TOPIC: -

MORPHOMETRIC ANALYSIS.

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PAPER NAME: - ADVANCED GEOMORPHOLOGY.
SUBJECT: - GEOGRAPHY
SEMESTER: - M.A. –I.
PAPER CODE: - (GEO-101)
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MORPHOMETRIC ANALYSIS

Introduction: -

The word '**Morphometry'** means the measurement of the external form and **'Analysis'** means detail evaluation. Morphometric Analysis in Geomorphology means detail evaluation of landforms through mathematical measurement. Mathematical or quantitative measurement helps us in analyzing the landforms accurately for any planning and development purposes. Morphometric Analysis is also very useful as it quantifies the landform features of evolutionary significance.

Morphometric Analysis of River Basins: -

Generally, River Basins are taken as units for Morphometric Analysis for better understanding of geomorphic and hydrologic processes. A **river basin** is defined as an area of land where surface water enter the area in any direction from any source which converge to a single point before exiting the basin (Fig. 1). After exiting the basin, waters join another water body, such as a river, lake, sea, or ocean. The River basins are very important and ideal ecological unit for management and planning of natural resources, as there is only one outlet/ exit point for materials (soil and water) of the whole area. Morphometric Analysis of river basins is very useful for management and planning purposes as it provides accurate information through mathematical calculation.

The Morphometric Analysis of a river basin is done under following 3 heads.

- Linear Aspects: one dimension
- Areal Aspects: two dimensions
- Relief Aspects: three dimensions

Fig.1: River Basin

Linear Aspects:

Stream Order:-

In a river basin, a network of streams is distributed or arranged in a hierarchical order (Fig. 2). The networking starts from small fingertip channels draining into progressively larger channels downstream. Stream Order refers to the method of assigning designation to each stream in that hierarchical arrangement. Stream ordering is the first step of measuring the landform characteristics of a river basin upon which most of the Morphometric Analysis relies. Many eminent geomorphologists have developed different ways to array or designate streams in a river basin during 20^{th} Century. **Strahler's method** is widely accepted and extensively used all over the world. According to him the smallest fingertip tributaries are designated as 1^{st} order streams. Where two 1^{st} order streams join together, a 2^{nd}order stream is formed; where two 2^{nd}order streams join together, a 3^{rd} order stream is formed; and so on. The highest order stream exits the river basin, where all the lower order streams converge to a single point.

While designating the order to streams in a river basin, one should remember the following points.

- Do not follow mathematical calculation
- When two of the same order streams come together, increase the number by one to designate the resultant stream
- When two streams of different order come together, take the number of the higher order stream

One will observe the following characteristics while moving from lower order streams to higher order streams

- Velocity of the water flow decreases
- Width of the stream or volume of stream water increases
- Temperature of stream water increases
- Sediment load increases
- Turbidity increases
- Mineral nutrients increase
- Rocky bottom becomes muddy/ sandy bottom

Stream Number: -

The total number of streams in each order is termed as the Stream Number. After Stream Order, the 2^{nd} step in Morphometric analysis is to count the Stream Number. The Stream Number decreases with the increasing order of stream (Table 1). In other words, stream number is inversely proportional to stream order. Horton has developed **'Law of Stream Number'**. According to this Law, when Stream Number (taken in arithmetic scale) is plotted against Stream Order (taken in logarithmic scale), it gives a negative linear pattern (Fig. 2). It means number of streams from highest to lowest order in a particular basin tend to give a Geometric Series. In a 6th order river basin, it should be 1, 3, 9, 27, 71 and 213 in ideal condition. In the 4^{th} order river basin shown in Figure 2, the series is 1, 5, 14 and 62 which is plotted on the logarithmic scale to the right side of the Figure.

Bifurcation Ratio: -

Bifurcation Ratio is the ratio between the number of streams of any given order and the number of streams in next higher order. It can be expressed in following equation.

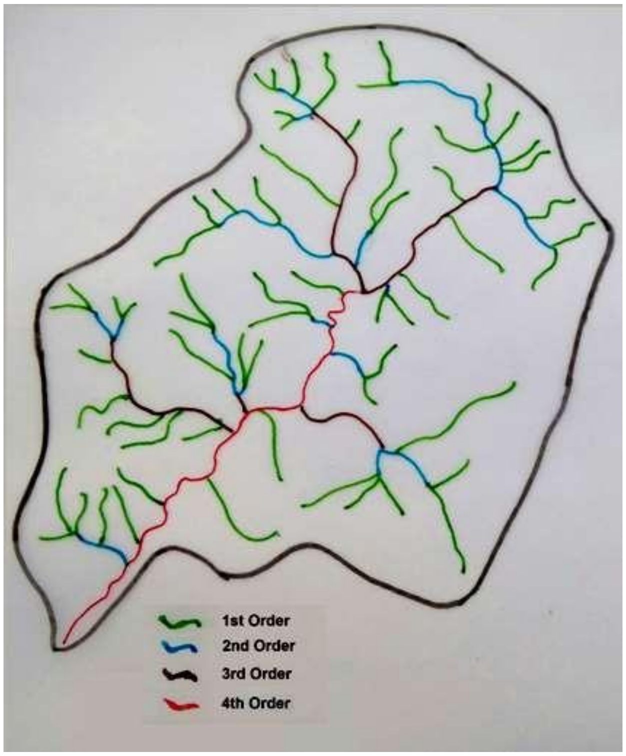
BR= Sn / Sn+1

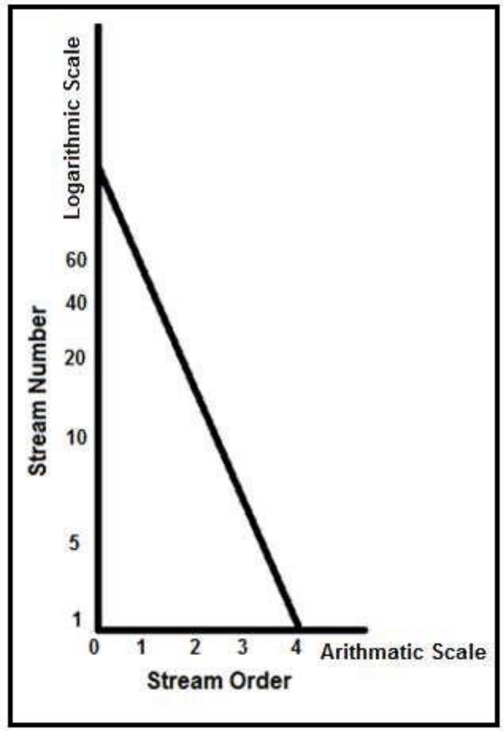
Where BR= Bifurcation Ratio

Sn = Total Number of streams in nth order

Sn+1=Total Number of streams in n+1th order

Fig.2: Stream Order and Stream Number





We can calculate the Bifurcation Ratio between the number of streams in 1st order and that of in 2nd order; between the number of streams in 2nd order and that of in 3rd order and so on. The Mean Bifurcation Ratio is calculated by taking average of all the bifurcation ratios of consecutive streams in the river basin. The Bifurcation Ratio and Mean Bifurcation Ratio of the river basin shown in Figure 2, is calculated in the Table 1. The Mean Bifurcation Ratio of the river basin shown in Figure 2 is 4.07. The Mean Bifurcation Ratio of a river basin says approximately how many times the number of stream segments increases when we move from higher to lower order. It is nothing but the constant of the Geometric Series explained under the heading Stream Number.

Bifurcation Ratio depends upon relief, rock type and dissection of rocks. In relatively homogeneous rock type, the value of Mean Bifurcation Ratio of a river basin varies between 3 and 5. When any geological structure controls the drainage pattern, the Mean Bifurcation Ratio goes beyond 5. A value of 2 is rarely found. A value of 10 or more is possible in very elongated basins where there are narrow, alternating outcrops of soft and resistant strata. When bifurcation ratio is low, there are high possibilities of flooding as water tends to accumulate rather than spreading out. The human intervention plays important role to reduce bifurcation ratio which in turn augment the risk of flooding within the basin. In an area of uniform climate, rock type and history of geologic development, the Bifurcation Ratio tends to be constant from one order to the next, hence that is the single ratio characterizes the entire basin.

Stream Length: -

Stream Length is the total length of all the streams of a particular order and Mean Stream Length is the average stream length of that order. As we have seen the number of streams increases with the decrease of stream order, likewise the total length of the streams increases with the decrease of stream order. However, the mean stream length decreases with the decrease of stream order. Unlike Bifurcation Ratio, the Stream Length Ratio is the ratio between the mean length of streams of a particular order and that of next lower order. It can be expressed in following equation.

SLR= Ln / Ln-1

Where SLR= Stream Length Ratio

Ln = Mean Length of streams in nth order

Ln-1= Mean Length of streams in n-1th order

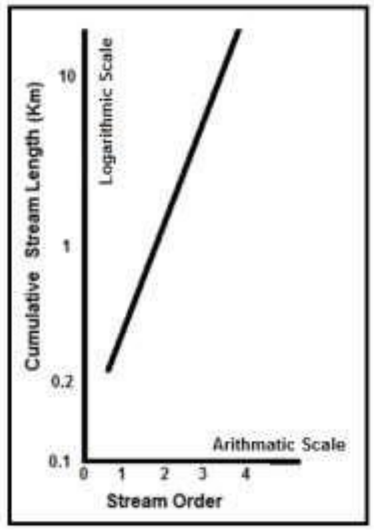
Table 1: River Basin Characteristics of the River Basin Shown in Fig. 2

Stream Order	Stream Number	Bifurcation Ratio	Mean Stream Length (km.)	Stream Length Ratio	Average Basin Area (km^2)	Average Channel Slope (tan θ)
1	62	4.43	.6	1.8	0.05	0.29
2	14	2.8	1.08	1.19	0.15	0.14
3	5	5	1.29	3.79	0.86	0.075
4	1		4.9		6.1	.03

Mean Bifurcation Ratio: 4.43+2.8+5/ 3 = 4.07

We can calculate the Stream Length Ratio between the mean length of all streams in 4^{th} order and that of in 3^{rd} order; between the mean length of all streams in 3^{rd} order and that of in 2^{nd} order and so on (Table 1). Like Law of Stream Number, Horton has also developed **'Law of Stream Length'**. According to this Law, the Cumulative Mean Length of streams increases in geometrical progression with increase of Stream Order. If stream order is taken on X-axis on an arithmetic scale and cumulative mean length of streams on Y-axison a logarithmic scale, it gives a positive linear pattern. The relationship between Stream Length and Basin Order is very interesting which is as follows.

Fig.3: Stream Order Vs Cumulative Stream Length of Drainage Basin Shown in Figure 2



- There is negative relationship between Stream Order and Total Stream Length
- There is positive relationship between Stream Order and Mean Stream Length
- There is positive relationship between Stream Order and Cumulative Mean Stream Length. (Fig. 3) Besides, the later increases geometrically with successive higher order.

Sinuosity Index: -

No river ever flows in a straight path. The Sinuosity Index explains how much a river deviates from the straight path. It is the ratio between the actual length of a stream and the length of the expected straight path of the stream. It helps us understanding the effect of terrain characteristics on river flow. Many scholars have developed methods to calculate Sinuosity Index. Schumm’s method is widely used which is expressed in the following equation.

SI =AL/EL

Where, SI= Sinuosity Index

AL= Actual length of the stream

EL= Expected straight path of the stream

On the basis of the values, Schumm categorized 5 courses of river. When it is 1, the course is straight, when it is more than 20, the course is torturous. In between there are transitional, regular and irregular courses. Figure 4 shows the shape of all these types of streams. The Sinuosity Index of the main stream shown in Figure 4 is 1.17 (5.75 km. / 4.9 km.). It means the course of the stream is transitional, i.e., in between straight and regular.

Areal Aspects:

Basin Shape: -

The shape of the basins varies from place to place depending upon relief, rock type, slope, geological structure etc. The ideal shape of a drainage basin resembles a pear. Streams descending from a mountainous zone to hilly or plateau regions generally have more elongated basins compared to those streams descending from hilly or plateau regions to the plains. Assessment of a basin's shape can be used to explain certain hydrological processes. There are various methods to assess the shape of basins. Schumm's Elongation Ratio is very popular which is used widely which is expressed as follows.

$ER=D/L$

$D= 2\sqrt{A} /\sqrt{\pi}$

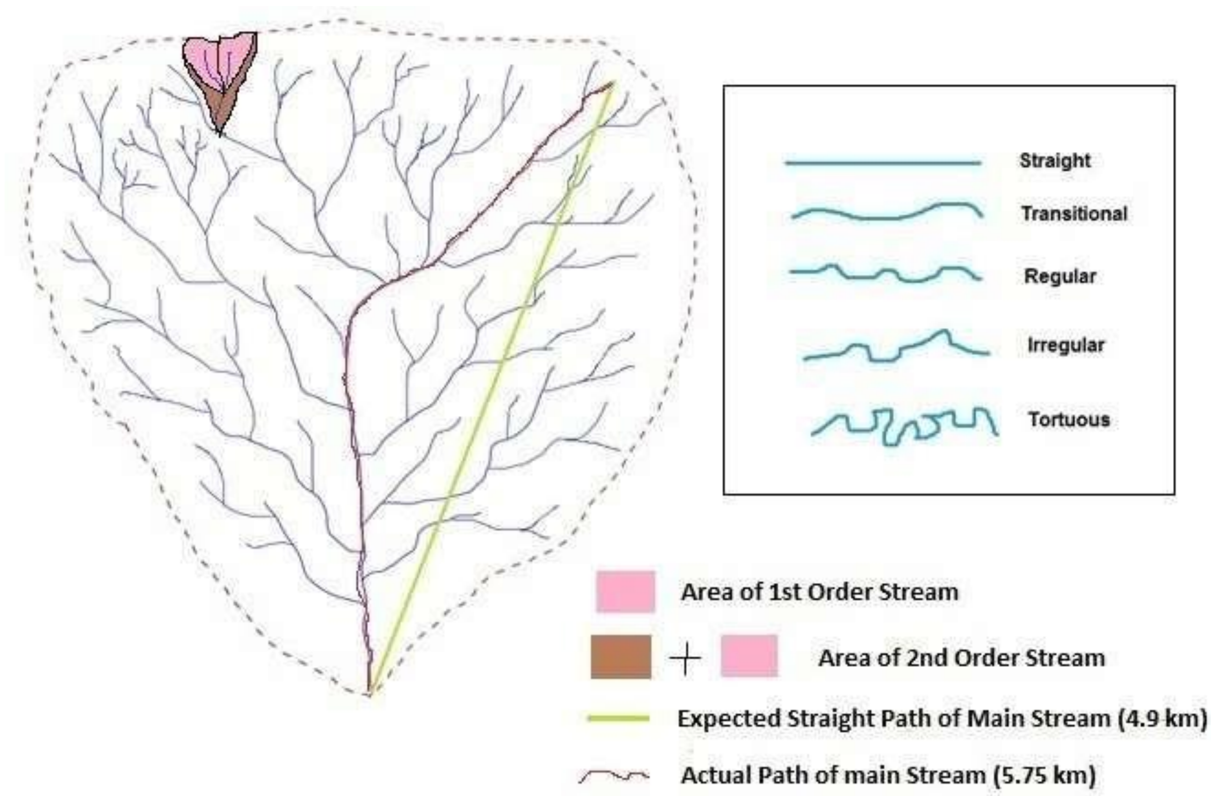
Where, ER= Elongation Ratio

D= Diameter of the circle with same area as basin

L= Basin length

A= Area of the basin

Fig.4: Sinuosity Index, Basin Shape and Basin Area

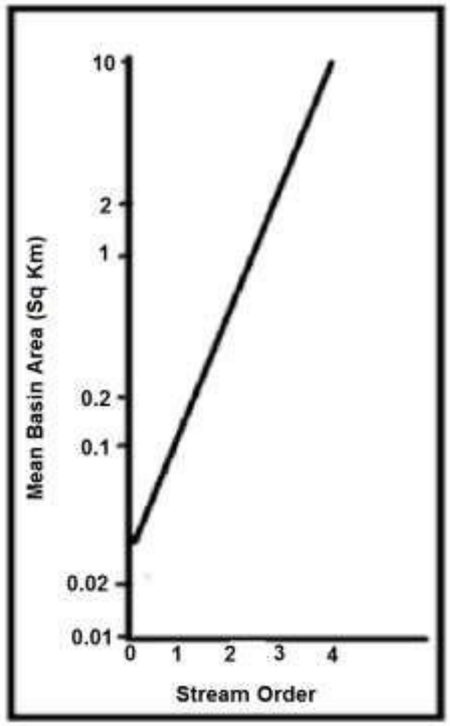


The value of Elongation Ratio varies from 0 to 1. Higher the value of the Elongation Ratio, more circular is the basin. Lower the value of the Elongation Ratio, more elongated is the basin.
The basin area of the river basin shown in Figure 4 is 44.2 km^2 and basin length is 4.9 km. After putting the values in the above equation, the Elongation Ratio is determined as 0. 76.. It shows the basin shape is more towards circular rather than elongated. The shape of the basin is ideal, i.e., pear shape.

Basin Area:-

Every stream/ river has a basin. The basin area of any stream having any stream order can be determined. Basin Area is the total area of a stream of a particular order and Mean Stream Area is the average stream area of that order. The area of the basins increases with order. As for example, the Basin Area of 2^{nd} order stream is the total area of all 1^{st} order streams contributing it plus total inter-basin areas (as shown in Fig. 4). According to **Law of Basin Area**, developed by Strahler, the mean basin areas of successive higher stream orders tend to form a geometric series beginning with mean basin area of 1^{st} order basin. When Mean Basin Areas are plotted on a logarithmic scale of vertical axis against the respective basin orders on arithmetic scale of horizontal axis, it produces a straight line. The relationship between Mean basin Area and Basin Order of the drainage basin (shown in Fig. 2) is shown in Fig. 5.

Fig.5: Stream Order Vs Mean Basin Area of Drainage Basin Shown in Figure 2



Like Bifurcation Ratio and Stream Length Ratio, Basin Area Ratio is also determined. Basin area Ratio is the ratio between the mean area of the streams of any given order and mean area of streams in previous lower order. It can be expressed in following equation

BAR= An / An-1

Where, BAR= Basin Area Ratio

An= Mean area of the stream of nth order

An-1= Mean area of the stream of n-1th order

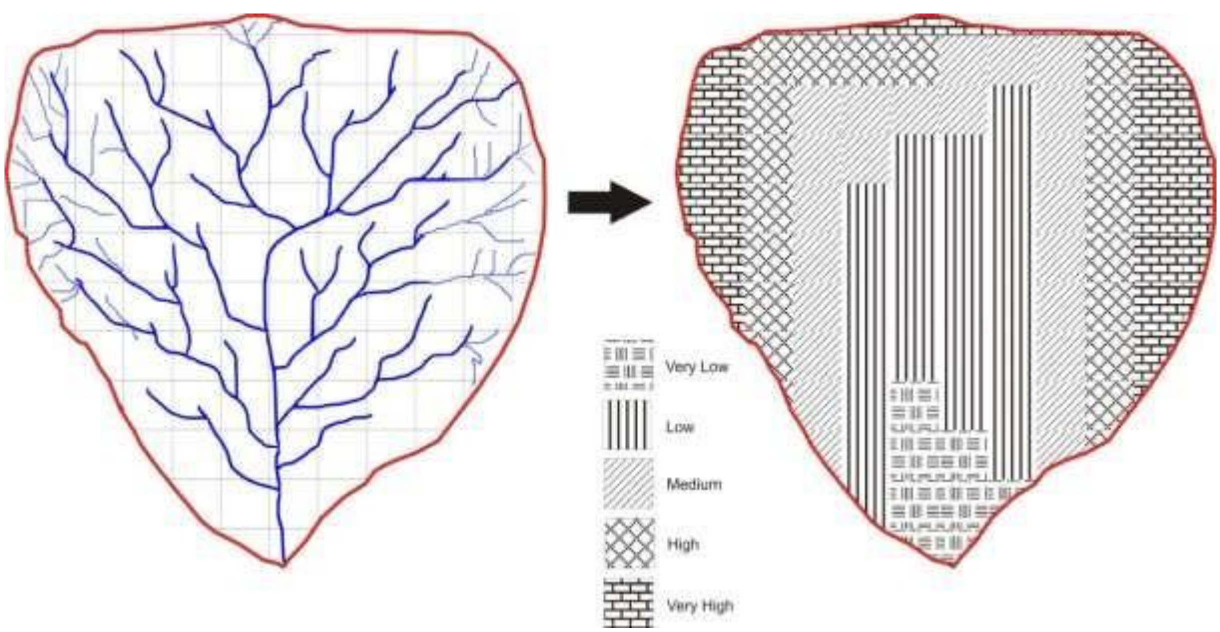
We can calculate the Basin Area Ratio between streams of the 4th order and 3rd order; between 3rd order and 2nd order; and between 2nd order and 1st order.

Drainage Frequency: -

Drainage Frequency is defined as the total number of streams per unit area. The Drainage Frequency shows the dissection or the destruction of a relatively flat landscape through incision and erosion by streams. Generally, most of the first order and second order streams of many regions are seasonal, i.e., they develop along the hill slopes during rainy season due to torrential rain and become dry after the rainy season and look like gullies, the depth and width of which increase during subsequent rainy season. The process is called dissection by which a land surface is cut up by eroding streams. Thus, the uniformity of a surface is broken up by gullying and stream incision. Higher Drainage Frequency indicates lesser permeability and infiltration. Drainage Frequency depends on the variation in rock structure in the basin. Mature topography shows lesser number of streams in comparison to younger topography.

To determine Drainage Frequency, drainage basin is divided into small grid cells of equal area. The streams are counted for each cell and then divided with area of the cell. To show the spatial pattern of Drainage Frequency, the grid cell values are classified into 4/5 categories and choropleth map is developed out of it (Fig. 6). The general categories of Drainage Frequency are: Very Poor, Poor, Moderate, High and Very High.

Fig. 6: Drainage Frequency of Drainage Basin Shown in Figure 4



Drainage Density: -

Drainage Density is a very significant characteristic of drainage basin, because it influences the texture of a drainage system. Drainage density is influenced by geology, climate and character of terrain. For example, in humid climatic region, high relief areas have higher drainage density than sub- humid region with lower relief areas. Density is also high on impermeable but easily erodible rocks, e.g., clay. Drainage Density has also an important influence on the area when there is storm or cloud burst, because water flow in channels is faster than overland flow. The risk of fast flood decreases where the drainage density is high. Drainage density is expressed as the ratio of the total length of all stream channels within a drainage basin to the total area of that basin. It can be derived as follows.

$Dd = L1 + L2 + L3 + L4 \ldots\ldots\ldots LN / A$

Where Dd= Drainage Density

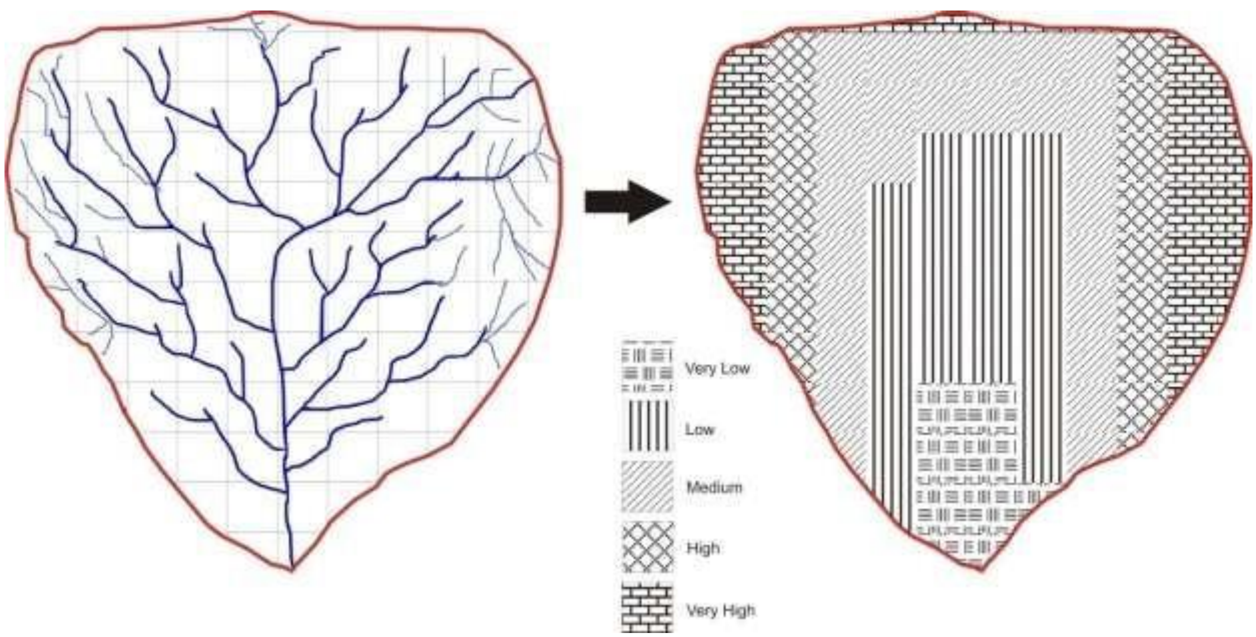
L1= Length of stream No. 1

N= Total number of Nth streams

A= Total area of the basin

The DD of the given basin is .6 m/ km^2. This figure does not show the spatial variation of Drainage Density within the basin. To know the spatial variation, the drainage basin can be divided into small grid squares of equal area. The DD of each grid square is calculated and on the basis of the values choropleth map is prepared. (Fig. 7)

Fig. 7: Drainage Density of Drainage Basin Shown in Figure 4



Relief Aspects:

Stream Slope: -

Every stream flow on a slope. The velocity of water in a stream depends on stream slope. Stream Slope is the ratio of vertical drop of a stream to its horizontal distance. The vertical drop of a stream is determined by subtracting the absolute relief of the stream at its mouth from that of at its origin. The horizontal distance of stream is determined by measuring distance between the origin and mouth of the stream. The Mean Stream Slope of any stream order is the average slope of that order. The Stream Slope and Mean Stream slope are expressed in the following equation.

SS= V/H

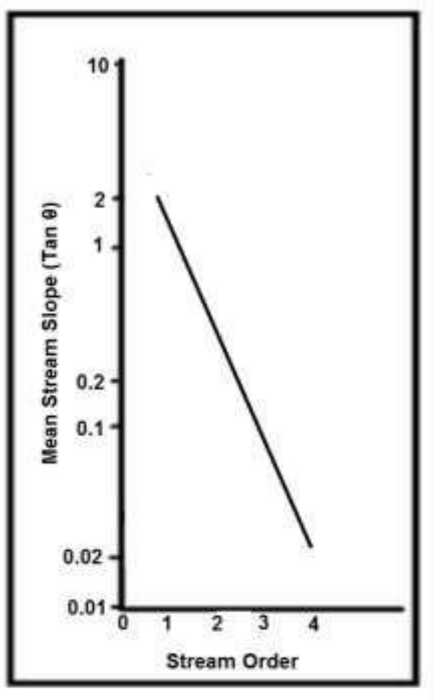
Where, SS= Stream Slope

V= Vertical drop

H= Horizontal distance

MSS= Summation of V nth order stream/ no nth order streams ⁄Summation of H nth order stream/ no nth order streams.

Fig. 8: Stream Order Vs Mean Stream Slope of Drainage Basin Shown in Figure 2



The **Law of Stream Slope** has been developed by Horton. According to the Law, Mean Stream Slope increases with decreasing stream orders in geometric series. It means when the Mean Stream Slope are plotted on a logarithmic scale of vertical axis against the respective basin orders on arithmetic scale of horizontal axis, it produces a straight line of negative relation (Fig. 8).

River Profile:-

River Profile is an outline of the course of the river as seen in a vertical section. The profiles of a river can be shown in two ways- a) along the river, and b) across the river. The profile along the river is called Long Profile and the profile across the river is called Cross Profile. To show Long/ Longitudinal Profile, a graph of distance verses elevation along the river is prepared (Fig. 9). It shows changes in the altitude of the course of a river from its source to its mouth. It is usually concave and the slope becomes gentler towards the mouth of the river. The profile of a river which has been gone through rejuvenation, shows numerous pronounced breaks indicating nick points or heads of rejuvenation. To show Cross Profile, a graph of distance verses elevation across the river is prepared (Fig. 10). Cross profile can be drawn at various stages of river. In upper course of the river, it is generally 'V' shaped. The shape of the Cross Profile changes with advancement of river. Both Longitudinal Profile and Cross Profiles at various parts of the river tell us about underlying materials as well as give insights into geologic processes and geomorphic history of an area.

Fig. 9: Longitudinal Profile of River

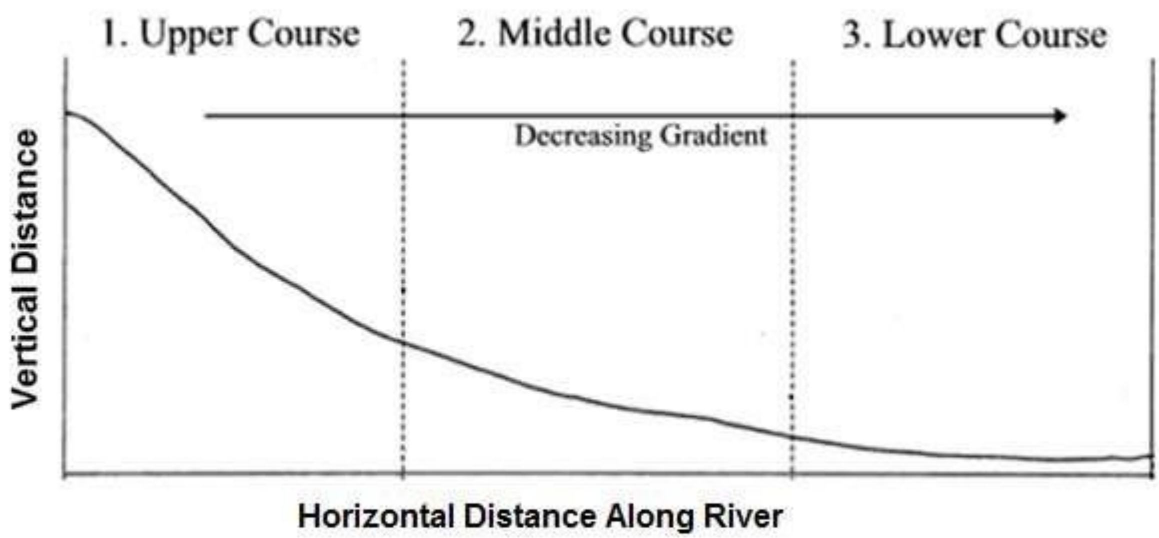
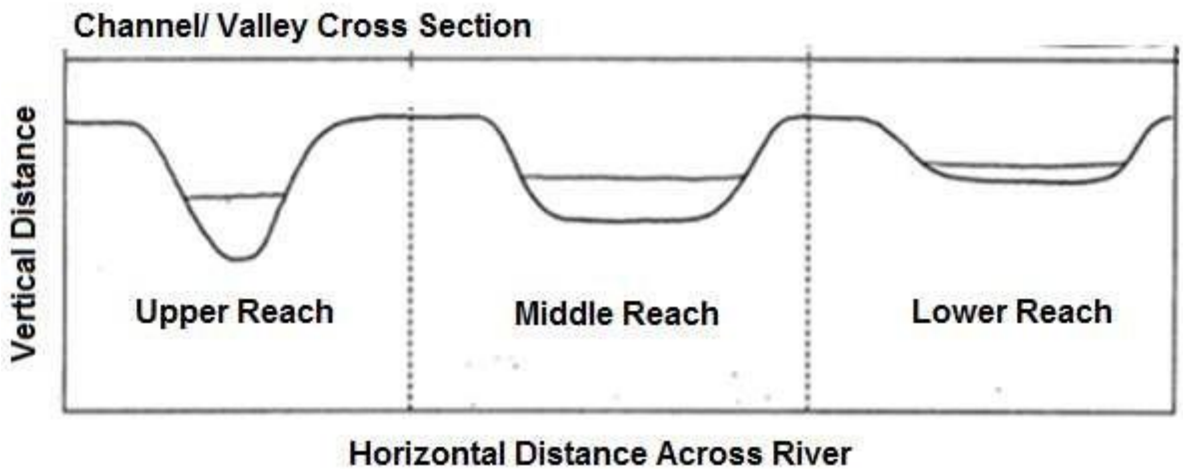


Fig. 10: Cross Profiles at Various Stages of River



Area- Height analysis: -

Area-Height analysis of a river basin shows the measurement and analysis of relationship between altitude and basin area to understand the degree of dissection and stage of erosion. The Area-Height analysis is popularly known as Hypsometric analysis. Hypsometric curves are drawn on graph paper to know the relationship between area and height.

Fig 11: Hypsometric Curve (Type 1)

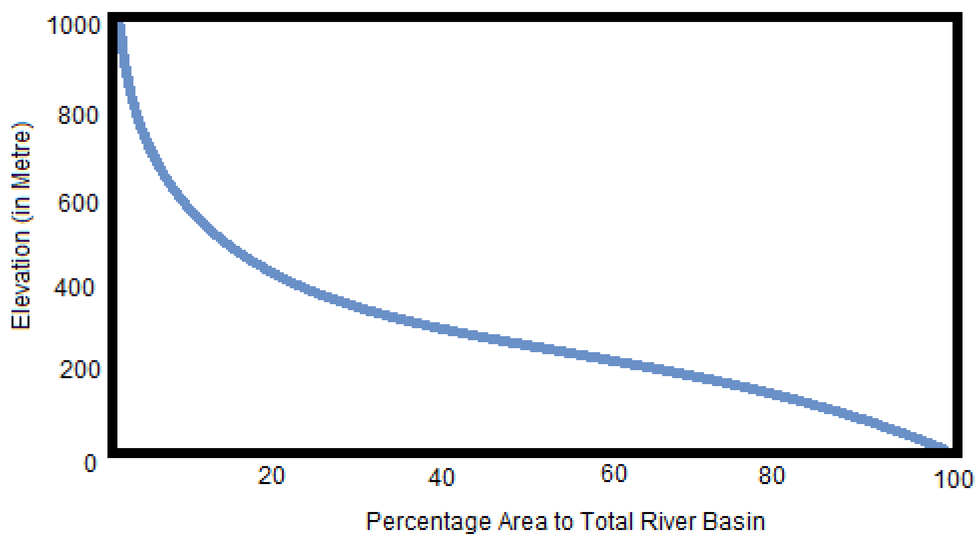
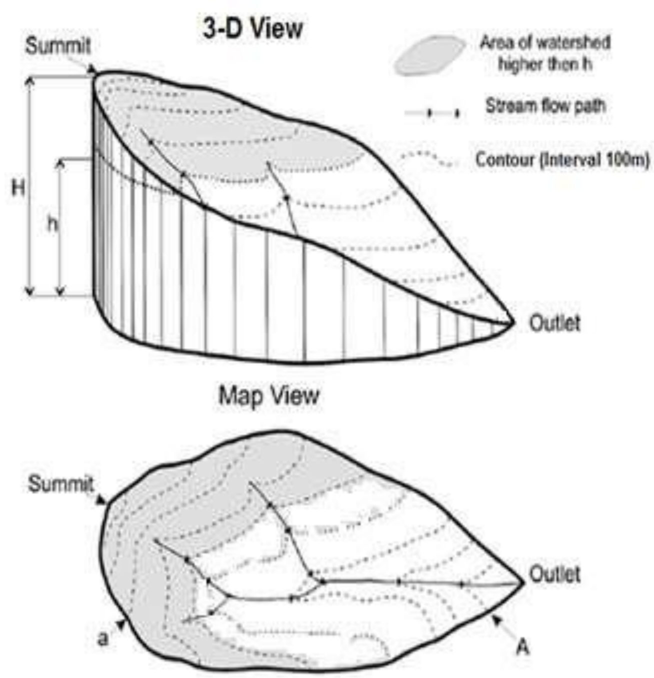
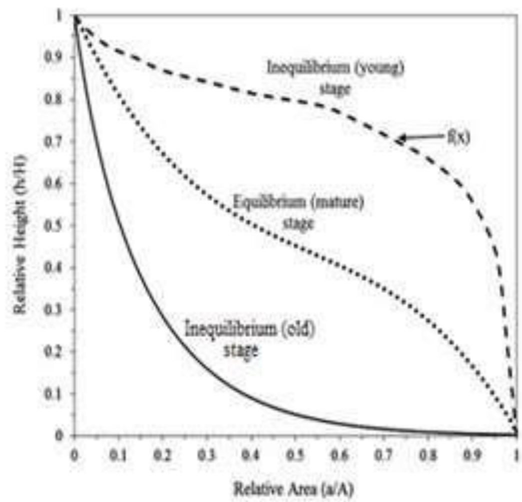


Fig. 12: Hypsometric Curve (Type 2)





There are usually two methods to draw hypsometric curve in a river basin. In 1st method the values of contours are plotted against the percentage of surface area above that contour in a river basin (Fig.11). The more mature the river, the hypsometric curve is more concave. By drawing Hypsometric curve by this method, we can compare one part of a river basin is more or less eroded in comparison to other part.

In the 2nd method, the relative height (h/H) is taken on Y-axis and relative area (a/A) is taken on X-axis. Here 'h' is obtained by subtracting the value of a specific contour from the height of the basin. 'H' is the height of the basin; 'a' is the area above a specific contour and 'A' is the total area of the river basin (Fig. 12). The different shapes of the curve show the different stages of river, i.e., Youth, Mature and Old. We can compare stages of denudation of two different river basins by applying this method.

Conclusion: -

Mathematical or quantitative analysis of the external features of earth is termed as Morphometric Analysis. Morphometric Analysis of river basins is explained due to two reasons- a) It is easy to understand the technique (Morphometric Analysis technique) through river basins; b) The Morphometric Analysis of river basin as unit is very useful for planning purposes as river basin is the ideal ecological unit. Twelve important parameters of morphometry are explained under linear, areal and relief aspects. The measurement, calculation of these parameters along with the significance of their values is explained with suitable examples.