Evaluation of Morphometric Parameters – A comparative study from Cartosat DEM, SRTM and SOI Toposheet in Karabayyanahalli sub-watershed, Karnataka

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ABSTRACT

The accurate delineation of the catchment boundaries is the first important step in the determination of catchment geometry and extraction of stream network for morphometric analysis. Morphometric analysis were carried out for Karabayyanahalli sub-watershed in Karnataka state from three different sources viz., Cartosat DEM (30m), SRTM DEM (90m) and SOI topographic maps (1:50,000). Different morphometric parameters are derived from these three data are evaluated to examine the difference within the results for the planning and management of micro watershed in the study area. Drainages are extracted from the DEM by using Archydro tool in ArcGIS 9.3 version. The drainage networks are digitized from SOI toposheet. The flow of water from higher to lower elevation and steepest descent in a pixel are considered for the extraction of drainages from DEM. Result from SOI topographic maps are more or less correlated with Cartosat DEM data. SRTM data shows less drainage density and frequency compared to Cartosat DEM and SOI toposheet. The shape parameters from all the three data show the sub-watershed is oval in shape. The results shows that the morphometric parameters derived from Cartosat DEM data provide good and satisfactory information about the catchment characteristics and it also reveals that accuracy of the watershed delineation depends upon the resolution of DEM.

Keywords:

1. INRODUCTION

The term watershed generally applies to a naturally occurring hydrologic unit defined by natural boundaries. It is a land area that contributes storm runoff to a common point along a single waterway, and is classified on the basis of its geographical area (AIS and LUS, 1990). Watershed is further sub classified in to sub-watershed (30-50 km²), mini-watershed, (10-30 km²) and micro-watershed, (5-10 km²). Morphometry is the measurement and mathematical analysis of the configuration of the earth's surface, shape and dimension of its landforms (Agarwal, 1998). A major emphasis in geomorphology over the past several decades has been on the development of quantitative physiographic methods to describe the evolution and behaviour of surface drainage networks (Horton, 1945). The source of the watershed drainage lines have been discussed since they were made predominantly by surface fluvial runoff (Sharp et al. (1975), Hynek et al. (2003), and Pareta (2004). Pioneering works by Horton (1932, 1945) explained the significance of quantitative

geomorphological analysis and watershed morphometry. Since then, methods of watershed morphometry were further developed by several geomorphologists (Strahler, 1957, 1964, Gregory, 1966).

Morphometric analysis of a watershed provides a quantitative description of the drainage system, which is an important aspect of the characterization of watersheds (Strahler, 1964). The influence of drainage morphometry is very significant in understanding the landform processes, soil physical properties and erosional characteristics. The development of landforms and drainage network are depends on the bed rock lithology and also associated geological structures. Hence, information on geomorphology, hydrology, geology and land cover can be obtained by studying reliable information of the drainage pattern and texture. The morphometric parameters include basic parameters, derived parameters and shape parameters. The Basic parameters are catchment area, perimeter, basin length, stream order, stream length and maximum & minimum heights. The derived parameters are stream length ratio, bifurcation ratio, RHO-Co-efficient, drainage density, drainage texture, stream frequency, basin relief, relief ratio and slope angle and the shape parameters are Elongation ratio, Circularity ratio and Form factor. The characteristic and properties of the drainages are well studied by comparing the data from toposheet with high resolution satellite products.

Remote sensing and GIS techniques are now a day used for assessing various terrain and morphometric parameters of the drainage basins and watersheds, as they provide a flexible environment and a powerful tool for the manipulation and analysis of spatial information. Digital Elevation Models (DEM) derived from different satellites (SRTM and Cartosat DEM) has proven its capability to delineate the watershed boundary and extract the drainage network. The morphometric parameters derived from satellite products are used for the study of Geomorphology, Geology, Water resource conservation and management of watersheds and has shown satisfactory results (Ahmed et al 2010, Sreedevi et al 2012, Pareta et al 2012). In this paper an attempt has been made to examine the morphometric parameters derived from Cartosat DEM, SRTM DEM and SOI toposheet for proper planning, management of the sub-watershed and prioritization of micro watershed.

2. STUDY AREA

The Karabayyanahalli sub-watershed covers an area of 65 sqkm. The area extent in between 76°23'25.33"E to 76°29'45.152"E Longitude and 14°4'39.259"N to 14°10'41.483"N Latitude (Fig.1). The annual rainfall is less than 500mm and the area suffer severe drought and deficiency of water in most of the year. Structural hills and pediplain are major geomorphic units in the area. Volcanic and metamorphic rocks are mainly found in the region followed by consolidated sedimentary rocks. The major soil types are loamy sand, sandy loamy and sandy loam clay. Moist & dry deciduous open forest, crop land and land with scrub are the major land use and land cover types in the region.

Fig.1 Location Map of Karabayyanahalli sub-watershed

3. MATERIALS AND   METHODOLOGY
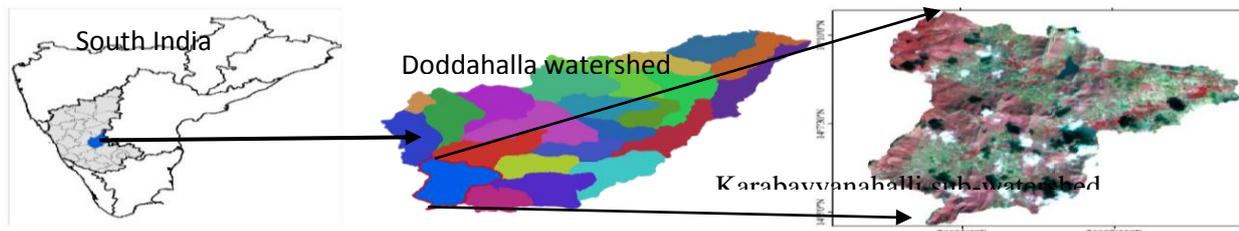
The morphometric analysis were carried out by the three different sources such as SOI topographic map (57 B/8, 1:500000), Cartosat DEM (1 arc second) and SRTM DEM (3 arc second). The Cartosat DEM data was downloaded from NRSC open EO data Archive (NOEDA) and SRTM data was download from http://srtm.csi.cgiar.org/. Both data are used for the delineation of drainage network by Archydro tool in the ArcGIS Software. The drainages from toposheet are digitized from ArcGIS software. The entire streams are ordered and calculated according Strahler's method. The morphometric parameters for Karabayyanahalli sub-watershed were calculated based on standard procedures (Horton 1945, Miller 1953, Schumm 1956, Strahler 1964,) and they are given in the Table.1. The methodology adopted for the delineation of the drainage network from the DEM was explained in Fig.2. DEM usually consist the depressions in the form of sink and tall cell which cause the trapping and obstruct to the flow of water. Hence in any hydrologic modelling the sink cell to be filled and chopping off tall cells was first carried out (Fig.3 (A)). Flow direction was calculated for each pixel using the filled DEM to determine the direction of flow. Flow direction cell contain the numerical value from 1 to 128 in an eight directions such as east, southeast, south, southwest, west, northwest, north and northeast (Fig. 3 (B)). The water always flows along the direction of steepest adjacent cell value. Flow accumulation is the next step in the hydrological modelling and was used to generate a drainage network, based on the direction of flow of each cell. The drainage network was extracted by considering the pixels greater than a threshold of 25 by a trial-and-error approach (Mark, 1983). Further watersheds can be delineated by giving an outlet or pour point where water flows out from a watershed and this is the lower most point in watershed.

Fig.2 Methodology of delineation of streams from DEM
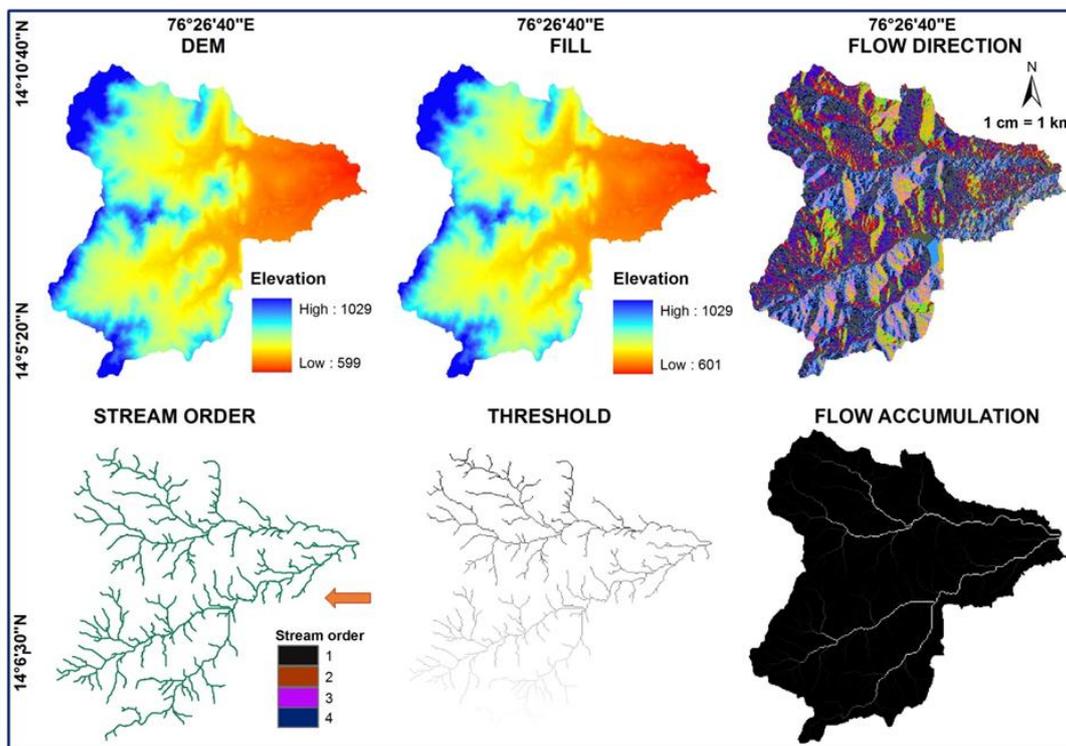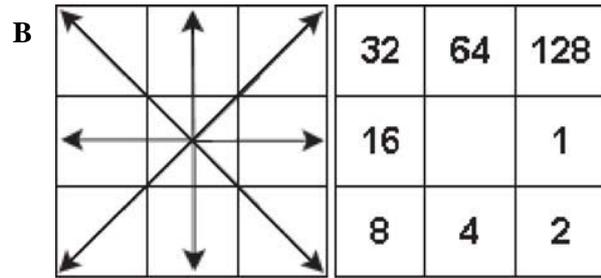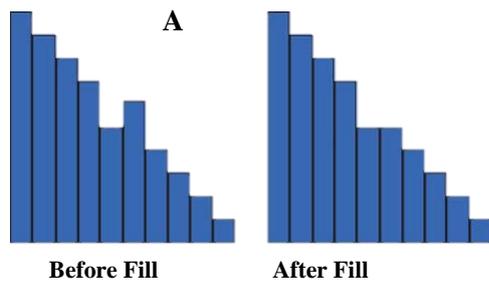
Fig.3 Cross section of an image showing fill (A) and 3X3 cell neighbourhood showing the flow direction (B).

4. RESULTS AND DISCUSSION

The morphometric parameters for Karabayyanahalli sub-watershed were calculated using the parameters shown in Table.1 and analysed basic, derived and shape parameter was showed in the Table.2, Table.3 and Table.4 respectively.

4.1 BASIC PARAMETER

The perimeter (P) is the total length of the drainage basin boundary and Karabayyanahalli sub-watershed shows 40 km for both toposheet and SRTM and 45 km for the Cartosat DEM. The total drainage area (A) of sub-watershed remained the same for all three sources of the data. The length of the basin (L) measured parallel to the main drainage line. The basin length is almost similar for all the three data set and the values are shown in table.2.

4.1.1 STREAM ORDER (Nu)

The designation of stream orders is the first step in drainage basin analysis and is based on a hierarchical ranking of streams. Stream order or classification of streams is a useful indicator of stream size, discharge and drainage area (Strahler, 1957). The number of streams (N) decreases with increase in stream order which shows watershed is a hilly terrain with undulating topography. The sub-watershed shows moderate to steep slope which is clearly depicted by Cartosat DEM and SRTM data. Therefore, the satellite data show a very high variation in I, II and III order streams.

4.1.2 STREAM LENGTH (Lu)

The number of streams of various orders in a sub-watershed was counted and their lengths were measured. The stream length characteristics of the sub-basins confirm Horton's second law (1945) "laws of stream length" which states that the average length of streams of each of the different orders in a drainage basin tends closely to approximate a direct geometric ratio. Karabayyanahalli sub-watershed shows the variation in stream segments of various orders in general observation i.e. stream length is maximum in the First order and decreases with the least at fifth order (Table.2). However, stream length calculated from Cartosat DEM and SRTM DEM shows variation from the general observation. In SRTM data the length of third order stream is less than the length of the fourth order stream and the length of the fifth order is negligible (Fig.4). The fifth order stream show considerable variation between toposheet and Cartosat DEM data. This change may indicate again the morphology of the terrain and the slope accuracy obtained from the Cartosat DEM data. The maximum and minimum height (H and h) corresponds to the highest and lowest points of the basin. The values of length (Lu) and total stream length (Lt), H and h are shown in Table. 2.

Table.1 Morphometric parameters

Morphometric Parameters	Formula	Description	References
Basic parameters Total Stream	$\sum Nu$	Total order number in the basin	Strahler (1964)
Total Stream Length	$\sum Lu$	Total length of each order was computed at basin level	Horton (1945)
Derived parameters Bifurcation Ratio (Rb)	$Rb = Nu / Nu+1$	The ratio between the number of streams of any given order to the number of streams in ratio (Rb)	Horton (1945)
Stream length Ratio (Rl)	$RL = Lu / Lu-1$	The ratio of mean stream length of any given segment to the mean stream length of the next lower order	Sreedevi *et al.* (2005)
RHO Co-efficient	$RHO = Rl/Rb$	The ratio between the stream length ratio and the Bifurcation ratio	Mesa (2006)
Stream frequency (Fs)	$Fs = \sum Nu/A)$	The ratio between total number of streams and area of the basin	Horton (1945)
Drainage density (Dd)	$Dd = \sum Lu/A$	The ratio between the total stream length of all (Dd) orders to the area of the basin	Horton (1945)
Texture ratio (T)	$T = \sum Nu/P$	The ratio between the total number of streams of all orders and perimeter of the basin	Smith (1950)
Basin relief (Bh)	$Bh = H_{max} - H_{min}$	The maximum vertical distance between the lowest and the highest points of a sub-basin	Hadley and Schumm (1961)
Relief ratio (Rr)	$Rr = H/L$	The ratio of maximum vertical distance between the lowest and the highest points of a sub-basin to the basin length	Schumm (1963)
Slope angle (S)	$S = \tan^{-1}\{(H-h)/L\}$	The inverse tangent value for the ratio between the Present maximum vertical distance between the lowest and work the highest points of a sub-basin to the basin length	Ahmed *et al* (2010)
Shape Parameters Elongation ratio (Re)	$Re = 2p((A/\pi/Lb)$	The ratio between the diameter of a circle with the same area as that of the basin and the maximum length of the basin	Schumm (1956)
Circularity index (Rc)	$Rc = 4\pi A/P^2$	The ratio of basin area to the area of a circle having the same perimeter as the basin	Strahler (1964)
Form factor (Ff)	$Ff = A/Lb^2$	The ratio of the basin area to the square of the basin length	Horton (1945)

Source	Basin area in KM₂	Perimeter in KM	Basin Length in KM	Stream order					Total no of Stream order
				I	II	III	IV	V	
Cartosat	65.20	45.32	11.62	302	82	18	5	2	409
SRTM	65.1	40.83	11.15	74	17	5	2	-	99
Toposheet	65.24	40.56	11.48	188	43	10	3	1	245

Table.2 Basic parameters of Karabayyanahalli sub-watershed

Source	Stream Length in KM					Total Length in KM	Elevation in Meter	
	I	II	III	IV	V		Max	Min
Cartosat	102.43	50.80	16.66	11.47	16.34	197.70	1029	601
SRTM	44.92	17.18	9.95	15.44	-	87.58	1126	517
Toposheet	109.85	30.03	18.65	10.56	9.04	178.15	1051	634

Table.2 continued….

Table.3 Derived parameters of Karabayyanahalli sub-watershed

Source	Bifurcation ratio (Rb)				Mean	Stream length ration (RL)			
	I/II	II/III	III/IV	IV/V		II/I	III/II	IV/III	V/IV
Cartosat	3.68	4.55	3.6	2.5	3.58	0.49	0.33	0.69	1.42
SRTM	4.35	3.4	2.5	2	3.06	0.38	0.57	1.55	-
Toposheet	4.37	4.3	3.33	3	3.75	0.27	0.62	0.56	0.85

Table.3 continued….

Source	RHO	Stream frequency	Drainage Density	Texture ratio	Basin Relief	Relief ratio	Slope Angles
Cartosat	0.73	6.27	3.03	9.02	428	0.03	2.1
SRTM	0.47	1.52	1.34	2.42	609	0.05	3.12
Toposheet	0.57	3.75	2.73	6.04	417	0.03	2.08

Table. Shape

Source	Elongation Ratio	Circularity index	Form Factor
Cartosat	0.78	0.39	0.48
SRTM	0.81	0.49	0.52
Toposheet	0.79	0.49	0.49

4

parameters of Karabayyanahalli sub-watershed

4.2 DERIVED PARAMETERS

4.2.1 BIFURCATION RATIO (Rb)

The term 'bifurcation ratio' (Rb) was introduced by Horton (1932) to express the ratio of the number of streams of any given order to the number in the next lower order. According to Strahler (1964), the ratio of number of streams of a given order (Nu) to the number of segments of the next higher order (Nu+1) is termed as the bifurcation ratio. Bifurcation ratio is not the same from one order to its next order. These irregularities are dependent upon the geology and lithology development of the basin (Strahler, 1964). The bifurcation ratio for all the three data is given in Table. 3. The bifurcation ratio values for I and II order streams are higher than the bifurcation ratio of higher order stream which indicate the hilly terrain and active gullies and ravines. In the present case, mean bifurcation ratio (Rbm) varies from 3.06 to 3.75 and sub-watersheds fall under normal basin category (Strahler, 1957).

4.2.2 STREAM LENGTH RATIO (Rl)

Horton's law (1945) of stream length states that mean stream length segments of each of the successive orders of a basin tends to approximate a direct geometric series with streams length increasing towards higher order of streams. Toposheet values show an increasing trend in the length ratio from lower to higher order, whereas in Cartosat DEM and SRTM DEM the values change from one order to another order. Stream length ratio between successive streams order varies due to differences in slope and topographic conditions, and has an important relationship with the surface flow discharge and erosional stage of the basin (Sreedevi *et al*., 2004).

4.2.3 RHO COEFFICIENT (RHO)

It is an important parameter that determines the relationship between the drainage density and the physiographic development of the basin, and allows the evaluation of the storage capacity of the drainage network (Horton, 1945). The RHO of the basin varies from 0.47, 0.57 and 0.73 for SRTM, SOI toposheet, and Cartosat DEM respectively (Table.3).

4.2.4 STREAM FREQUENCY (Fs)

Hypothetically, it is possible to have the basin of same drainage density differing in stream frequency and basins of same stream frequency differing in drainage density. For Karabayyanahalli sub-watershed Cartosat DEM data shows very high stream frequency indicating the basin has moderate relief, high vegetation conditions and high infiltration capacity (Reddy *et al*., 2004). The stream frequency values are shown in Table.3

4.2.5 DRAINAGE DENSITY (Dd)

Drainage density is a measure of the degree of fluvial dissection and is influenced by numerous factors, among which resistance to erosion, infiltration capacity, vegetation cover, surface roughness and run-off intensity index and climatic conditions rank high (Reddy *et al*., 2004). Drainage density indicates the closeness of spacing of channels. According to Nag (1998), low drainage density generally results in the areas of highly resistant or permeable subsoil material, dense vegetation and low relief. High drainage density is the resultant of weak or impermeable subsurface material, sparse vegetation and mountainous relief. In the present study the drainage density is very low in the SRTM data and medium in both the Cartosat DEM and toposheet.

4.2.6 DRAINAGE TEXTURE (T)

The drainage texture (T) is an expression of the relative channel spacing in a fluvial dissected terrain. It depends upon a number of natural factors such as climate, rainfall, vegetation, rock and soil type, infiltration capacity, relief and stage of development of a basin. The value of

drainage texture for the sub basins are shown in Table. 3.

4.2.7 BASIN RELIEF (R)

Basin relief is the difference in elevation between the highest and the lowest point of the basin. The basin relief controls the stream gradient and therefore influences floods patterns and the amount of sediment that can be transported (Hadley and Schumm, 1961).

4.2.8 RELIEF RATIO (Rh)

The relief ratio (Rh) of maximum relief to horizontal distance along the longest dimension of the basin parallel to the principal drainage line is termed as relief ratio (Schumm,1956). There is also a correlation between hydrological characteristics and the relief ratio of a drainage basin. The relief ratio normally increases with decreasing drainage area and size of sub-watersheds of a given drainage basin. The value of relief ratio is given in Table. 3 and ranges from 0.03 (toposheet and Cartosat DEM) to 0.05 (SRTM DEM).

4.2.9 SLOPE ANGLE

Steep slopes generally have high surface run-off values and low infiltration rates. Sediment production thus tends to be high except when largely barren slopes are concerned (Ahmed, 2010). The slope angle

of Karabayyanahalli sub-basin is shown in Table. 3. This value is in relationship with the hilly topography of the basin.

4.3 SHAPE PARAMETERS

4.3.1 ELONGATION RATIO (Re)

Schumm (1956) defined elongation ratio (Re) as the ratio between the diameter of the circle of the same area as the drainage basin and the maximum length of the basin. The values of elongation ratio generally vary from 0.6 to 1.0 over a wide variety of climatic and geologic types. The elongation ratio of study area varies from 0.78 to 0.81 (Table. 4).

4.3.2 CIRCULARITY RATIO (Rc)

It is the ratio of the area of the basin to the area of a circle having the same circumference as the perimeter of the basin (Miller, 1953) is expressed as the ratio of the basin area and the area of a circle with the same perimeter as that of the basin.

4.3.3 FORM FACTOR (Ff)

Horton (1945) proposed this parameter to predict the flow intensity of a basin of a defined area. Form factor varies between 0.48 and 0.49 (Cartosat DEM and toposheet) and 0.52 (SRTM) and thus indicates that the Karabayanahally sub-watershed is more or less elongated in shape with value <0.5 (Table. 4).
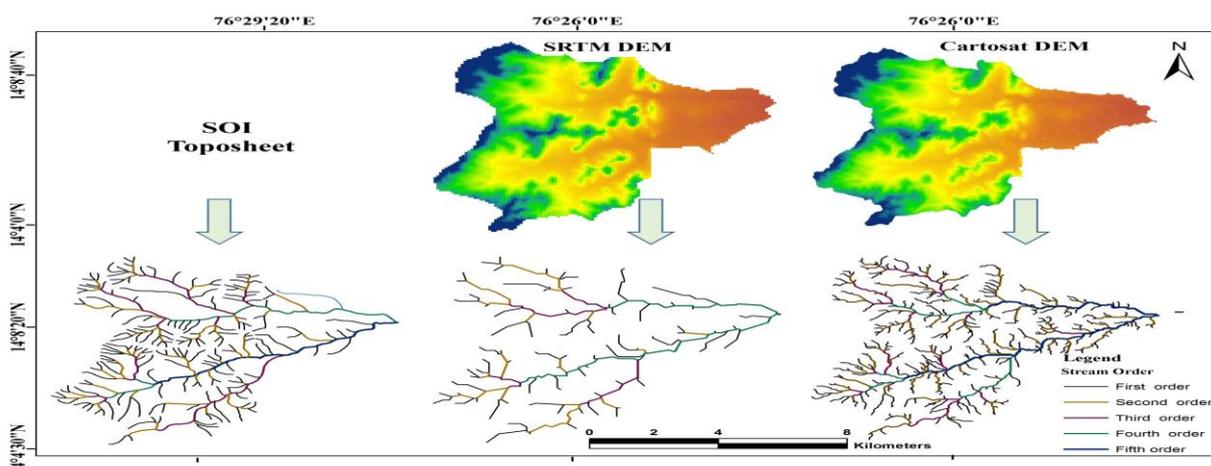
Fig.4 Drainage networks map derived from SOI topographic map, SRTM and Cartosat DEM.

5. CONCLUSION

Delineation of drainage network can be achieved by using traditional methods such as field observations and topographic maps. Systematic analysis of morphometric parameters with in the drainage network using Remote Sensing and GIS can provide significant value in understanding the basin characteristics. The development of stream segments is affected by slope and local relief. Those factors produce differences in values of drainage density among the sub-basins. The physiographic structure of the basin area produces high surface run-off values and low infiltration rates. The high proportion and velocity of the overland flow easily leads to sheet, rill and gully erosion, and a high amount of sediment can be transported. Comparative morphometric study from the Cartosat DEM, SRTM and toposheet data reveals that the high resolution CartoDEM only gives the satisfactory result and useful for the drainage delineation. The coarse resolution SRTM DEM gives poor result compared to high resolution Cartosat DEM and SOI Topographic maps. Efficient results can be obtained by using high resolution satellite data like Cartosat DEM (30 m) which can be used for meso and micro level watershed characterization, proper planning and management of drainage area. The derived parameters are very much essential for the terrain, Geomorphological and Hydrological studies.

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