, viz., for the lower orders and for the higher order. Most of the sub-basins extend over two major relief units, the high land and the midland, having the rocks of different characters offering resistance of erosion. Two regression lines may also occur owing to a change in the rate of evolution of the sub-basin, either by human intervention like deforestation and urbanization or by tectonic movements. Maruthapuzha, Karimpuzha, Mukkom and Panamaram violate the law for the highest order.

The total length of streams of all orders (ΣL) is calculated from the geometric progression of summed stream length that is,

$$L = L_1 \frac{(1 - R_L{}^{u-1})}{R_L - 1}$$ (Table 4 8 and 4 9).

Table 4 10 Law of average length of streams - Chalıyar basın

Sl No	Sub basin	Confluence rat o (R_c)	Summed length ratio (R_L)	Average length ratio (r_l)	Observed average length of streams (km)					Calculated average length of streams (km)				
					$\bar{L}_1$	$\bar{L}_2$	$\bar{L}_3$	$\bar{L}_4$	$\bar{L}_5$	$\bar{L}_1$	$\bar{L}_2$	$\bar{L}_3$	$\bar{L}_4$	$\bar{L}_5$
1	Kanhırapuzha	3 13	10 45	0 30	4 46	9 80	0 60	-	-	4 46	1 33	0 40	-	-
2	Kuth rapuzha	3 52	2 73	1 29	7 53	7 87	24 00	-	-	7 53	9 70	12 50	-	-
3	Mukkom	6 12	3 21	1 91	5 02	13 13	7 60	-	-	5 02	9 50	18 27	-	-
4	Maruthapuzha	4 41	2 91	1 51	3 59	8 80	6 40	-	-	3 59	5 40	8 22	-	-
5	Chal yar	4 24	3 20	1 41	4 45	4 79	1 07	26 80	-	4 45	6 28	8 86	12 50	-
6	Koodathaı	2 41	5 00	0 44	4 82	1 66	3 80	10 00	-	4 82	2 11	0 93	0 41	-
7	Punnapuzha	4 18	2 75	1 52	3 60	6 04	6 67	4 40	-	3 60	5 48	8 34	12 68	-
8	Arecode	4 08	2 72	1 28	4 18	5 35	8 13	26 67	56 00	4 18	5 34	6 83	8 73	11 16
9	Kar mpuzha	3 76	2 89	1 30	3 77	5 66	5 66	25 00	10 00	3 77	4 89	6 35	8 24	10 75

Table 4.11 Law of average length of streams - Kabbani basin

Sl.No.	Sub-basin	Confluence ratio (R_c)	Summed length ratio (R_L)	Average length ratio (r_l)	Observed average length of streams (km)					Calculated average length of streams (kg)				
					$\bar{L}_1$	$\bar{L}_2$	$\bar{L}_3$	$\bar{L}_4$	$\bar{L}_5$	$\bar{L}_1$	$\bar{L}_2$	$\bar{L}_3$	$\bar{L}_4$	$\bar{L}_5$
1	Manjat	3.00	1.30	2.30	3.47	8.0	-	-	-	3.47	8.01	-	-	-
2	Vazhavatta	3.00	3.59	0.84	8.13	6.80	-	-	-	8.13	6.80	-	-	-
3	Kakkavayal	3.20	2.69	1.19	4.50	4.17	12.00	-	-	4.50	5.83	6.95	-	-
4	Muthanga	2.35	1.41	1.66	1.89	2.44	6.00	-	-	1.89	3.15	5.24	-	-
5	Thirunelli	5.25	3.15	1.73	2.44	4.67	4.60	-	-	2.44	4.22	7.28	-	-
6	Thondar	4.93	2.32	2.13	3.09	6.60	10.40	-	-	3.09	6.58	13.79	-	-
7	Baveli	5.68	3.91	1.45	3.03	5.51	4.00	6.00	-	3.03	4.40	6.39	9.27	-
8	Choorani	2.80	3.11	0.90	3.32	3.24	4.28	1.20	-	3.32	2.99	2.69	2.40	-
9	Manantoddy	3.81	2.45	1.56	2.75	4.93	3.90	14.00	25.68	2.75	4.28	6.67	10.34	16.2
10	Panamaram	3.82	3.57	1.07	3.99	2.83	13.50	18.46	11.40	3.99	4.27	4.58	4.90	5.25

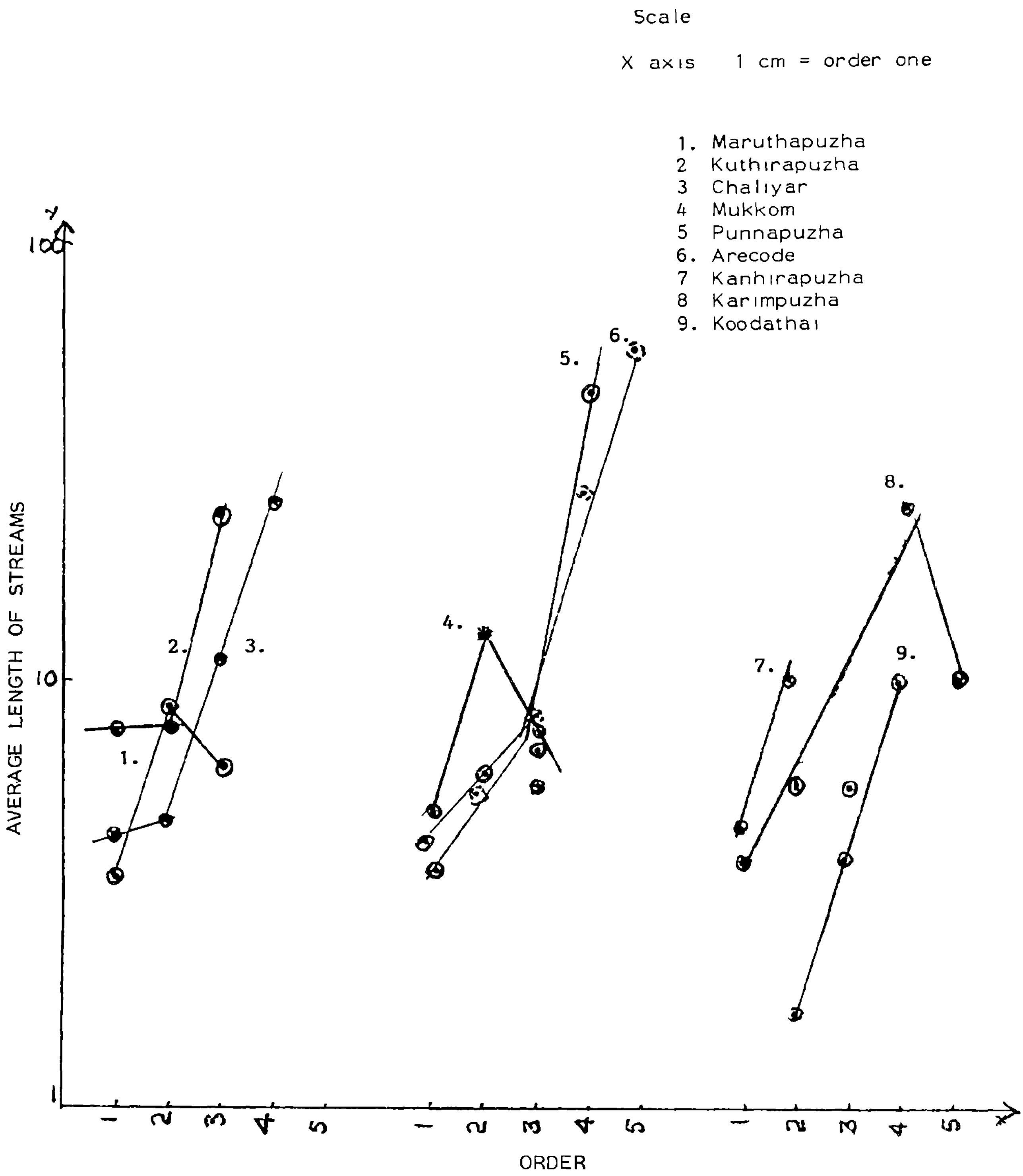


Fig.4.9 ORDER Vs AVERAGE LENGTH OF STREAMS - CHALIYAR RIVER BASIN

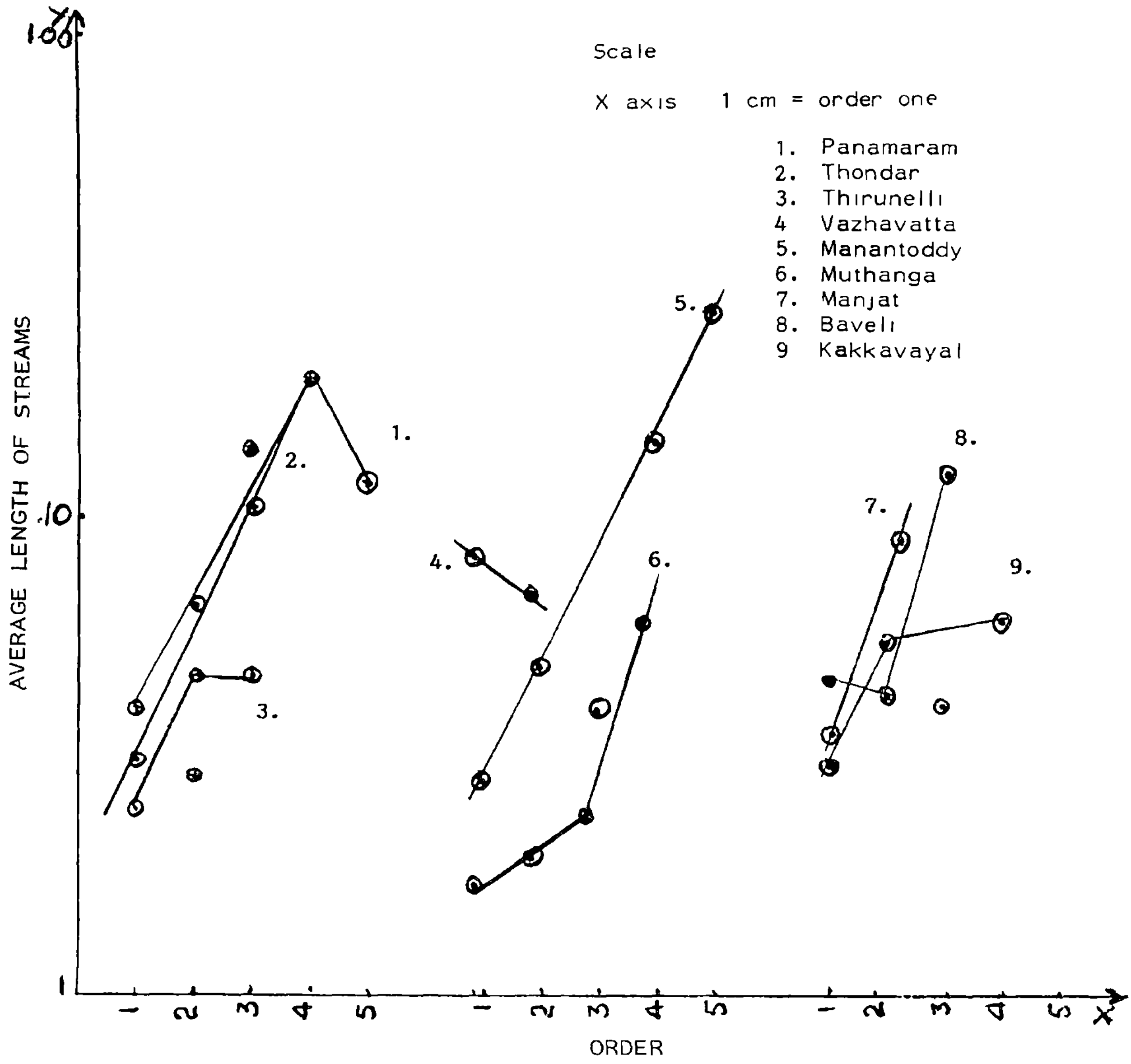


Fig.4.10 ORDER Vs AVERAGE LENGTH OF STREAMS - KABBANI RIVER BASIN

4.5 Basin shape

The shape of the sub-basins are represented by four parameters, (1) the maximum straight length of the sub-basin (L_m) (2) length of the main stream (L_s), (3) form factor (R_f) and (4) elongation ratio (R_e). Table 4.12 gives an account of the basin shape. The relationship between form factor and elongation ratio is expressed in Fig.4.11 and 4.12. Elongation ratio is less than that for a square (1.128) and greater than the minimum value (0.2) of the circle The form factor and elongation ratio indicate that the sub-basins resemble a rectangle than a circle. Form factor increases with the order of the sub-basin, indicating the tendency of the sub-basins to become elongated with increasing order. The relationship cannot be predicted for higher orders because the highest order of streams available is only five. Fig. 4.13 and 4.14 show the relationship between confluence ratio and the maximum straight length of the sub-basin. a, b, and c represent the sub-basins of third order, d, e and f are of fourth order and g and h give the fifth order sub-basins. In Fig.4.14, j denotes the second order sub-basin. It is clear that the maximum straight length of the sub-basin increases with the order. Fig 4.14 verifies the increase in sub-basin length with the order. An increase in the area and maximum straight length of the sub-basins with the order is shown in Table 4 13

The maximum straight length L_m has a direct relationship with the average monthly monsoon discharge (correlation 0.93 for both the periods 1976-'80 and 1981-'85), for the sub-basins of Chaliyar

Table 4.12 Relationship between order, area and basin shape

River basin	Sl.No.	Sub-basin	Order	Area (km^2)	Form factor	Elongation ratio	Maximum straight length of sub-basin (km)	Lenth of main stream (km)
Chaliyar	1	Kanhirapuzha	3	68	0.201	0.506	18.80	18.80
	2	Kuthirapuzha	3	284	0.384	0.700	27.60	36.60
	3	Mukkom	3	221	0.252	0.567	29.60	32.84
	4	Maruthpuzha	3	144	0.391	0.751	20.40	19.60
	5	Chaliyar	4	386.69	0.224	0.534	42.40	51.44
	6	Koodathai	4	103	0.258	0.573	20.00	19.68
	7	Punnapuzha	4	344	0.203	0.508	40.80	33.80
	8	Arecode	5	1841	0.322	0.641	76.00	98.64
	9	Karimpuzha	5	670.35	0.311	0.630	45.20	48.80
Kabbani	1	Manjat	2	47.50	-	-	-	-
	2	Vazhavatta	2	57.50	0.493	0.793	10.80	11.00
	3	Kakkavayal	3	90	0.200	0.905	21.20	17.80
	4	Muthanga	3	192	0.567	0.850	18.40	19.20
	5	Thirunelli	3	38	0.194	0.497	14.00	14.00
	6	Thondar	3	30	0.085	0.329	18.80	12.40
	7	Baveli	4	190	0.140	0.423	36.80	41.20
	8	Choorani	4	35	0.144	0.428	15.60	16.40
	9	Manantoddy	5	398	0.264	0.581	38.8	49.20
	10	Panamaram	5	460	0.261	0.577	42.00	58.20

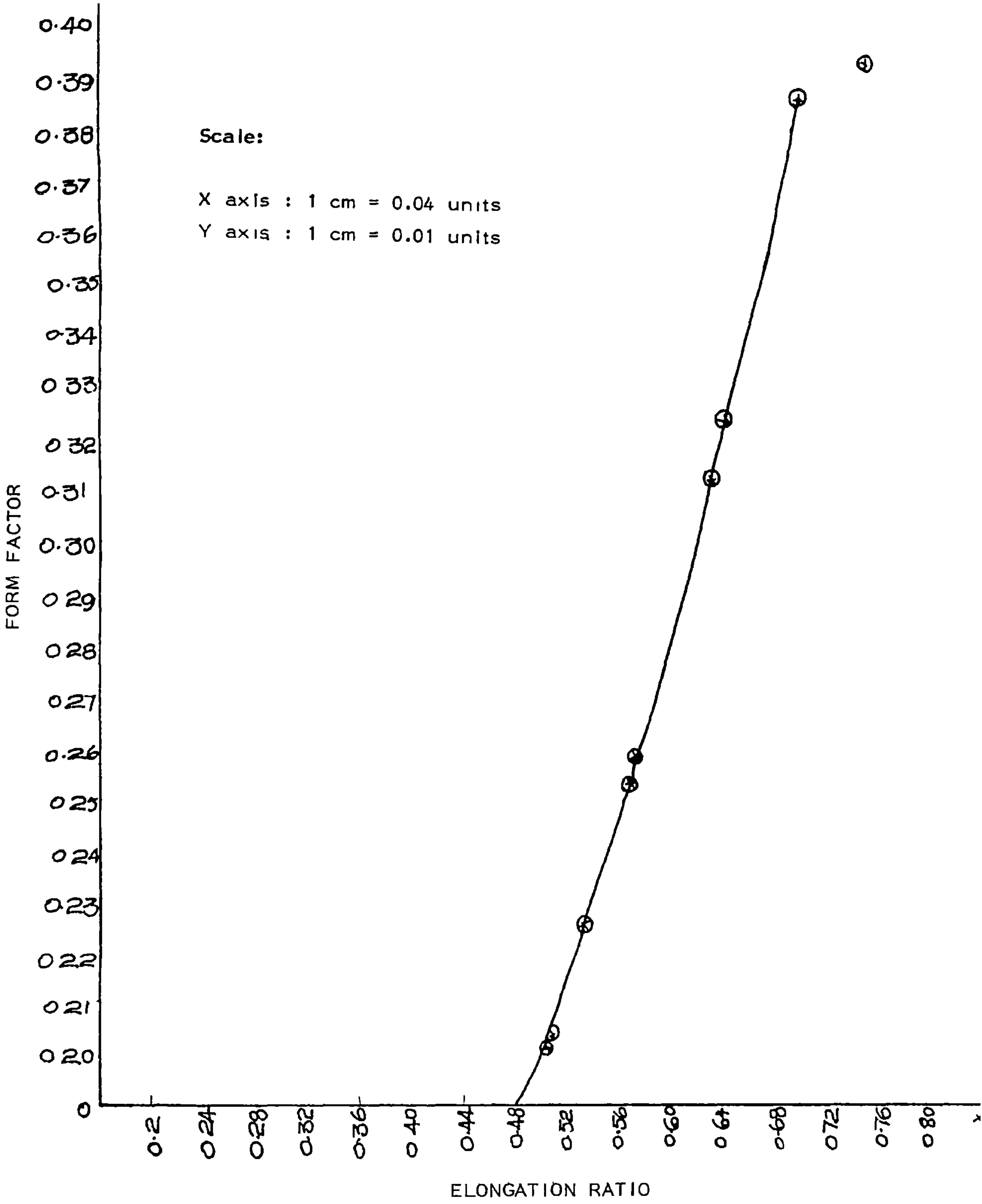


Fig.4.11 FORM FACTOR Vs ELONGATION RATIO - CHALIYAR RIVER BASIN

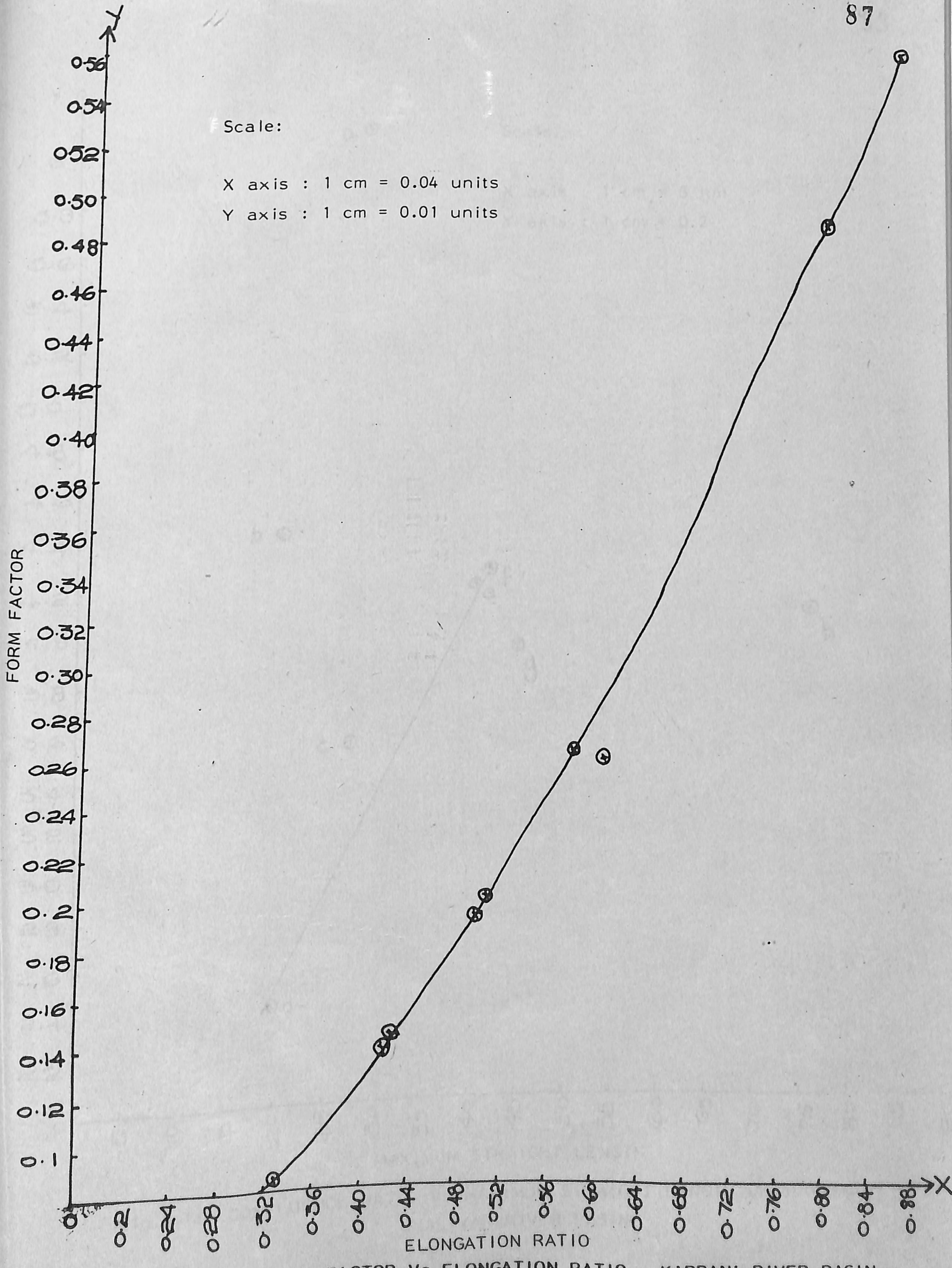


Fig. 4.12 FORM FACTOR Vs ELONGATION RATIO - KABBANI RIVER BASIN

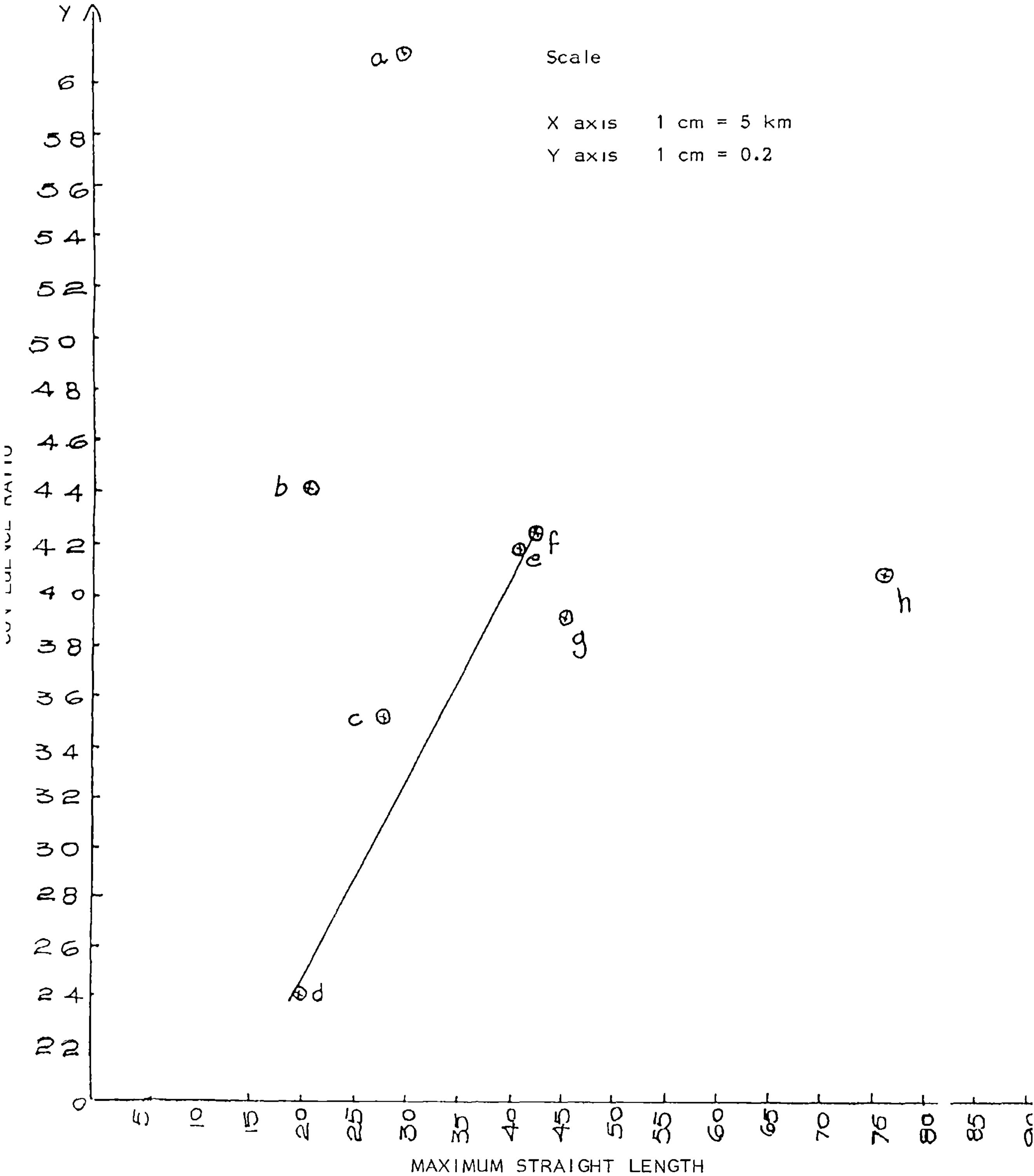


Fig.4.13 CONFLUENCE RATIO Vs MAXIMUM STRAIGHT LENGTH OF SUB-BASIN - CHALIYAR RIVER BASIN

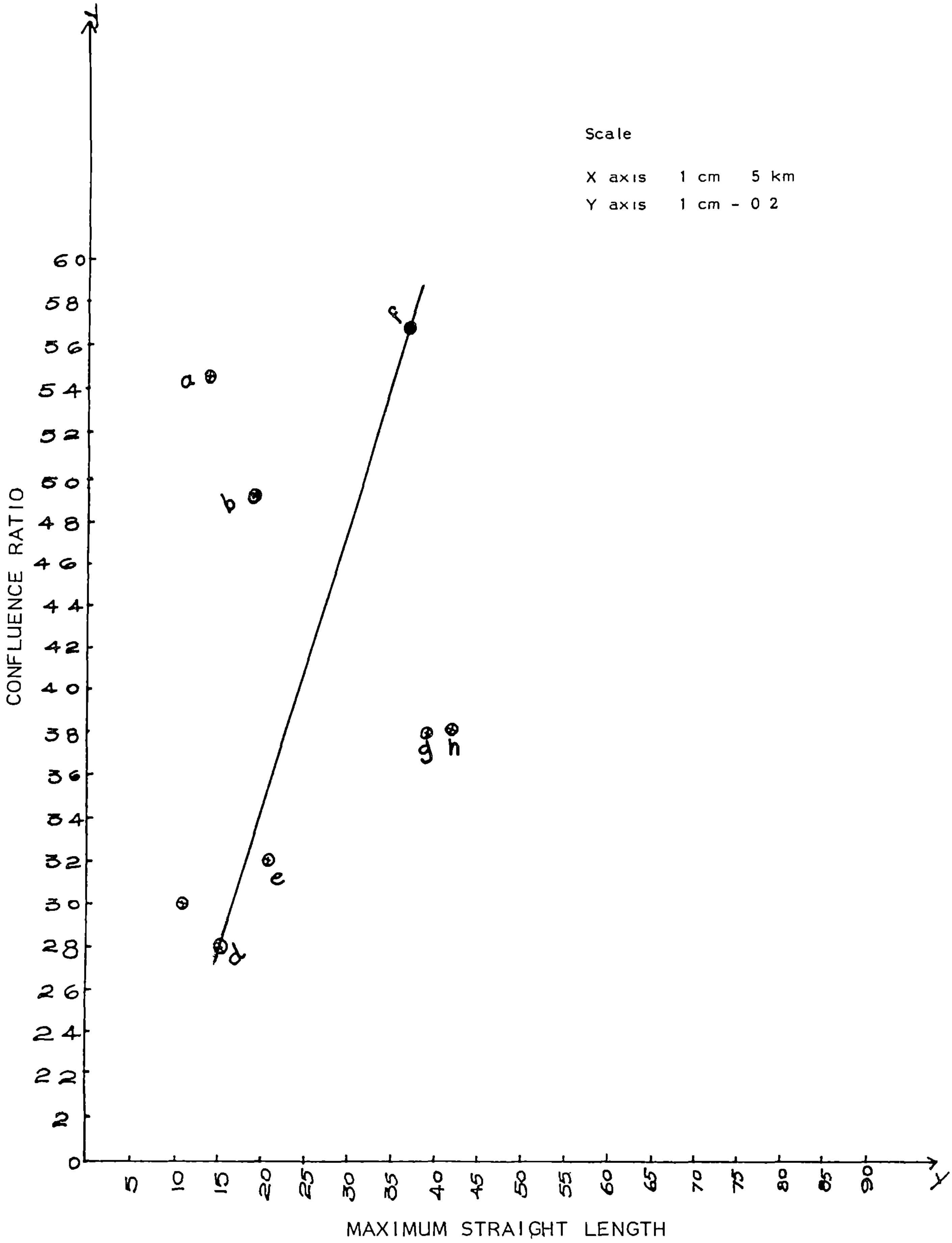


Fig 4 14 CONFLUENCE RATIO Vs MAXIMUM STRAIGHT LENGTH OF SUB-BASIN - KABBANI RIVER BASIN

Table 4 13 Relationship between order, area maximum straight length and discharge

River basin	Sl No	Sub-basin	Order	Area (km^2)	Maximum straight length of sub basin (km)	Average monthly monsoon discharge (Mm^3) 1976- 80	Average monthly monsoon discharge (Mm^3) 1981- 85
	1	Kanhirapuzha	3	68	18 80	38 22	30 87
	2	Kuthirapuzpha	3	284	27 60	122 00	119 78
	3	Mukkon	3	221	29 60	205 01	161 45
	4	Maruthapuzha	3	144	20 40	42 47	26 94
Chal yar	5	Chaliyar	4	386 69	42 40	198 89	109 98
	6	Koodathai	4	103	20 00	124 85	60 71
	7	Punnapuzha	4	344	40 80	104 28	87 78
	8	Arecode	5	1841	76 00	589 64	532 48
	9	Karimpuzha	5	670 35	45 20	235 83	203 98
	1	Manjat	2	47 50		7 73	5 42
	2	Vazhavatta	2	57 50	10 80	17 26	7 50
	3	Kakkavayal	3	90	21 20	16 25	28 05
	4	Muthanga	3	192	18 40	35 26	35 94
Kabbani	5	Thirunelli	3	38	14 00	36 31	22 66
	6	Thondar	3	30	18 80	24 77	17 96
	7	Baveli	4	190	36 80	44 94	34 52
	8	Choorani	4	35	15 60	56 50	25 07
	9	manantodddy	5	398	38 80	221 02	60 03
	10	Panamaram	5	460	42 00	14 87	12 96

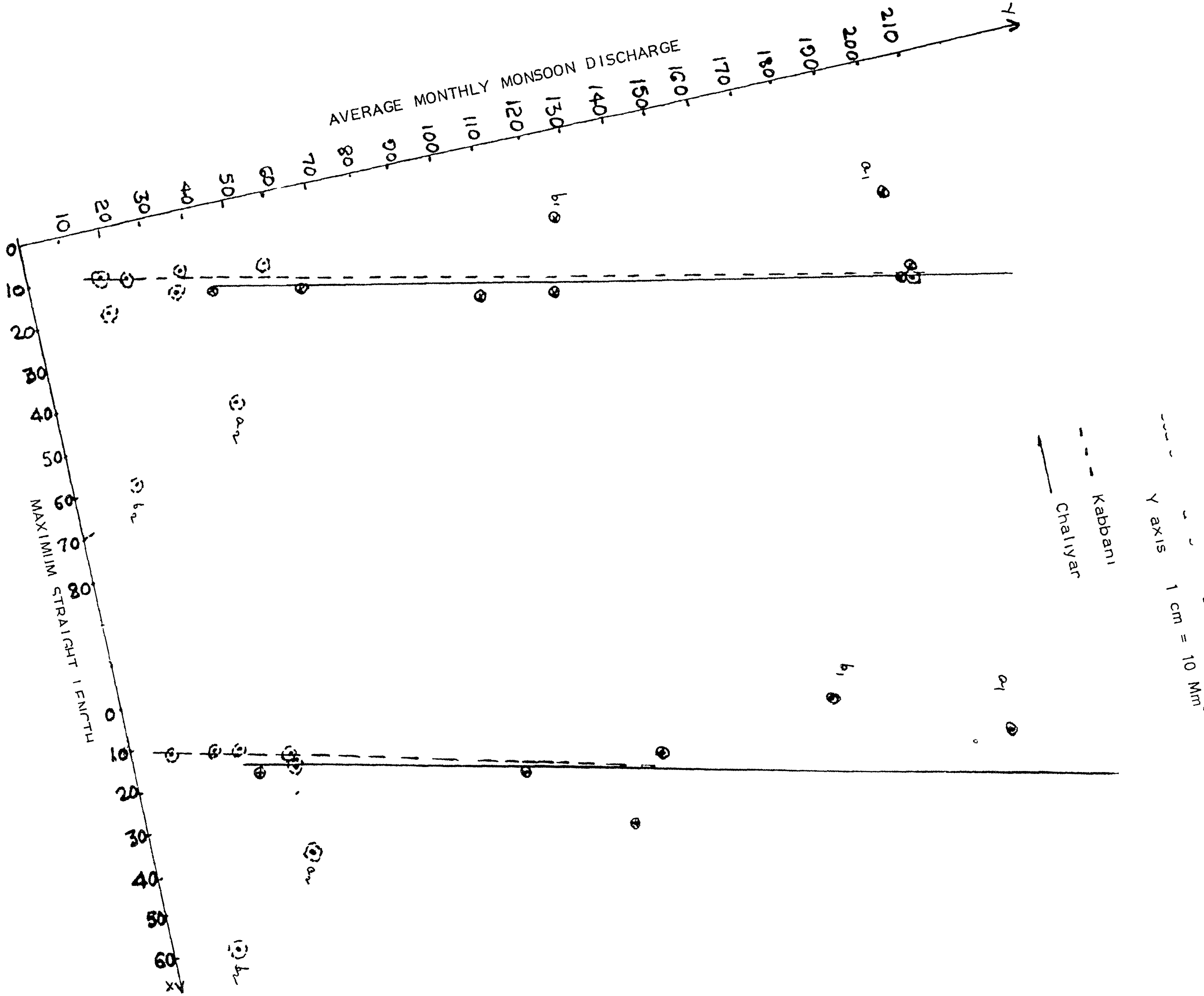
The correlation is much lower for the sub-basins of Kabbani (0.44 for the two periods). In Fig.4.15 Koodathai, Mukkom, Baveli and Panamaram are more deviated from the straight line (a_1, b_1, a_2, b_2). Since the discharge increases with the order of the stream which controls the length of the sub-basin, the relationship between discharge and the maximum straight length of the sub-basin is quite agreeable. The proportional increase in the average monthly monsoon discharge with respect to the maximum straight length of the sub-basins of Kabbani basin is noted in Table 4.13.

4.6 Area

The relationship of area with the maximum straight length and with the length of the main stream is indicated in Table 4 13 It is clear that for a given order the length of the main stream is larger for elongated sub-basins. The area is highly correlated with the maximum straight length of the sub-basins (0.95 and 0.89 for Chaliyar and kabbani). The length of the main stream is closely related to the area The regression equations are

$$A = 1\ 76\ L_s^{0.53} \quad \text{(Chaliyar, } r = 0\ 97\text{)}$$
$$A = 1.6\ L_s^{0.56} \quad \text{(Kabbani, } r = 0.97\text{)}$$

The coefficients are more or less the same for both the river basins. The elongation of the basin, thus has a significant role in drainage basin evolution. Discharge depends not only on drainage area, but also on the order of the main stream (Fig.4.16). Discharge increases



AVERAGE MONTHLY MONSOON DISCHARGE
MAXIMIM STRAIGHT LENGTH
Y
X
Y axis 1 cm = 10 Mm^3
Kabbani
Chaliyar

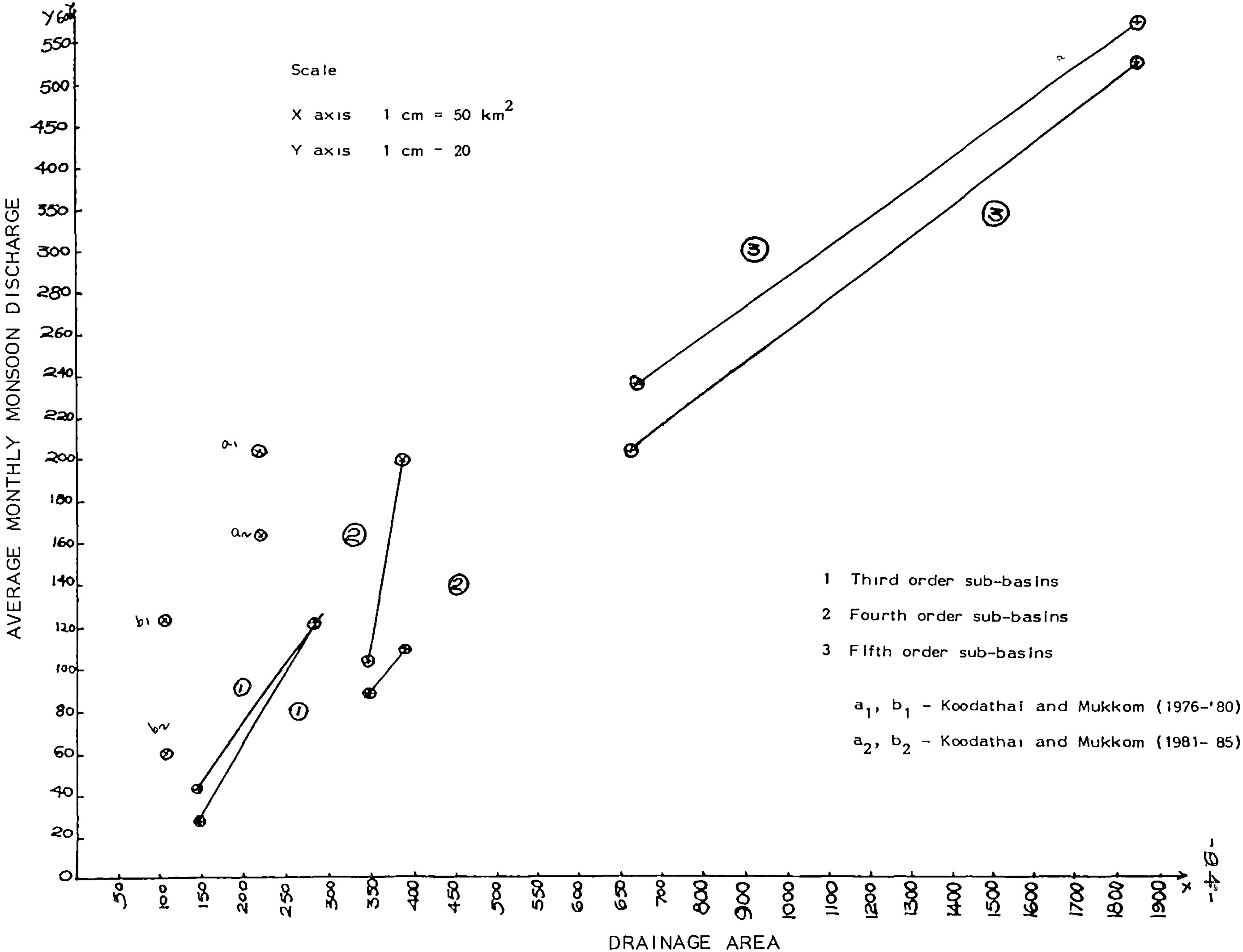


Fig.4.16 DRAINAGE AREA Vs AVERAGE MONTHLY MONSOON DISCHARGE

with the order and drainage area. The relationship between order and basin area is shown in Fig 4.17 The higher the order, the greater is the area of the sub-basin The increase in area is rather abrupt for fifth order This agrees with the high correlations of the maximum straight length of the sub-basins with the order and area

Area is one of the most important parameters affecting discharge Correlations with the average monthly monsoon discharge of the sub-basins of Chaliyar are 0.96 and 0.97 and 0.49 and 0 45 for Kabbani, during the 1976-'80 and 1981-'85 respectively. Average monthly monsoon discharge and area are given in Table 4.13. The flood discharge per unit are is universely proportional to size because the more intense storms are usually of the smaller size. The correlations of area with the average monthly monsoon discharge per unit area are -0.41 and -0.49, during 1976-'80 and -0.31 and -0 62 during 1981-'85 for Chaliyar and Kabbani river basins. The discharge contributed by unit area is obviously due to the rainfall (correlation 0.87 for Chaliyar basin during the two periods). A comparative increase in the discharage per unit area with the increase of rainfall is noted for the three sub-basins, Manantoddy, Choorani and Thirunelli of Kabbani river basin, in which the correlation and regression studies were not possible due to lack of data

4.7 Drainage density and stream frequency

Drainage densities and stream frequencies of the sub-basins are given in Table 4.14. The relationship is expressed graphically in

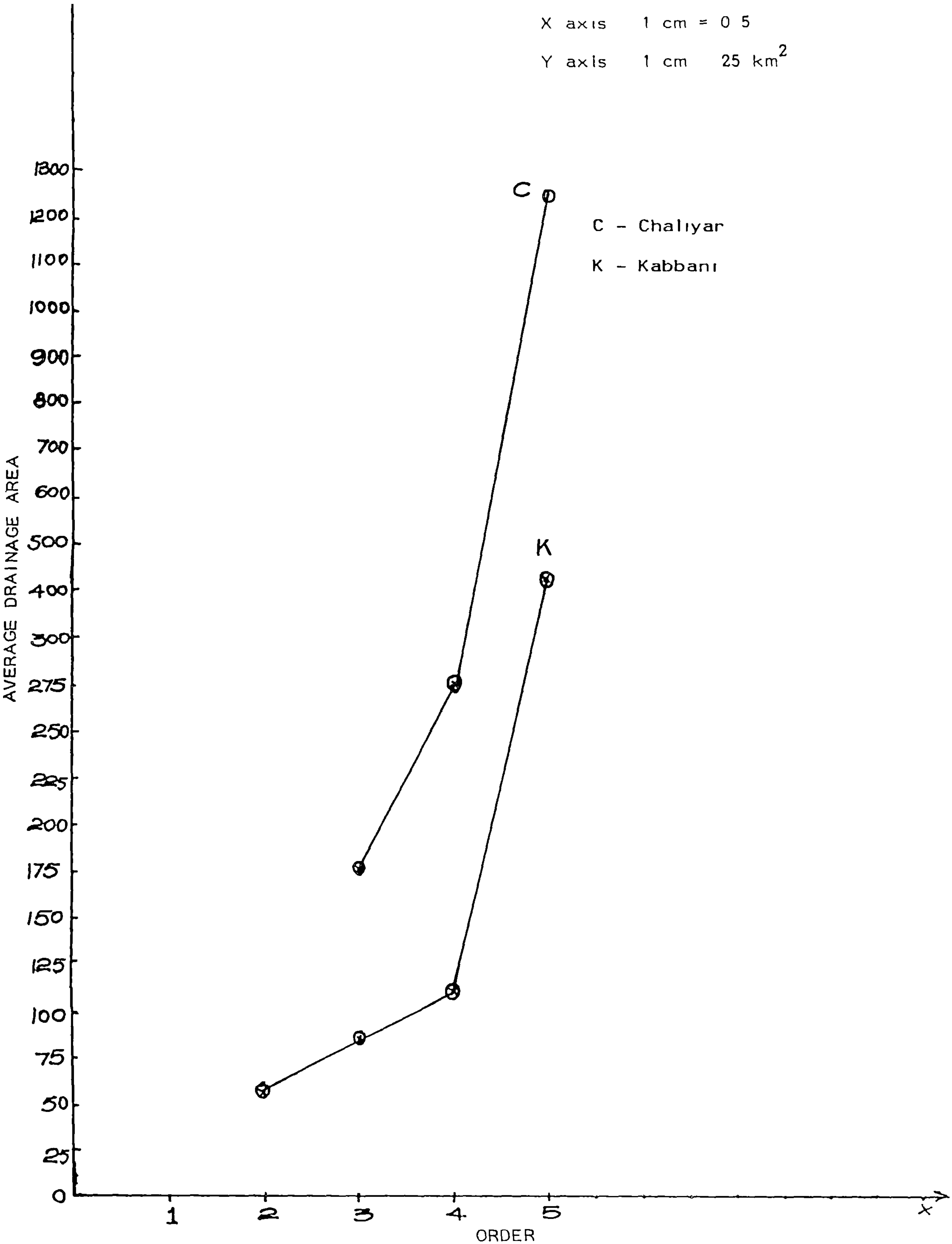


Fig 4 17 ORDER Vs DRAINAGE AREA

Table 4.14 Relationship between stream frequency, drainage density and discharge

River basin	Sl. No.	Sub-basin	Stream frequency (D_s)	Drainage density km/km^2 (D_d)	Monthly monsoon discharge per unit area mm^3/km^2 1976-'80	1981-'85
	1	Kanhirapuzha	0.147	0.756	0.562	0.454
	2	Kuthirapuzha	0.053	0.459	0.430	0.422
	3	Mukkom	0.109	0.667	0.928	0.731
	4	Maruthapuzha	0.160	0.738	0.300	0.187
Chaliyar	5	Chaliyar	0.199	1.008	0.514	0.284
	6	Koodathia	0.214	0.907	1.212	0.589
	7	Punnapuzha	0.253	1.176	0.303	0.255
	8	Arecode	0.165	0.823	0.320	0.289
	9	Karimpuzha	0.234	1.065	0.351	0.304
	1	Manjat	0.084	0.387	0.163	0.114
	2	Vazhavatta	0.070	0.543	0.300	0.131
	3	Kakkavayal	0.211	1.072	0.181	0.312
	4	Muthanga	0.042	0.106	0.184	0.187
Kabbani	5	Thirunelli	0.553	1.581	0.956	0.596
	6	Thondar	0.667	2.655	0.826	0.599
	7	Baveli	0.363	1.243	0.237	0.182
	8	Choorani	0.743	2.448	1.615	0.716
	9	Manantoddy	0.276	1.001	0.555	0.151
	10	Panamaram	0.270	1.155	0.032	0.028

Fig.4.18 (correlation 0.97 for both the basins). The regression equations are

$$D_d = 2.363 \quad D_s^{0\ 573} \quad \text{(Chaliyar)}$$

$$D_d = 0.507 \quad D_s^{0.918} \quad \text{(Kabbani)}$$

The drainage density can be computed from the stream frequency using the above equation under the prevailing geomorphologic conditions. A well-defined inverse relationship between area and the two factors is not possible since the number and length of stream segments are not constant for different areas. The average stream frequency of the sub-basins of Chaliyar is 0.171 and that of Kabbani is 0.328 The average drainage densities of the two basins are 0.844 and 1.22. An increase in drainage density and stream frequency is noted upto the fourth order sub-basins. The value decreases for the fifth order sub-basins due to the much higher area which reduces the drainage density of stream segments to a considerable extent However, the relationship cannot be predicted since there are no higher order streams

Drainage density affects runoff pattern. A high drainage density removes surface runoff rapidly, decreasing lag time and increasing the peak of hydrograph.

The spatial distribution of stream segments depends on a number of factors, permeability, type of rocks and soil, resistance to erosion, vegetal cover and climatic factors. Chaliyar basin has larger

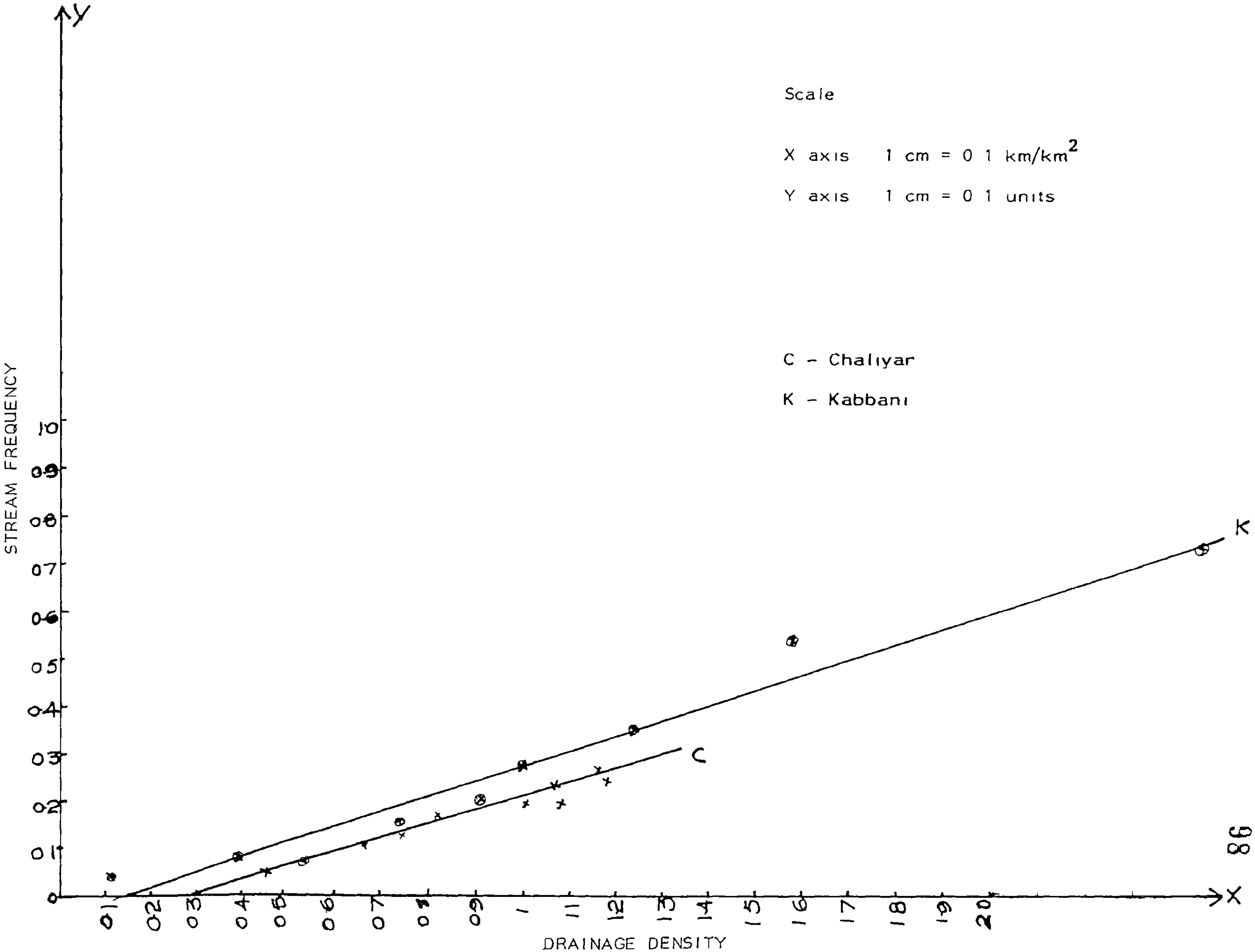


Fig.4.18 DRAINAGE DENSITY Vs STREAM FREQUENCY

area under cultivation. This, together with the urbanization explains the lower stream frequency and drainage density (0.844 as against 1.22 of Kabbani basin) of Chaliyar river basin Single crop cultivation is practised in the lands of Kabbani basin and about 1,21,500 hectares of land is left as dry land The larger variation in the drainage density values of the basin may be due to these factors A quantitative assessment of all factors like man's influencing intervention and passage of time is not possible.

Table 4.15 shows the constant of channel maintenance (M) The area required to maintain 1 km of the channel is different for each sub-basin Being the reciprocal of the drainage desnity, the relationship with the discharge per area is of inverse nature It is clear that, as the area required to maintain 1 km of the channel segment increases the discharge contributed by unit area decreases.

4.8 Rainfall

Correlation and regression studies have been conducted to find the relationship between runoff and rainfall of the sub-basins. Prediction equations has not been calculated for Kabbani basin due to the lack of data.

Annual average monsoon discharge and total discharge have good correlations with the average monsoon and the total rainfalls (Table 4.16) The correlation coefficient for monsoon and total

Table 4.15 Constant of channel maintenance of the sub-basins

River basin	Sl. No.	Sub-basin	Constant of channel maintenance
	1	Kanhirapuzha	1.323
	2	Kuthirapuzha	2.179
	3	Mukkom	1.499
	4	Maruthapuzha	1.355
Chaliyar	5	Chaliyar	0.992
	6	Koodathai	1.025
	7	Punnapuzha	0.850
	8	Arecode	1.215
	9	Karimpuzha	0.939
	1	Manjat	0.387
	2	Vazhavatta	0.543
	3	Kakkavayal	1.072
	4	Muthanga	0.106
Kabbani	5	Thirunelli	1.581
	6	Thondar	2.655
	7	Baveli	2.655
	8	Choorani	2.448
	9	Manantoddy	1.001
	10	Panamaram	1.155

Table 4 16 Correlation between the annual discharge and rainfall

Sub-basin	Discharge	Rainfall of the same year			Rainfall of the previous year		
		Monsoon	Non-monsoon	Total	Monsoon	Non-monsoon	Total
Mukkom	Monsoon	0 52	0 33	0 53	0 61	-0 01	0 06
	Non-monsoon	0 31	0 07	0 31	0 37	-0 18	0 14
	Total	0 50	0 31	0 52	-0 03	0 59	0 14
Karimpuzha	Monsoon	0 36	-0 10	0 32	-0 12	-0 003	0 12
	Non-monsoon	0 15	0 07	0 15	-0 33	0 06	0 30
	Total	0 34	-0 08	0 31	-0 15	0 004	0 14
Punnapuzha	Monsoon	0 16	0 24	0 09	0 47	0 59	0 52
	Non monsoon	0 08	0 07	0 06	0 22	-0 43	0 60
	Total	0 13	-0 21	0 07	0 52	0 028	-0 52
Arecode	Monsoon	0 65	-0 10	0 59	0 26	0 19	0 28
	Non-monsoon	0 83	0 43	0 86	0 06	0 65	0 18
	Total	0 69	-0 06	0 64	0 25	0 23	0 28
Kuthirapuzha	Monsoon	0 52	0 11	0 50	0 36	0 04	0 33
	Non monsoon	-0 11	-0 25	0 16	0 07	-0 13	0 03
	Total	0 51	0 09	0 48	0 35	0 03	0 33
Chaliyar	Monsoon	0 68	0 56	0 71	0 67	0 27	0 36
	Non-monsoon	0 52	0 59	0 56	0 33	0 28	0 40
	Total	0 66	0 58	0 69	0 73	0 28	0 38
Maruthapuzha	Monsoon	0 49	0 46	0 52	0 27	0 16	0 27
	Non-monsoon	0 30	-0 28	0 11	0 17	0 05	0 13
	Total	0 51	0 2	0 46	0 23	0 16	0 23
Koodathai	Monsoo	0 80	0 10	0 74	0 65	0 22	0 62
	Non-monsoon	0 55	0 02	0 49	0 52	0 07	0 45
	Total	0 79	0 09	0 73	0 63	0 001	0 57
Manantoddy	Monsoon	0 77	0 39	0 47	0 47	-0 08	0 02
	Non-monsoon	0 06	0 60	0 14	0 38	0 24	0 34
	Total	0 78	0 38	0 46	0 46	-0 09	0 03
Choorani	Monsoon	0 55	0 49	0 55	-0 30	-0 11	-0 29
	Non monsoon	0 45	0 42	0 45	-0 18	0 007	-0 16
	Total	0 55	0 49	0 55	-0 30	-0 11	-0 28
Thirunelli	Monsoon	0 53	-0.21	0 54	-0 40	0 31	-0 41
	Non-monsoon	0 30	0 04	0 32	0 001	-0 13	0 02
	Total	0 41	0 20	0 42	0 05	-0 16	0 07

rainfalls are more or less the same The rainfall of the same year is more influential than that of the previous year Non-monsoon discharge do not form a significant fraction of the total discharge and has low correlations with the rainfall.

Tables 4 17 to 4 19 give the relationship between the monthly discharge and the rainfall of the corresponding month and that of the previous two months. The correlation coefficient is the highest with the rainfall of the same month and decreases for previous months About 80-90 per cent of the monthly discharge is contributed by the rainfall of the corresponding month and the previous month The runoff resulting from the rainfall of the earlier months is not much effective. Hence it is not included in the equations for the monthly monsoon discharge. Table 4.20 gives monthly monsoon discharge during the periods 1976-1980 and 1981-1985 in terms of the rainfall of the same month and the previous month. Equations for the monthly monsoon discharge for all the sub-basins of Chaliyar during 1976- 80 and 1981-'85, in terms of average monthly monsoon rainfall (P) and area (A) are given below. The discharge is highly correlated with the area than with the rainfall (correlation 0.97 with the area in all cases).

$$Q_{m1} = 0.001395\ P - 0.00009854\ A - 0.14688$$

$$Q_{m2} = 0\ 0008212\ P - 0\ 00025415\ A - 0.02674$$

Where, Q_{m1} = Average monthly monsoon discharge during 1976- 80

Q_{m2} - Average monthly monsoon discharge during 1981-'85

Table 4.17 Correlation coefficients of monthly discharge with rianfall of the same month

Sub-basin	Correlation coefficient									
	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985
Mukkom	0.93	0.90	0.86	0.82	0.96	0.97	0.90	0.86	0.96	0.99
Karimpuzha	0.87	0.79	0.95	0.81	0.94	0.92	0.91	0.94	0.93	0.98
Punnapuzha	0.79	0.74	0.74	0.81	0.88	0.82	0.84	0.76	0.79	0.54
Arecode	0.66	0.80	0.81	0.85	0.93	0.92	0.85	0.86	0.90	0.99
Kuthirapuzha	0.87	0.75	0.92	0.82	0.96	0.87	0.81	0.75	0.91	0.97
Chaliyar	0.90	0.87	0.88	0.87	0.85	0.93	0.87	0.84	0.91	0.95
Maruthapuzha	0.75	0.79	0.83	0.73	0.81	0.73	0.86	0.79	0.79	0.93
Koodathai	0.85	0.89	0.98	0.85	0.85	0.90	0.96	0.90	0.80	0.94
Manantoddy	0.95	0.94	0.95	0.85	0.89	0.92	0.71	0.91	0.80	1.00
Choorani	0.92	0.96	0.84	0.84	0.94	0.91	0.80	–	–	–
Thirunelli	0.83	0.87	0.82	0.88	0.90	0.74	0.87	0.90	0.87	0.67

Table 4.18 **Correlation coefficient of monthly discharge with monthly rainfall of the previous month**

Sl.No.	Sub-basin	Correlation coefficient									
		1976	1977	1978	1979	1980	1981	1982	1983	1984	1985
1.	Mukkom	0.65	0.74	0.69	0.96	0.70	0.60	0.85	0.87	0.67	0.14
2.	Karimpuzha	0.40	0.61	0.70	0.81	0.72	0.68	0.83	0.87	0.60	0.49
3	Punnapuzha	0.79	0.77	0.69	0.87	0.82	0.71	0.77	0.95	0.70	0.84
4.	Arecode	0.75	0.80	0.81	0.81	0.74	0.76	0.83	0.85	0.69	0.40
5.	Kuthirapuzha	0.48	0.65	0.77	0.80	0.70	0.63	0.87	0.89	0.57	0.33
6.	Chaliyar	0.77	0.79	0.76	0.80	0.83	0.76	0.89	0.91	0.68	0.47
7.	Maruthapuzha	0.74	0.67	0.64	0.79	0.90	0.59	0.75	0.97	0.76	0.59
8	Koodathai	0.66	0.71	0.73	0.55	0.86	0.58	0.68	0.84	0.47	0.73
9.	Manantoddy	0.71	0.73	0.78	0.77	0.73	0.70	0.24	0.90	0.80	0.39
10.	Choorani	0.75	0.47	0.54	0.66	0.54	0.65	0.62	-	-	-
11.	Thirunelli	0.85	0.82	0.90	0.79	0.83	0.84	-	0.87	0.84	0.54

Table 4.19 Correlation coefficient of monthly discharge with the rainfall before two months

Sl.No	Sub-basin	Correlation coefficient									
		1976	1977	1978	1979	1980	1981	1982	1983	1984	1985
1	Mukkom	0.069	0.24	0.24	0.39	0 002	0.31	0.33	0 46	0 002	0 19
2	Karimpuzha	0 31	0.35	0.42	0.37	0.10	0.46	0 30	0.41	-0 005	0 23
3.	Punnapuzha	0 51	0.67	0.71	0.39	0.30	0.55	0.38	0.69	0.06	0 71
4	Arecode	0 37	0.44	0.45	0.32	0.05	0.49	0 30	0.48	0 006	0 15
5	Kuthirapuzha	0.33	0.32	0.23	0.30	0.02	0.57	0.35	0 59	0 13	0 11
6	Chaliyar	0.09	0.37	0.47	0.41	0.10	0.52	0.33	0.53	0.07	0 41
7	Maruthapuzha	0.43	0.50	0.53	0 53	0.39	0.55	0 50	0 42	0.05	0 54
8	Koodathai	0 23	0.43	0.17	0.55	0.47	0.58	0 25	0 50	0 14	0 29
9.	Manantoddy	0 14	0.32	0.31	0.24	0 03	0.23	0.28	0.35	-0 19	0 29
10.	Choorani	0.03	-0.09	0.08	0.05	-0.19	0.16	0.34	-	-	-
11.	Thirunelli	-0.13	0.48	0.43	0 04	0.20	0.52	-	0.43	0 23	0 70

Table 4 20 Equations for monthly discharge

Sub basin	Period	Correlation with		Equations
		P_1	P_2	
Mukkom	1976- 80	0 75	0 69	Q_1 0 14 P_1 + 0 113 P_2 - 1 578
	1981 85	0 91	0 65	Q_2 0 134 P_1 + 0 044 P_2 + 3 180
Karimpuzha	1976- 80	0 73	0 60	Q_1 0 468 P_1 + 0 263 P_2 - 27 580
	1981- 85	0 88	0 64	Q_2 0 396 P_1 + o 140 P_2 - 22 144
Punnapuzha	1976 80	0 79	0 77	Q_1 0 197 P_1 + 0 180 P_2 - 9 410
	1981- 85	0 64	0 63	Q_2 0 112 P_1 + 0 106 P_2 + 5 376
Arecode	1976- 80	0 79	0 74	Q_1 0 859 P_1 + 0 710 P_2 - 99 500
	1981- 85	0 87	0 71	Q_2 0 511 P_1 + 1 034 P_2 101 417
Kuth rapuzha	1976- 80	0 88	0 71	Q_1 - 0 202 P_1 + 0 090 P_2 - 20 700
	1981 85	0 77	0 63	Q_2 0 205 P_1 + 0 120 P_2 24 020
Chaliyar	1976-'80	0 83	0 76	Q_1 0 159 P_1 + 0 121 P_2 + 1 596
	1981- 85	0 84	0 74	Q_2 - 0 101 P_1 + 0 069 P_2 + 2 261
Maruthapuzha	1976- 80	0 75	0 73	Q_1 = 0 082 P_1 + 0 074 P_2 - 7 174
	1981- 85	0 77	0 73	Q_2 0 053 P_1 + 0 042 P_2 0 913
Koodathai	1976- 80	0 89	0 80	Q_1 0 098 P_1 + 0 064 P_2 - 9 909
	1981 85	0 74	0 60	Q_2 0 820 P_1 + 0 033 P_2 - 0 277
Manantoddy	1976- 80	0 83	0 71	Q_1 = 0 227 P_1 + 0 120 P_2 - 34 590
	1981 85	0 79	0 42	Q_2 3 380 P_1 + 0 070 P_2 - 0 002
Choorani	1976- 82	0 64	0 44	Q 0 103 P_1 + 0 017 P_2 - 22 610
Thirunelli	1976 80	0 82	0 30	Q_1 0 040 P_1 - 0 012 P_2 + 5 947
	1981 85	0 07	0 26	Q_2 0 012 P_1 + 0 029 P_2 + 14 776

The expression for average monthly monsoon discharge per unit area of Chaliyar basin are expressed here

q_{m1} = 0 0014707 P - 0.23605 (r = 0.90 with P)

q_{m2} = 0 00084095 P- 0 0495737 (r = 0.87 with P)

Where,

q_{m1} = Average monthly monsoon discharge per unit area during 1976-'80

q_{m2} - Average monthly monsoon discharge per unit area during 1981-'85

The results have been verified for 1986, 1987 and 1988 and shown in Table 4 21 Chaliyar and Mukkom have no representative raingauge stations and hence, show some deviations. The equations developed for 1981-'85 seems to be more adaptable. Hence, the average annual discharge per unit area of Chaliyar basin can be computed from the equation,

q_{m2} = 0.00084095 P - 0 0495737

Where,

q_{m2} = Average monthly monsoon discharge per unit area (Mm^3/km^2)

P = Average monthly monsoon rainfall (mm)

Table 4.21 Verification of the equation for average monthly monsoon discharge per unit area

Sl. No.	Year	Sub-basin	Monthly monsoon discharge per area	
			Observed (mm^3/km^2)	Calculated (mm^3/km^2)
1		Kuthirapuzha	0.190	0.193
2		Mukkom	0.394	0.269
3		Maruthapuzha	0.187	0.134
4	1986	Chaliyar	0.114	0.189
5		Koodathai	0.349	0.327
6		Punnapuzha	0.180	0.185
7		Arecode	0.229	0.229
8		Karimpuzha	0.148	0.145
1		Kuthirapuzha	0.206	0.199
2		Mukkom	0.202	0.242
3		Maruthapuzha	0.170	0.158
4	1987	Chaliyar	0.119	0.209
5		Koodathai	0.512	0.523
6		Punnapuzha	0.102	0.112
7		Arecode	0.170	0.174
8		Karimpuzha	0.152	0.155
1		Kuthirapuzha	0.553	0.655
2		Mukkom	0.240	0.250
3		Maruthapuzha	0.418	0.441
4	1988	Chaliyar	0.235	0.251
5		Koodathai	0.279	0.314
6		Punnapuzha	0.365	0.365
7		Arecode	0.553	0.554
8		Karimpuzha	0.235	0.251

Rainfall data available from one of the representative raingauge stations is used.

Area, length of sub-basin, length of main stream, order and the confluence ratio are the morphological parameters controlling the stream flow Length of the sub-basin, length of the main stream and order are closely related to the area Hence, factors other than the area are not incorporated in the final equation. The equations are based on the discharge measured at three stations of Chaliyar. It was not a sufficiently large sample.

Summary

This study was conducted to analyse the morphological parameters and the effect of geomorphology as well as the effect of rainfall on the stream flow and to arrive at a relationship between the parameters and the stream flow. The data for the analysis, covered the period from 1976-'85.

The river bains were divided into sub-basins, each with a river gauging station. The morphological factors considered were the number of stream segments of each order, the length of stream segments of each order, basin shape, area, drainage density and stream frequency. Horton-Strahler system of classification was used to designate the order of the segments. The geological composition and the land use of the basins as a whole, were described. Arithmetical average of the rainfall of the raingauge stations within the limits of each sub-basin was computed. Weighted monthly discharge of each gauging station was recorded.

The annual discharge for each year and its correlations with rainfall of the same year and previous year were studied. Annual monsoon, non-monsoon and total discharges were studied to find the effect of rainfall. The expressions were derived for the average monthly monsoon discharge of the sub-basins in terms of the area and rainfall.

Horton's law of stream numbers and the law of stream lengths have been verified. The evolution of the basins is not complete and as such order and length of stream segments will considerably be altered in due course of time, especially for Kabbani basin. The first order streams, that is the fingertip tributaries constituted the major portion of the stream segments. The inverse relationship of confluence ratio with the annual monsoon discharge per unit area verifies that larger streams of higher orders are more powerful in controlling the stream flow The destruction of these streams by human intervention affects the discharge to a great extent.

The deviation of the law of stream lengths is due to the erosion and meandering in the flat land which indicates the evolution taking place in the basin. Area is one of the most important parameters influencing discharge The discharge contributed by unit area is highly correlated with the rainfall. Massive deforestation increases the runoff reaching the stream. Discharge is also affected by the maximum straight length and the length of the main stream which in turn is related to the area of the sub-basins. The drainage area can be calculated from the length of the main stream using exponential equations. Stream frequency being known, drainage density can be calculated from the computed equations. Generally, stream frequency and drainage density are lower in cultivated lands. The stream segments of higher orders increases with the deforestation or urbanization and hence runoff increases suddenly in such areas.

The annual monsoon discharge has good correlations with the corresponding rainfall of the same year and the previous year The correlation is maximum with the monthly discharge and the corresponding monthly rainfall. The correlation is significant only for the corresponding month and the previous month and it becomes insignificant for the earlier months. The equations developed for average monthly discharge per unit area for monsoon period in terms of average monthly rainfall for the period (1981-'85) can be used for projecting the monsoon discharge of the basin.

Stream flow is closely related to the geomorphology and the rainfall of the river basin. If the morphological balance of the river basin is disturbed, the tributaries of all orders are affected. When the intercepted part of the rainfall decreases, the runoff becomes flashy in the streams. Most of the morphological parameters are inter-related Hence, area has only been considered for the final equation, as all other parameters influencing the discharge are related to drainage area. The prediction equation involves two factors, area and rainfall. It can be used for the prediction of discharge for the coming years The accuracy of the equation can be improved by the data from more gauging stations

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* Originals not seen

Appendices

Appendix I

Confluence ratio by the method of weighted means

I Chaliyar river basin

Sl No	Sub-basin	N_1	N_2	N_3	N_4	N_5	a_1	a_2	a_3	a_4	b_1	b_2	b_3	b_4	R_c
1	Kanhirapuzha	7	2	1	–	–	9	3		–	3 50	2 00	–	–	3 13
2	Kuthirapuzha	11	3	1	–	–	14	4	–	–	3 67	3 00	–	–	3 51
3	Mukkom	20	3	1	–	–	23	4	–	–	6 67	3 00	–	–	6 13
4	Maruthapuzha	18	4	1	–	–	22	5		–	4 50	4 00	–	–	4 41
5	Chaliyar	59	14	3	1	–	73	17	4	–	4 21	4 67	3 00	–	4 24
6	Koodathai	14	5	2	1	–	19	7	3	–	2 80	2 50	2 00	–	2 41
7	Punnapuzha	66	17	3	1	–	83	20	4	–	3 88	5 67	3 00	–	4 18
8	Arecode	228	57	15	3	1	285	72	18	4	4 00	3 80	5 00	3 00	4 08
9	karimpuzha	115	32	7	2	1	147	39	9	3	3 59	4 57	3 50	2 00	3 93

II Kabbani river basin

Sl No	Sub-basin	N_1	N_2	N_3	N_4	N_5	a_1	a_2	a_3	a_4	b_1	b_2	b_3	b_4	R_c
1	Manjat	3	1	–	–	–	4		–		3 00	–	–	–	3 00
2	Vazhavatta	3	1	–	–	–	4	–			3 00	–	–	–	3 00
3	Kakkavayal	13	5	1	–	–	18	6	–		2 60	5 00	–	–	3 20
4	Muthanga	5	2	1	–	–	7	3			2 50	2 00	–	–	2 35
5	Thirunelli	17	3	1	–	–	20	4	–	–	5 67	3 00	–	–	5 45
6	Thondar	16	3	1	–	–	19	4	–		5 33	3 00	–	–	4 93
7	Baveli	57	9	2	1	–	63	11	3	–	6 33	4 50	2 00	–	5 68
8	Chooranl	17	6	2	1		23	8	3		2 83	3 00	2 00		2 80
9	Manantoddy	81	20	6	2	1	101	26	8	3	4 05	3 33	3 00	2 00	3 81
10	Panamaram	91	25	5	2	1	116	30	7	3	3 64	5 00	2 50	2 00	3 82

$a_1 = N_1 + N_2$ a_2 $N_2 + N_3$ a_3 $N_3 + N_4$ a_4 $N_4 + N_5$

$b_1 = \frac{N_1}{N_2}$ $b_2 = \frac{N_2}{N_3}$ b_3 $\frac{N3}{N_4}$ b_4 $\frac{N_4}{N_5}$ R_c $\frac{\Sigma a \; b_i}{\Sigma a}$

Appendix II

Computation of number of streams using the confluence ratio

I Chaliyar river basin

Sl.No.	Sub-basin	R_c	N_1	N_2	N_3	N_4	N_5	N
1	Kanhirapuzha	3.13	7	2.24	0.72	-	-	9 96
2	Kuthirapuzha	3.51	11	3.15	0.90	-	-	15 11
3	Mukkom	6.13	20	3.30	0.53	-	-	23 02
4	Maruthapuzha	4.41	18	4.03	0.93	-	-	23 09
5	Chaliyar	4.24	59	13.92	3.28	0.77	-	76.97
6	Koodathai	2.65	14	5 28	1.99	0.75	-	22 02
7	Punnapuzha	4.18	66	15.76	3.78	0.90	-	86 50
8	Arecode	4.08	228	55.63	13.63	3.34	0.82	300 37
9	Karimpuzha	3.93	115	29.14	7.41	1-89	0.48	153 42

II Kabbani river basin

Sl.No.	Sub-basin	R_c	N_1	N_2	N_3	N_4	N_5	N
1	Manjat	3.00	3	1.00	-	-	-	4 00
2	Vazhavatta	3.00	3	1.00	-	-	-	4 00
3	Kakkavayal	3.20	13	4.06	1.27	-	-	18 33
4	Muthanga	2.35	5	2.13	0.91	-	-	8 03
5	Thirunelli	5.45	17	3 12	0.57	-	-	20 69
6	Thondar	4.93	16	3.24	0.66	-	-	19 90
7	Baveli	5.68	57	10.04	1.77	0.31	-	69 11
8	Choorani	2.8	17	6.07	2.17	0.77	-	26 01
9	Manantoddy	3.81	81	21.26	5.58	1.47	0.38	109 69
10	Panamaram	3.82	91	23.83	6.24	1.63	0.43	123 12

$$N_u = \frac{N_1}{R_c^{u-1}} \qquad N = \frac{N_u\,(1-R_c^{u})}{1-R_c}$$

Appendix III

Length ratio by the method of weighted means

I Chaliyar river basin

Sl No	Sub basin	L_1	L_2	L_3	L_4	L_5	p_1	p_2	p_3	p_4	q_1	q_2	q_3	q_4	R_L
1	Kanhirapuzha	31 20	19 60	0 60	–	–	50 80	20 20	–	–	1 59	32 67	–	–	10 45
2	Kuthirapuzha	82 80	23 60	24 00	–	–	106 40	47 60	–	–	3 51	0 98	–	–	2 73
3	Mukkom	100 40	39 40	7 60	–	–	139 80	47 00		–	2 55	5 18	–	–	3 21
4	Maruthapuzha	64 60	35 20	6 50	–	–	99 80	41 60	–	–	1 84	5 50	–	–	2 91
5	Chaliyar	262 60	67 00	33 20	26 80	–	329 60	100 20	60 00	–	3 92	2 02	1 24	–	3 20
6	Koodathai	67 52	17 40	7 60	10 00	–	84 92	25 00	17 60	–	3 88	2 29	0 76	–	5 00
7	Punnapuzha	237 80	102 72	20 00	44 00	–	340 52	122 72	64 00	–	2 32	5 14	0 45	–	2 75
8	Arecode	953 20	304 67	122 00	80 00	56 00	1257 87	426 67	202 00	–	3 13	2 50	1 53	1 43	2 72
9	Krimpuzha	433 00	181 00	39 60	50 00	10 00	614 00	220 60	89 60	10 00	2 39	4 57	0 79	5 00	2 89

II Kabbani river basin

Sl No	Sub basin	L_1	L_2	L_3	L_4	L_5	p_1	p_2	p_3	p_4	q_1	q_2	q_3	q_4	R_L
1	Manjat	10 40	8 00	–	–	–	18 40	–	–	–	1 30	–	–	–	1 30
2	Vazhavatta	24 40	6 80	–	–	–	31 20		–	–	3 59	–	–	–	3 59
3	Kakkavayal	63 64	20 84	12 00	–	–	84 48	32 84	–	–	3 05	1 74		–	2 69
4	Muthanga	9 44	4 88	6 00	–	–	14 32	10 88		–	1 95	0 81	–	–	1 41
5	Thirunelli	41 48	14 00	4 60	–	–	55 48	18 60		–	2 96	3 04	–	–	3 15
6	Thondar	49 44	19 80	10 40	–	–	69 24	30 20		–	2 50	1 90	–		2 32
7	Baveli	172 72	49 60	8 00	6 00	–	222 32	57 60	14 00	–	3 48	6 20	1 33	–	3 91
8	Choorani	56 48	19 44	8 56	1 20	–	75 92	28 00	9 76	–	2 91	2 27	7 13	–	3 11
9	Manantoddy	222 96	98 68	23 40	28 00	25 68	321 64	122 08	51 40	53 68	2 26	4 22	0 84	1 09	2 45
10	Panamaram	363 09	70 64	67 56	36 92	11 40	433 73	138 20	104 48	48 32	5 14	1 05	1 83	3 24	3 57

$p_1 \quad L_1 + L_2 \qquad p_2 \quad L_2 + L_3 \qquad p_3 \quad L_3 + L_4 \qquad p_4 \quad L_4 + L_5$

$q_1 \quad \frac{L_1}{L_2} \qquad q_2 \quad \frac{L_2}{L_3} \qquad q_3 \quad \frac{L_3}{L_4} \qquad q_4 \quad \frac{L_4}{L_5} \qquad R_L \quad \frac{\Sigma p_{u\ 1} \quad {}_{u-1}}{\Sigma p_{u\ 1}}$

Appendix IV

Computation of summed stream length and average stream length from length ratio

I Chaliyar river basin

Sl No	Sub-basin	R_L	L_1	L_2	L_3	L_4	L_5		r_l	$\bar{L}_1$	$\bar{L}_2$	$\bar{L}_3$	$\bar{L}_4$	$\bar{L}_5$
1	Kanhirapuzha	10 45	31 20	2 99	0 29	–	–	34 47	0 30	4 46	1 33	0 4	–	–
2	Kuthirapuzha	2 73	82 80	30 35	11 13	–	–	124 28	1 29	7 53	9 70	12 5	–	–
3	Mukkom	3 21	100 40	31 26	9 73	–		141 42	1 91	5 02	9 58	18 27	–	–
4	Maruthapuzha	2 91	64 60	22 17	7 60	–		94 39	1 51	3 59	5 40	8 22	–	–
5	Chaliyar	3 20	262 60	82 04	25 63	8 01	–	378 28	1 41	4 45	6 28	8 86	12 [illegible]0	–
6	Koodathai	5 00	67 50	13 51	2 71	0 54	–	82 77	0 44	4 82	2 11	0 93	0 41	–
7	Punnapuzha	2 75	237 80	86 61	31 50	11 49		367 42	1 52	3 60	5 48	8 34	12 68	–
8	Arecode	2 72	953 20	350 32	128 75	47 32	17 39	1497 26	1 28	4 18	5 34	6 83	8 73	11 16
9	Krimpuzha	2 91	64 60	22 17	7 60	–		94 39	1 30	3 77	4 89	6 35	8 24	10 75
II Kabbani river basin														
1	Manjat	1 30	10 40	8 00	–	–		18 40	2 30	3 47	8 01	–	–	–
2	Vazhavatta	3 59	24 40	6 80	–	–	–	31 20	0 84	8 13	6 80	–	–	–
3	Kakkavayal	2 69	63 64	23 70	8 83	–		96 17	1 19	4 50	5 83	6 95	–	–
4	Muthanga	1 41	9 44	6 69	4 74	–	–	20 86	1 66	1 89	3 15	5 24	–	–
5	Thirunelli	3 15	41 48	13 15	4 17	–		58 80	1 73	2 44	4 22	7 28	–	–
6	Thondar	2 32	49 44	21 34	9 20	–		79 99	2 13	3 09	6 58	13 79	–	
7	Baveli	3 91	172 72	44 40	11 28	2 88	–	231 02	1 45	3 03	4 40	6 39	9 27	–
8	Choorani	3 11	56 48	18 15	5 83	1 87		82 34	0 90	3 32	2 99	2 69	2 40	–
9	Manantoddy	2 45	222 96	91 11	37 24	15 22	6 22	372 75	1 56	2 75	4 28	6 67	10 34	16 20
10	Panamaram	3 57	363 09	96 65	27 11	9 04	21 33	478 06	1 07	3 99	4 27	4 58	4 90	5 25

$$L_U \quad \frac{L_1}{R_L^{u-1}} \qquad L \quad L_U \quad \frac{(1 \; R_L^{u})}{1 \; R_L} \qquad \bar{L}_U \quad \bar{L}_1 \; r_l^{u \; 1}$$

Computation of discharge at the rivergauge stations

Gauge reading	=	G metres
Area	=	A m^2
Velocity	=	V m/s
Discharge (Q)	=	A Vm^3/s

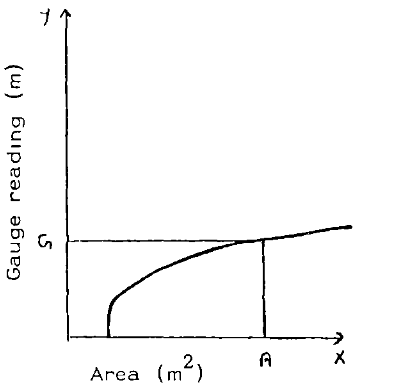

Fig 1 Gauge reading Vs Area

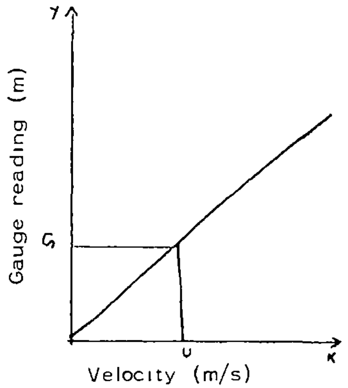

Fig. 2 Gauge reading Vs Velocit

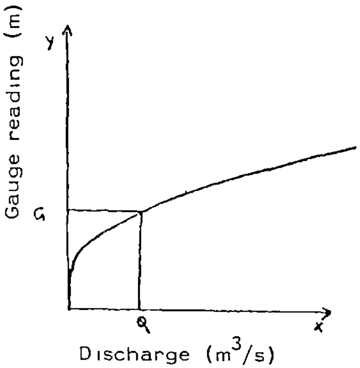

Fig 3 Gauge reading Vs discharge

Appendix VI

Computation of weighted discharge at the river gauge stations

Gauge readings are taken at 8 am, 12 pm, and 4 pm. The corresponding discharges are measured as in Appendix

Dicharge at 8 am	=	Q_1 m^3/s
Discharge at 12 pm	=	Q_2 m^3/s
Discharge at 4 pm	=	Q_3 m^3/s

Q_1 is assumed as the discharge during the first ten hour (from midnight to 10 am), Q_2 is the discharge during the four hours, i.e., from 10 am to 2 pm and Q_3 is the discharge during the ten hours from 2 pm to the midnight.

Weighted discharges can be computed from Q_1, Q_2 and Q_3.

Weighted discharges during ten hours period

$$= Q_1 \ (Q_3) \times 10 \times 60 \times 60 \times 10^6$$

$$= 0.036 \quad Q_1 \ (Q_2) \ mm^3$$

Weighted discharges during four hours period

$$= Q_2 \times 4 \times 60 \times 60 \times 10^6$$

$$= 0.0144 \ Q_2 \ mm^3$$

If the gauge readings are the same throughout the day,

$$\text{Weighted discharge} = Q \times 24 \times 60 \times 60 \ 10^6$$

$$= 0.0864 \ Q \ mm^3$$

QUANTITATIVE ANALYSIS OF RUNOFF PARAMETERS IN SELECTED RIVER BASINS OF KERALA

By

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ABSTRACT OF A THESIS

Submitted in partial fulfilment of
the requirement for the degree

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ABSTRACT

The evolution of a drainage basin is the result of the flow of mass and energy and the resistance of topographical surface Precipitation is the major source of matter and solar radiation, the source of energy The stream flow is a function of geomorphological and hydrological factors of the river basin

The objectives of this study were to make a quantitative analysis of the effects of geomorphological and climatic factors on the stream flow and to study the inter-relationships between these factors The selected river basins were Chaliyar and Kabbani The specific objective was to express stream flow in terms of morphological factors and rainfall

The river basin was divided into sub basin, each of which contains a rivergauge station. Morphological factors were measured from the map. Monthly rainfall from all the raingauge stations were collected and the arithmetical average for each sub-basin was computed. The monthly stream flow was also collected

It was found that the morphological factors were inter-related. The number of stream segments of successive order form a decreasing geometric progression whereas the length of stream segments of successive orders form an increasing geometric

progression. Confluence ratio is inversely related to stream flow Elongation and drainage area are highly correlated A larger value for the confluence ratio indicates a more elongated basin and a lower flood peak The sub-basins are similar to the form of a rectangle Area and elongation are the morphological parameters strongly influencing the stream flow Drainage density and stream frequency are highly correlated. Drainage density gets altered by the land use, vegetal cover, deforestation and urbanization. Drainage density also affect stream flow. Finally, the expressions for drainage area in terms of the main stream length, drainage density in terms of stream frequency and average monthly stream flow contributed by unit area in terms of the average monthly rainfall were obtained

The data used for the final equation was inadequate. The equation may be improved, by increasing the number of rivergauge stations and providing more representative raingauge stations