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Research Article

ASSESSMENT OF MORPHOMETRIC CHARACTERISTICS IN MADURAI BASIN (CAUVERY SUB WATERSHED REGION OF TAMIL NADU – INDIA)

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ABSTRACT
The present assessment for morphometric analysis of the Madurai drainage basin was undertaken to understand the hydro-geological behavior of the drainage basin and to know more about the prevailing climate, geology, geomorphology and structure in the Cauvery sub water shed region of Tamil Nadu (India). In the present case study, geomorphometric analysis of Madurai drainage basins (A part of Cauvery sub watershed region of Tamil Nadu in India) investigates the influence of relief, slope, geologic structure, tectonic uplift and climate change on basin geometry, pattern of drainage network, landform evolution and basin hydrology. The geomorphometric analysis includes quantitative measurement and analysis of topography and drainage characteristics like, altitude variation (relief and slope), channel network morphometry (stream order, stream number, stream length, bifurcation ratio etc.) and drainage basin morphometry (drainage density and frequency, basin shape, drainage texture, constant of channel maintenance etc.). On the basis of stream order, stream number, stream length and bifurcation ratio, the stream denotes the normal geomorphic characteristic i.e. order wise the number, length and bifurcation ratio is decreasing which is a clear indication of normal tectonically undisturbed landform. The drainage frequency and drainage density values show little bit abnormality i.e. for the range of 2.1 to 4.0 and 2 – 4 for drainage density and drainage frequency respectively, hike in the area as compared to the lower and higher range is the important point of study of this particular category. The absolute relief indicates the abnormality in the second category which ranges from 2.1 to 3 towards the higher order. In addition to this the absolute relief values for category 4, 5 and 6are decreasing. The kinds of lower and higher repetition indicate the influence of the tectonic activity in the study area. Geomorphologically the terrain occupies very little high relief area where steep slope occurs, while rest of the area shows the normal landform conditions.

Keywords: *Aerial and Linear Parameters; Drainage Basin; Morphometry; Watershed*

INTRODUCTION
Morphometry may be defined as the measurements and mathematical analysis of the configuration of the earth’s surface and of the shape and dimensions of its landforms (Clarke, 1996; Ajibade *et al.,* 2010). A major emphasis in geomorphology over the past several decades has been on the development of quantitative physiographic methods to describe the evolution and behavior of surface drainage networks (Horton, 1945). The morphometric analysis of the drainage basin and channel network play a vital role in understanding the hydro-geological behavior of drainage basin and expresses the prevailing climate, geology, geomorphology and structure. It provides a quantitative description of the basin geometry to understand its slope, structural controls, geological and geomorphic history of drainage basin (Strahler, 1964). River basins comprise a distinct morphologic region and have special relevance to drainage pattern and geomorphology (Strahler, 1954). The total development of a region is a sum total development of sub basins of which it is composed. So by analyzing the development of each of the sub basins one can have a better understanding of the landscape of the terrain (Prakash *et al.,* 2010).
Morphometry represents the topographical expression of land by way of area, slope, shape, length, etc. (Ajibade, 2010). These parameters affect catchment stream flow pattern through their influence on concentration time. The significance of these landscape parameters was earlier pointed out by Morisawa

(1959), who observed that stream flow can be expressed as a general function of geomorphology of a watershed. Jain and Sinha (2003), who reported that the geomorphic characteristics of drainage basins play a key-role in controlling the basins hydrology. Morphometric analysis of drainage basins thus provides not only an elegant description of the landscape, but also serve as a powerful means of comparing the form and process of drainage basins that may be widely separated in space and time (Easterbrook, 1993).

Quantitative Geographic Analysis

Quantitative measurements of morphometric parameters of basin and sub basins have raised attraction of research in geology, geomorphology and hydrology since Horton's period. The morphometric analysis is significantly used for various small river basins and sub basins in the various parts of the world (Horton, 1945; Strahler, 1952a, 1957, 1958, 1964; Miller, 1953; Leopold and Miller, 1956; Morisawa, 1959; Shreve, 1967, 1974; Scheidegger, 1991, 2004; Smart, 1968; Gardiner, 1980; Tokunaga, 1978; Dodds and Rothman, 1999). The drainage basin morphometry helps to analyze and compare the form and processes of landscape evolution irrespective of time and space (Easthernbrook, 1993). The relational analyses between various morphometric parameters give us clue about stages of landscape development (Sabale, 2006).

Quantitative estimation of morphometric parameters are computed from drainage maps following the procedures proposed by Horton (1945); Strahler (1952, 1968); Schumm (1932); Smart and Surkan (1967); Avena *et al.*, (1967); Waugh (1995); Gupta (1999); El Hamdouni (2007); Thomas *et al.*, (1996); Dehbozorgi *et al.*, (2010), EllanWohl (2014); Baker (2014). In our study area, Madurai Basin, the Geomorphometric analysis of the drainage basin play a vital role in understanding the hydro-geological behavior of drainage basin and expresses the prevailing climate, geology, geomorphology and structure. It provides a quantitative description of the basin geometry to understand its slope, structural controls, geological and geomorphic history of drainage basin. The study of the present drainage basin investigates the influence of relief, slope, geologic structure, tectonic uplift and climate change on basin geometry, pattern of drainage network, landform evolution and basin hydrology. The geomorphometric analysis includes quantitative measurement and analysis of topography and drainage characteristics like, altitude variation (relief and slope), channel network morphometry (stream order, stream number, stream length, bifurcation ratio etc.) and drainage basin morphometry (drainage density and frequency, basin shape, drainage texture, constant of channel maintenance etc.).

Geology of the Study Area

The Precambrian formations of the drainage basin of the Cauvery River comprise of the Dharwar system, peninsular granite gneiss, charnockite and closepet granite (Krishnan, 1981). Special rock types for example eclogites, kometites, carbonatites etc., have also been reported from the Precambrian terrain of the drainage basin of the Cauvery. The Dharwar system consist of slates, phyllites, chlorite schists, biotite schists, sillimanite schists, hornblende schists garnetiferous schists, staurolite schists, kyanite schists ferruginous quartzites, greenstones and quartzites (Krishnan, 1981; Naqvi *et al.*, 1978). They occur in isolated strips and are limited to the northern part of the Cauvery drainage basin. The Peninsular granite gneiss are the dominant group of rocks found in the Cauvery basin. They consist of a very heterogeneous mixture of different types of granites intrusive into the schistose rocks (Figure 1). They include granites, granodiorites, gneissic granites and banded or composite gneisses. The banded gneisses consist of white bands of quartz-feldspar alternating with dark bands containing hornblende, biotite and minor accessories. The granitic group ranges in composition from granite through granodiorite to adamellite, augitediorite, monzonite etc. The middle Cauvery upland region is made up of charnockites. Charnockites are hypersthene bearing granites composed of blue quartz, feldspar and hypersthene. They range in composition from basic to acidic varieties. The closepet granite is drained by the river in the upper reaches of the drainage basin. The closepet granite is a pink coloured granite. It consists of porphyritic and non- porphyritic types. Mineralogically it consists mainly of quartz, plagioclase, myrmekite, microcline, perthite, subordinate amounts of hornblende, minor amounts of apatite, biotite, rutile, zircon and occassional fluorite (Chatterji, 1974). They occur as dome shaped discordant batholiths surrounded by the finer grained gneissic varieties. With respect to the deltaic area, the Cretaceous beds form the oldest formation. These formations were deposited under marine environment.

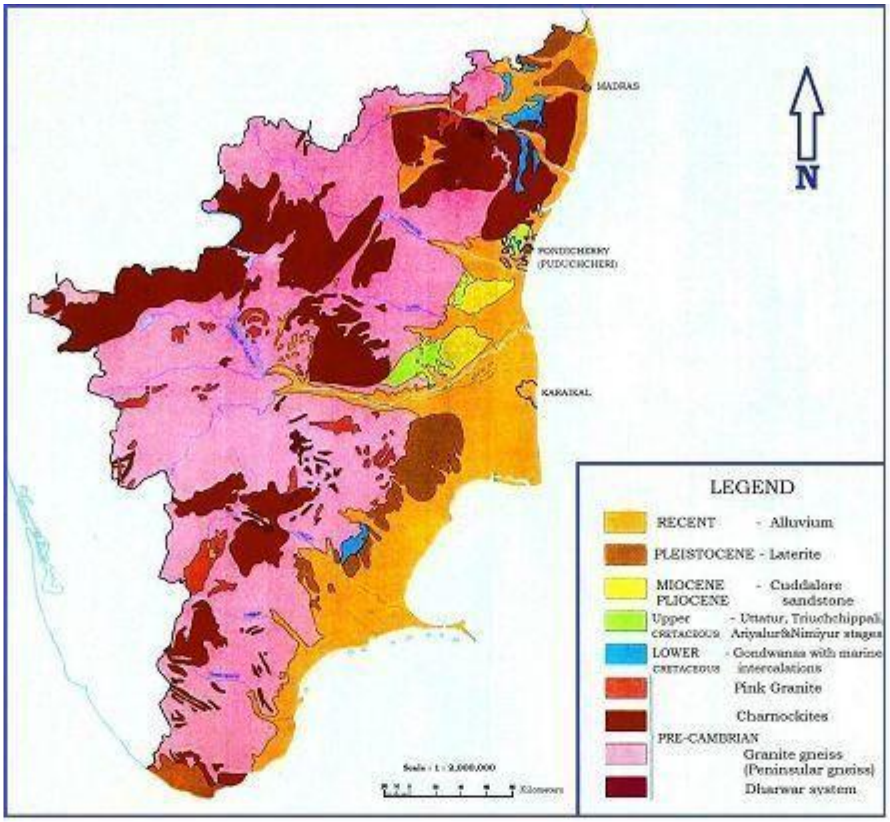

Figure 1: Map showing Geology of the Study Area

Observations of Quantitative Geomorphology Carried Out in the Study Area

Table 1: Linear Relief and Areal Morphometric Parameters

S. No	Parameters	Formulae	References
1	Stream Order (U)	Hierarchial rank	Strahler (1964)
2	Stream Length (Lu)	Length of the stream	Horton (1945)
3	Mean Stream Length (Lsm)	Lsm = Lu / Nu	Strahler (1964)
4	Stream Length Ratio (RL)	RL = Lu Lu - 1	Horton (1945)
5	Bifurcation Ratio (Rb)	Rb = Nu / Nu + 1	Schumm (1956)
6	Mean Bifurcation Ratio (Rbm)	Rbm = average of bifurcation ratios of all order	Strahler (1957)
7	Drainage density (Dd)	Dd = Lu / A	Horton (1945)
8	Drainage texture (T)	T = Dd x Fs	Smith (1950)
9	Stream Frequency (Fs)	Fs = Nu / A	Horton (1945)
10	Elongation ratio (Re)	Re = D / L = 1.128 A / L	Schumm (1956)
11	Circularity ratio (Rc)	Rc = 4 A / P2	Strahler 1964
12	Form factor (Ff)	Ff = A/L2	Horton (1945)
13	Length of overland flow (Lg)	Lg = 1/D*2	Horton (1945)
14	Relief	R = H - h	Hadley and Schumm (1961)
15	Relief Ratio	Rr = R/L	Schumm (1963)

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They rest upon an ancient surface of the Archean gneisses or on upper Gondwanas. The Cretaceous formations of the coastal tract of the Cauvery basin consist of faunal rich marine sedimentary rocks namely limestones, sandstones, clays, sandy beds etc. The Tertiary rocks overlie the Cretaceous formations. The outcrops here and there are seen in the form of Miocene and Pliocene formations of the upper tertiary period. The mouth of the basin is constituted by alluvium deposits which are composed of clays and silts.

Drainage Pattern of the Study Area

The drainage basin map of the present study area is shown in Figure 2. The river Cauvery is flowing in south-east direction and has its flow across the foliation direction of the rocks present. Hence, dendritic pattern of drainage is very well noticed in the river basin. Furthermore, the long profile of the river Cauvery through terraces and knick points clearly indicate the possibility of uplift and erosion in the geological past of the study area.

A very gentle gradient is seen in the drainage basin, therefore it cannot carry its load of sediments. Naturally, the river which is in its last part of the mature stage, deposits the material brought from the Western Ghats and rugged plateau of upland. This time the action of the river is aggradation and the continuous process of deposition leads to the development of distributaries. The distributaries divide and sub-divide into a number of small branches which form a network all over the delta. The branch which retains the name of the Cauvery through its course enters the Bay of Bengal finally marking the end of the study area.

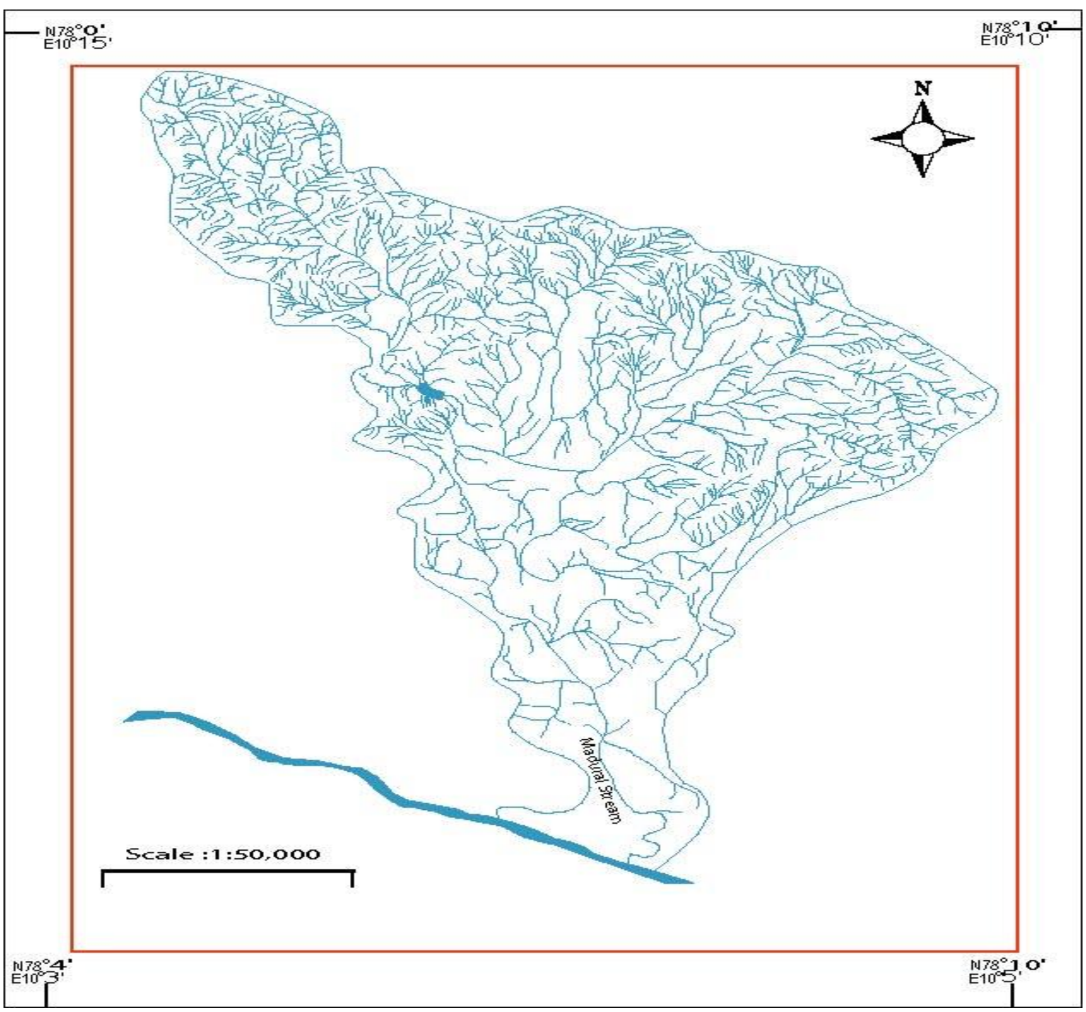

Figure 2: Showing the Drainage Pattern of the study area

RESULTS AND DISCUSSION

Results

a) Stream order *(U)* indicates the hierarchical position of stream segments in the drainage network. Strahler's method of drainage ordering (Strahler, 1964) has been adopted for this study. The designation of stream order is the first step in the drainage basin analysis. The primary step in drainage basin analysis is to designate stream orders. As per the Strahler's (1964) ordering scheme, the study area is a 7th order drainage basin. Higher stream order is associated with greater discharge. The trunk stream, through which all discharge of water and sediment passes is therefore the stream segment of highest order.

b) Stream number (*Nu*) is assigned as the total number of stream segments of each order. In the study basin *Nu* of first, second, third, fourth, fifth, and sixth order streams are 3259, 526, 100, 30, 8 and 1 respectively

c) Basin length (*L*) is the longest dimension of the basin parallel to the principal drainage line (Schumm, 1956). The basin length of Madurai basin is 8863.56 m. *L* of all sub basins.

d) The bifurcation ratio (*Rb*) is the ratio between stream numbers of an order and its next higher order (Horton, 1945).

e) Stream length ratio (*RL*) is the ratio between mean stream length of a given order and its next lower order.

Table 2: Stream Length Ratio of the Study Area

Sr. No.	Stream Order (U)	Stream Number (Nu)	Stream Length (L)	Bifurcation Ratio (Rb)
1.	I^{st}	3259	6465.73	6.174
2.	II^{nd}	526	1366.31	5.207
3.	III^{rd}	100	550.72	3.225
4.	IV^{th}	30	387.3	3.33
5.	V^{th}	8	93.5	4.000
6.	VI^{th}	1		0.5

The number of stream segments counted in each area has been shown in table No. 2. This table shows that in the case of each first order stream total stream numbers are maximum, while it is decreases with as the order increases.

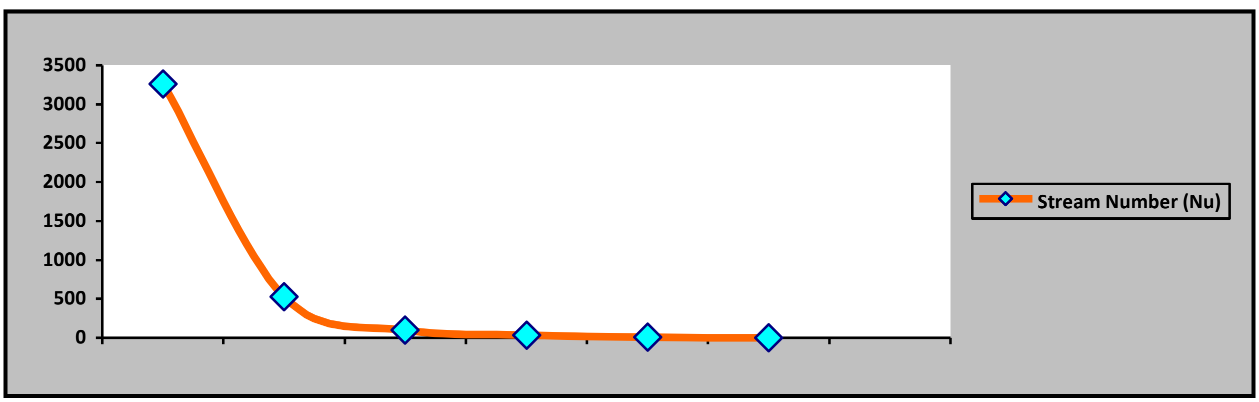

Figure 3: Stream Order V/s Stream Number

The graph which is plotted steam order verses number of stream indicates that the number of streams decreases as the order of stream increases and vice versa. As per the stream length is concern, as the order goes on increasing the length decreases and vice versa i.e. the first order stream shows maximum length while last order stream shows the minimum length.

Drainage Density (Dd)

Expresses total stream length per unit drainage area. It depends on climate (mainly rainfall), geology, vegetation cover, erosivity, infiltration capacity and permeability of underlying rock and soil, relief and slope aspect of the basin (Horton, 1932; Strahler, 1964; Morisawa, 1959; Verstappen, 1983). Drainage density are quietly depends on the stage of evolution. With the progress of youth stage towards maturity, *Dd* increases rapidly; while towards old stage it decreases.

Usually the drainage density factor determines the travel time of water. The measurement of the same is 'Dd' which is the numerical measure of land form dissection and run-off potential. As the drainage density value increase the rate of dissection is increase. Resulting the rate of flow of sediment increase. Therefore the intensity of this factor is depend upon the rate of precipitation, their duration, slope, type of rock and their properties, vegetation and environment. In this way the hydrology of the particular basin changes effectively in response to the change in drainage density.

Table 3: Drainage Density of the Study Area

Sr. No.	Range	Area in Sq. Km.	% of Area	Cumulative % of Area	Remark
1.	Less Than 2	539	25.55	25.55	Very Low
2.	2.1 – 4.0	659	31.24	56.79	Low
3.	4.1 – 6.0	559	26.50	83.29	Moderately Low
4.	6.1 – 8.0	292	13.84	97.13	Moderate
5.	8.1 – 10	58	2.75	99.88	Moderately High
6.	Greater Than 10	2	0.094	99.97	High
	Total	2109	100	100	

The Drainage Density of the study area showed in Table 3. The data in the table indicates that low drainage density (2.1 – 4.0) and Moderate Low (4.1 – 6.0) group dominate this study area and both of these groups share two group about 57.74 percentage of the total.

For addition to this the south western and northern part of the study area shows high absolute relief values, while the central and eastern part is composed of low absolute relief values. Comparatively medium value is present in between High and Low absolute relief areas.

Drainage Frequency

As stated above, the drainage frequency is the total number of stream segment of all orders per unit area (Horton, 1932). In an individual basin it might to be possible to have basins of some drainage density with differing frequency and basin of the same stream frequency which differing in drainage density. The drainage frequency is defined as, the ration between number of stream segment per unit area & in formula it is expressed as

$DF = \sum N/A$

Where $\sum N$ = Total number of stream segments

A = Unit area in Km^2 or Mt^2

A measure of topographic texture expressed as the ratio of the number of streams in a drainage basin to the area of the basin. It is the number of stream segments per unit area.

The Drainage frequency in Table 4 indicates that very low frequency (Less than 2) and Low (2 – 4) group dominates with in this the study area and both of these groups share two groups almost 86 percentage of the total.

The south western and central part of the study area i.e. towards the downstream Portion it shows high drainage frequency value while the extreme northern side to North Eastern Area shows comparatively less drainage frequency value. Over all in the source region, low frequency is seen while in the downstream area higher frequency of the stream is observed.

Table 4: Drainage Frequency of the study area

Sr. No.	Range	Area in Sq. Km.	% of Area	Cumulative % of Area	Remark
1.	Less Than 2	682	23.59	23.59	Very Low
2.	2 – 4	1719	59.46	83.05	Low
3.	4 – 6	372	12.86	95.91	Moderately Low
4.	6 – 8	100	3.45	99.36	Moderate
5.	8 – 10	14	0.48	99.84	Moderately High
6.	Greater Than 10	4	0.13	99.99	High
	Total	2891	100	100	

Relative Relief (Rr)

Relative relief is one of the most significant geomorphic variables which is used for overall assessment of morphological characteristics of a terrain and for assessing the degree of dissection of a terrain. Relative relief is also termed as relative altitude, topographic relief, and amplitude of available relief, local relief. Lithology, structure, slope, climatic parameters, geomorphic process and vegetal cover etc influence variation in the values of relative relief. It helps in finding out the terrain characteristics and their significance with the controlling factors. In short it is the difference of elevation between highest and lowest points in a unit area. It may be in the form of grid, square, rectangle, or a minute grid square. It is one of the important morphometric variable which is used for the overall assessment of morphological characteristics of the terrain and it's degree of dissection (Singh, 2001).

The relative relief (or basin relief) of Madurai basin is about 2341 Sq. Km. In the square sized grids, *Rr* ranges from 0 to 3 m.

Table 5: Relative Relief of Study Area

Sr. No.	Range	Area in Sq. Km.	% of Area	Cumulative % of Area	Remark
1.	0 – 1.99	2119	90.51	90.51	Low
2.	2 – 2.99	216	9.22	99.73	Medium
3.	Above 3	6	0.025	99.75	High
	Total	2341	100	100	

The relative relief data presented in the table shows majority dominancy of low (0 – 1.99) of 90.51% and Medium (2 – 2.99) of 9.22%. These two covers the largest area i.e. total of 99.73% cumulative area. Distribution of this relative relief indicates stage of Topography.

In the study area high relative relief is observed in the source areas of its network tributaries i.e. in the peripheral areas, while its low value is present in the central and eastern portion.

Absolute Relief (Ar)

It is a maximum elevation of a unit area. It provides an idea about the distribution of relief over the land. Generally, the absolute relief is used in the delineation of terrain morphology, which throws light on the structural and erosional characteristics of the region. It has received much significance particularly in land use, vegetation and resource planning, field study of this subject.

The absolute relief table shows that the attitudinal group of low absolute relief value ranging from (2.1 – 3) and moderate relief (3.1 – 4) respectively. These two groups cover an area of 35.59 % and 25.45 % respectively. Therefore they cover largest area of 61.04 % of the total.

The south western and northern part of the study area shows high absolute relief values, while the central and eastern part is composed of low absolute relief values. Comparatively, medium value is present in between high and low absolute relief areas.

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Table 6: Absolute Relief of the Study Area

Sr. No.	Range	Area in Sq. Km.	% of Area	Cumulative % of Area	Remark
1.	Less Than 2	53	3.235	3.235	Very Low
2.	2.1 – 3	583	35.59	38.82	Low
3.	3.1 – 4	417	25.45	64.27	Moderately Low
4.	4.1 – 5	203	12.39	76.66	Moderate
5.	5.1 – 6	219	13.36	90.025	Moderately High
6.	Greater Than 6	163	9.51	99.53	High
	Total	1638	100	100	

Dissection Index (DI)

It is the ratio between relative relief and absolute relief, gives a better understanding of the landscape. The sharpness of terrain character of an area cannot be expressed adequately by interpreting the absolute relief and relative relief separately. This can be obtained by the following formula.

$$\% \text{ Dissection Index} = \frac{\text{Relative relief (Rr)}}{\text{Absolute relief (Ar)}} \times 100$$

It is the index of the degree to which dissection has advanced. In other words, it expresses the relation between the vertical distance of relief from the erosion level and relative relief.

This parameter implies the degree of dissection or vertical erosion and expounds the stages of terrain or landscape development in any given physiographic region or basin.

It is the ratio between relative relief and absolute relief of an area. It is an important relief parameter that indicates the nature and magnitude of dissection of a terrain (Sinha, 1996).

Table 7: Dissection Index of the Study Area

Sr. No.	Range	Area in Sq. Km.	% of Area	Cumulative % of Area	Remark
1.	Less Than 1.5	1654	74.10	74.10	Very Low
2.	1.5 – 3.0	0	0	74.10	Low
3.	3.1 – 4.5	18	0.80	74.9	Moderately Low
4.	4.51 – 6.0	341	15.27	90.17	Moderate
5.	6.01 – 7.5	157	7.03	97.2	Moderately High
6.	Greater Than 7.5	62	2.77	99.97	High
	Total	2232	100	100	

The dissection Index data which shows in table 7 is divided into six categories such as very low, low, moderately low, moderate, moderately high and high. The range of data start from less than 1.5 to greater than 7.5 It is observed that the first group less that 1.5 and other group of range 4.51 – 6.0 having 74.10 % and 15.27 % of the area respectively covers the 89.27 % of the total. In the study area, more dissection is observed in western, northern and southern part of the basin i.e. towards the source and outlet areas. While in the central and eastern part of the study area show comparatively less dissection. This is due to the favorable slope in the peripheral areas which enables weathering and erosion of the rocks.

Drainage Slope

Slopes of any area directly give the geomorphic impression of the terrain Slopes which are significant morphometric attributes in the study of landforms of a drainage basin (Singh and Srivastava, 1975).

Slope defined as an angular inclination of terrain between hill tops and valley bottoms, resulting from the combination of many causative factors like geological structure, absolute and relative relief, climate, vegetation cover, drainage texture drainage frequency and percentage dissection index etc.

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Table 8: Drainage Slope of the Study Area

Sr. No.	Range	Area in Sq. Km.	% of Area	Cumulative % of Area	Remark
1.	0 – 0.031	2308	88.15	88.15	Low
2.	0.032 – 0.062	307	11.72	99.87	Medium
3.	Greater than 0.063	3	0.11	99.98	High
	Total	2618	100	100	

For the detailed study the drainage slope is divided in to 5 categories such as very low, low, medium, high and very high. Out of this low (0.032 – 1) and medium (11.72) covers 99.87 % of the total area in the present study area.

This data indicates the central – western portion of the study areas shows steep gradient of slope while the northern and eastern areas show a comparatively less gradient. In short the slope is increasing along the downstream channel of the river, in the study area.

Discussion and Conclusion

Based on the various morphometric features studied; it can be concluded that the watershed changes are considerable in response to the spatial variations of the morphometric parameters in the study area**.**On the basis of stream order, stream number, stream length and bifurcation ratio, the stream denotes the normal geomorphic characteristic i.e. order wise the number, length and bifurcation ratio is decreasing which is a clear indication of normal tectonically undisturbed landform. The drainage frequency and drainage density values show little bit abnormality i.e. for the range of 2.1 to 4.0 and 2 – 4 for drainage density and drainage frequency respectively, hike in the area as compared to the lower and higher range is the important point of study of this particular category. Except this, all the other readings are indicating the normal drainage characters of the basin. This abnormality might be due to slightly neo-tectonic deformation or change in the rate of weathering in this particular zone. The absolute relief which defines the maximum elevation of an unit area, indicates the abnormality in the second category which ranges from 2.1 to 3 towards the higher order. In addition to this the absolute relief values for category 4, 5 and 6are decreasing. The kinds of lower and higher repetition indicate the influence of the tectonic activity in the study area.

The dissection index is the important relief parameter which indicates the nature and magnitude of the dissection of a terrain. The value of this factor also indicate alternative high and low grade. This might indicate the change in lithology, surface texture, vegetation, land use – land cover, climate etc. factors at different places along the channel of the particular stream.

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