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Determination of Watershed Morphological Parameters Using Remote Sensing and GIS

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Abstract:
In the present study, an attempt has been made to determine morphological parameters of three sub watersheds falling in Nilgiris district of Tamil Nadu. Remote Sensing (RS) coupled with Geographical Information System (GIS) technique has proved to be an efficient tool in drainage delineation and their updation for morphometric analysis. For detailed study, we used four different DEM sources viz., Toposheet, ASTER, SRTM and Cartosat data for delineating watershed boundary and geographical information system (GIS) was used in evaluation of linear aspects of morphometric parameters. The three delineated sub watersheds were Devarshola, Pykara and Parsons Valley River. The comparison of morphological parameters of the watershed under consideration obtained using different sources viz., SRTM, ASTER and Cartosat DEM with the watershed derived from Survey of India topographical sheet, 1:25,000 scale was done. The use of geospatial technologies for this study, proved effective on comparison with the conservative approach in terms of time taken and output product.

Key words: ASTER, SRTM, CARTOSAT, DEM, Morphometry

1. INTRODUCTION:-

Watershed is a natural hydrological unit which allows surface run off to a defined channel drain, stream or river at particular point. It is the basic unit of water, which evolves over time. Chow (1964) defined watershed as the separating boundary of a drainage basin and termed it as a catchment. Watershed size varies from fractions of hectares to thousands of kilometers. The development of Geographic Information Systems (GIS), digital elevation models (DEM) have been generated throughout the world. DEMs provide good terrain representations and are applied routinely in watershed modeling. DEMs can be used to derive flow networks and then automatically generate watershed boundaries for given outlet points using GIS technology. Therefore, an essential component to watershed delineation is a hydrologically sound DEM of the land area of interest (Julia K. Pryde, 2007). Morphometry is the measurement and mathematical analysis of the configuration of the earth's surface, shape and dimension of its landforms (Clarke, 1966). Drainage analysis based on morphometric parameters is very important for watershed planning since it gives an idea about the basin characteristics in terms of slope. 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 Cartosat spacecraft launched by the Indian Space Research Organization in May 2005 is dedicated to stereo viewing for large-scale mapping and terrain modeling applications. ASTER (Advance Space borne Thermal Emission and Reflection Radiometer) is a high-spatial-resolution, multispectral imaging system flying aboard TERRA, a satellite launched in December 1999 as part of NASA's Earth Observing System (EOS). SRTM (Shuttle Radar Topography Mission) DEM is very similar to the DEM from the digitized contours from the 1: 50,000 topographic maps. In the present study, the spatial datasets namely, Topo DEM extracted from Survey of India Toposheet (1:25.000), Cartosat-30, ASTER-30, along with SRTM-90 have been used to determine the area, linear, and relief morphometric parameters with the help of ArcGIS software for the study area and also an effort has been made to compare morphological parameters of selected watershed delineated from DEM of Toposheet, Cartosat, SRTM and ASTER at the sub-catchment scale.

2. MATERIALS AND METHODS:-

2.1 Study Area

The present study lies in the Nilgiris district of Tamil Nadu state. Nilgiris is one of the important hilly areas in South India and lying in the junction of Eastern and Western Ghats of India. The geographical area of Nilgiris is 2549 Km^2. It is elongated in the east west direction and bounded by 11°30' and 11°15' North latitude and 76°45' and 77°00' East longitude. The elevation ranges from 300 m to 2700 m above mean sea level. Several rivers either flow through the Nilgiris or originate there are Pykara, Moyar, Bhavani, Chaliyar, Kodalundi, Bharathapuzha, Noyil, Kundah, Suvarnathi and Lakshmana tirtha.

2.2 Data Acquisition

The details of collection of DEM data required from different sources and the systems used for their collection are briefly discussed below.

2.3 DEM

A Digital Elevation Model (DEM) can be represented as a raster (a grid of squares, also known as a height map when representing elevation) or as a vector-based triangular irregular network (TIN). DEM provide good terrain representations and DEM can be used to derive flow networks and then automatically generate watershed boundaries for given outlet points using GIS technology. Therefore, an essential component to watershed delineation is a hydrologically sound DEM of the land area of interest. The DEM extracted from 1:25,000 scale Survey of India Toposheet and satellite derived DEM viz., ASTER, SRTM and Cartosat were used in this study (Table 1).

Table.1. Data collected for the study:-

Sl. No	Ancillary Data	Source
1.	Topo DEM	58A11 (NE), 58A11 (NW), 58A11 (SE) and 58 A11 (SW).
2	ASTER DEM	http://www.gdem.aster.ersdac.or.jp
3	SRTM DEM	http://srtm.csi.cgiar.org.
4	CARTOSAT DEM	http://bhuvan.nrsc.gov.in

3. METHODS

Attempts were made to delineate watershed by using ArcGIS 10.2 and calculate morphological parameters with the aid of materials collected. Methods adopted with a view to fulfill the objectives of this investigation are enumerated.

3.1 Delineation of watershed

Watershed boundaries were derived from different DEMs using automated procedures with the Watershed Delineator (written by ESRI and the Texas Natural Resource Conservation Commission), an ArcGIS extension that requires the Spatial Analyst extension to be installed as well. The GIS technique for watershed delineation consists of the following steps. First, the “Fill” tool was used to remove small imperfections in the data and enabled the “Flow Direction” tool (the second step) to run properly and create a grid of flow direction from each cell in the elevation grid to its steepest down slope neighbor. Then, the “Flow Accumulation” tool was used to create a grid of accumulated flow to each cell from all other cells in the flow direction grid. The next step was to identify the watershed outlet grid, ensuring that was located directly over a grid cell from the drainage network. A point shape file was created for indicating the possible pour point of the watershed. The snap pour point tool was used to exactly find the point which has maximum flow accumulation occurred in a specific radial distances. Finally, the “Watershed” tool was used to delineate the watershed for the specified outlet. Boundaries (in grid format) were defined. Using Spatial Analyst, the watershed boundary then vectorized to produce polygons of extracted watershed. The above procedure were repeated for all the DEMs and stored for further analysis and comparison.

3.2 Delineation of streams

The streams were delineated using different DEMs .This process required flow accumulation raster. The basic conceptual process is to reclassify all cells that meet a certain accumulated flow threshold to be 1, and all other cells to be no data. In the present study, threshold value for flow accumulation was taken as 100. A conditional statement was created using raster calculator which showed a threshold value for streams as 100. The streams for the area covered by flow Accumulation grid were obtained.

3.3 Quantitative Morphometry

Morphometric analyses of three selected watersheds were done. The linear, areal and relief aspects of the watersheds extracted from ASTER DEM have been carried out using the standard mathematical formulae and the details are given in the Table 2 Systematic description of the geometry of a drainage basin and its stream channel requires measurement of linear aspects of the channel network and contributing ground slopes.

Table.2. Description of Linear morphological parameters of a watershed

S. No.	Morphological parameters	Formula	References
1	Stream order (U)	Hierarchical rank	Strahler (1964)
2	Stream number (Nu)	No of streams	Horton (1945)
3	Stream length (Lu)	Length of the stream (kilometers	Hortan (1945)
4	Mean stream length (Lsm)	Lsm = Lu/Nu Lu = Total stream length of order u Nu = Total no. of stream segments of order u	Strahler (1964)
5	Length of overland flow (Lg)	Lg = 1/2D ; D = Drainage density	Horton (1945)
6	Bifurcation ratio (Rb)	Rb = Nu/(Nu + 1) Nu = Total no. of stream segments of order u Nu + 1 = Number of segments of the next $(u+1)^{th}$ order	Schumn (1956)
7	Mean bifurcation ratio (Rbm)	Average of bifurcation ratios of all orders	Strahler (1964)
8	Basin length (Lb)	$Lb=1.312\times A^{0.568}$	Nookaratnam (2005)

4. RESULTS AND DISCUSSION

To achieve the goal of the present research, DEM from the Shuttle Radar Topographic Mission (SRTM), Advanced Space borne Thermal Emission and Reflection Radiometer (ASTER), Cartosat and DEM extracted from Survey of India Toposheet was exported to a Geographic Information System (GIS) environment to extract all possible morphological parameters of the catchment in the area. Further, comparison of morphological parameters of sub watersheds in the study area was done.

4.1 Delineation of watershed

Three sub watersheds falling in the Nilgiris district were delineated. The delineated watersheds were Devarshola, Pykara and Parsons Valley River. This exercise was done using four different sources of DEMs viz., ASTER, SRTM, Cartosat and Survey of India Toposheet. Delineated watersheds are shown in Fig.1.The DEM extracted from Toposheet shown in Fig.2.The minimum and maximum elevation of the watershed was found to be 2159m and 2500m respectively.

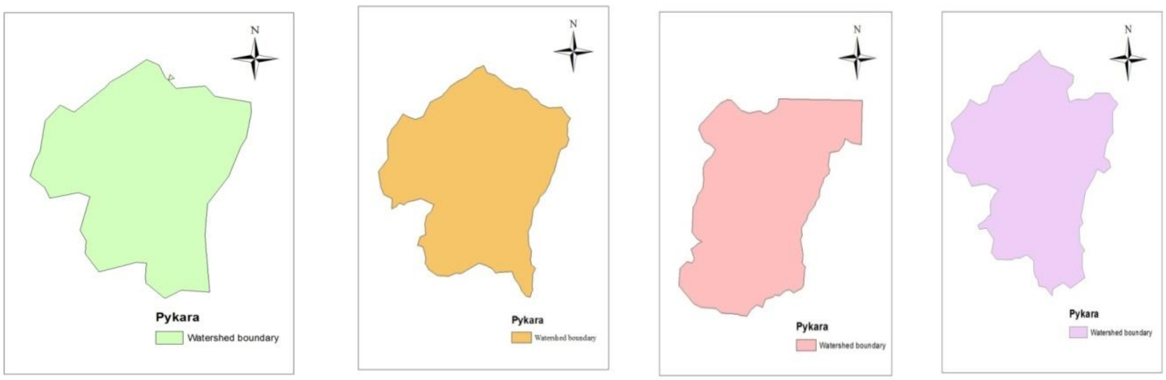


Figure.1. Pykara watershed delineated from SRTM, CARTO, TOPO and ASTER DEM

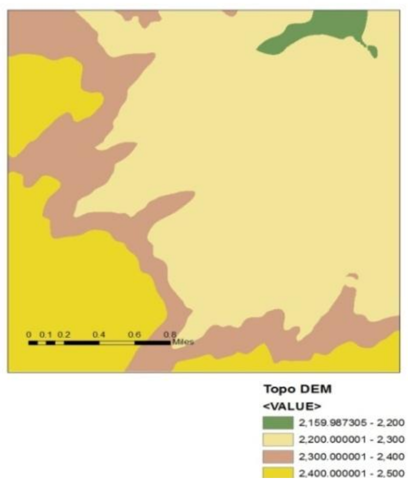


Figure.2. DEM extracted from Toposheet

4.2 Delineation of streams

Stream lines were delineated for Devarshola, Pykara and Parsons Valley from all the four DEM sources viz., Topo, ASTER, SRTM and Cartosat. The streams delineated from ASTER DEM are shown in Fig. 3.

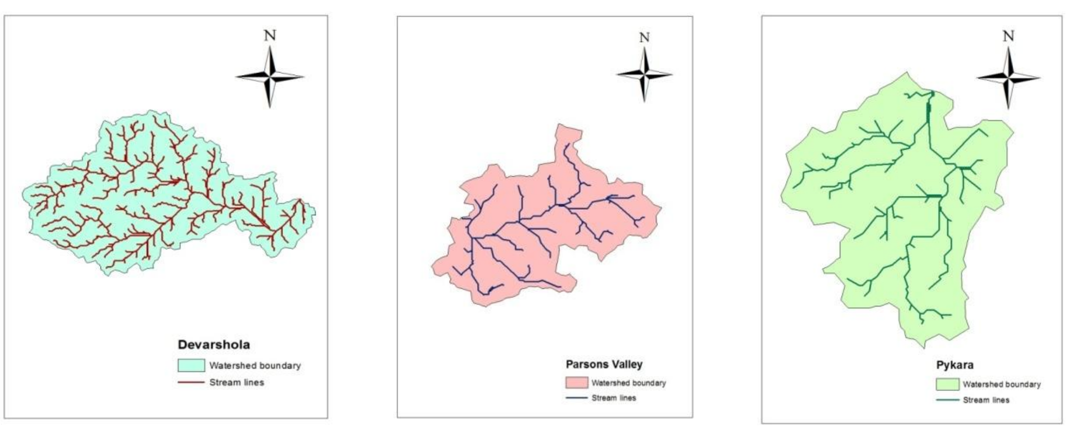


Figure.3. The streams delineated from ASTER DEM

4.3 Morphological parameters of watershed

The study of basin morphometry relates basin and stream network geometries to the transmission of water and sediment through the basin. Systematic description of the geometry of a drainage basin and its stream channel requires measurement of linear aspects of the channel network and contributing ground slopes.

4.3.1 Linear aspects

Linear aspects of the basins are closely linked with the channel patterns of the drainage network wherein the topological characteristics of the stream segments in terms of open links of the network system are analyzed.

4.3.1.1 Stream order: The designation of stream orders is the first step in drainage basin analysis and is based on a hierarchic ranking of streams. In the present study, ranking of streams has been carried out based on the method proposed by Strahler (1964). The order wise stream numbers and stream lengths of the three sub-watersheds are given in Table 5.

The highest stream order among the three sub watersheds is five in Devarshola watershed. While the remaining watersheds namely, Pykara and Parsons Valley showing four and three order respectively (Fig.4).

Higher stream order is associated with greater discharge, and higher velocity (Costa, 1987). Comparatively, Devarshola contributes more to discharge and since higher velocity enhances the erosion rates, therefore, this side also contributes higher sediment loads into the watershed. These results are agreement with the findings of by Althaf (2013).

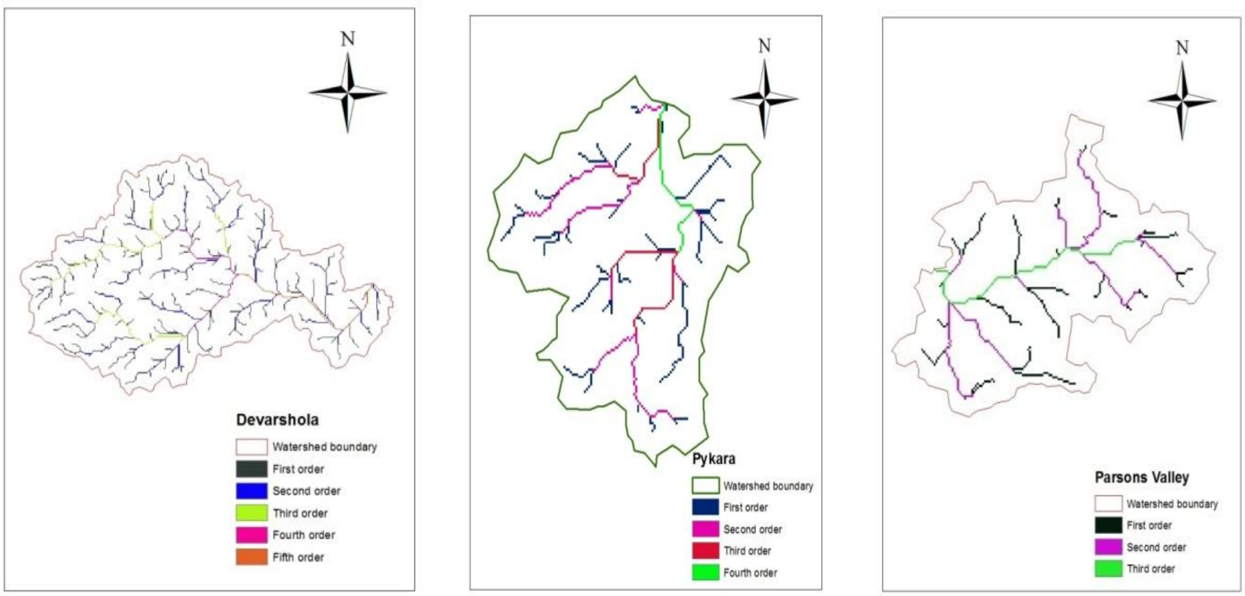


Figure.4. The streams delineated from ASTER DEM

4.3.1.2 Stream number (Nu)

The count of stream channels in a given order is known as stream number (Horton, 1945). Results of the study revealed that Devarshola having more stream number while comparing with other two watersheds, which is showing in the table 5. A higher stream number indicates lesser permeability and infiltration.

Stream number is directly proportional to size of the contributing basin and to channel dimensions. Devarshola and Parsons Valley watersheds show a negative correlation among the stream orders and stream numbers as shown in Fig.5..

It means that the several streams usually decreases in geometric progression as the stream order increases. Observation of the present investigation coincides with the results obtained by Hajam (2013).

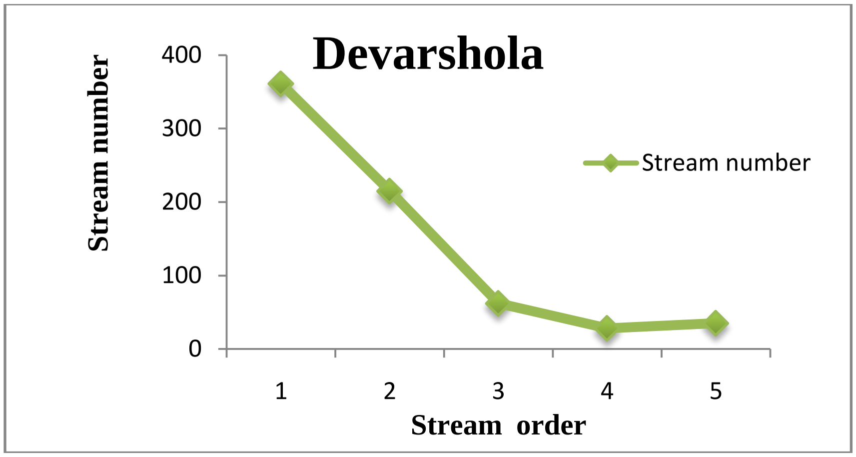
In case of Pykara, some deviations shown in Fig.5. This deviation indicates that the terrain is typified with high relief or moderately steep slopes, underlain by varying lithology and probable uplift across the basin (Singh, 1997).

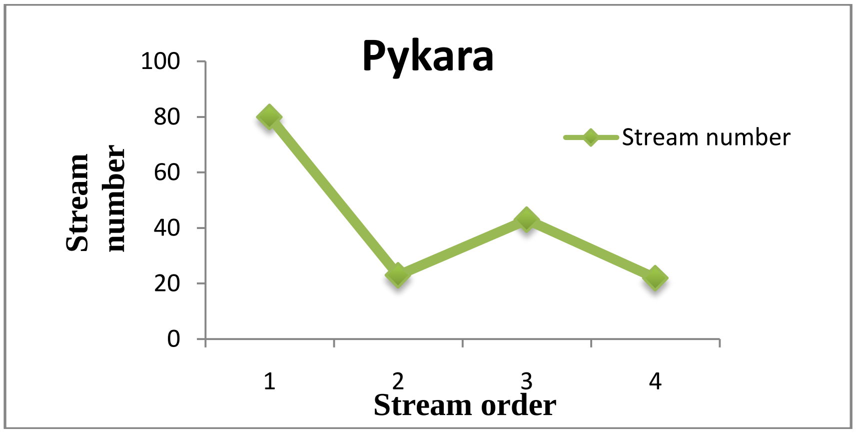
4.3.1.3 Stream length (Lu)

The stream length (Lu) has been computed based on the law proposed by Horton (1945). Stream length is indicative of the contributing area of the basin of a given order. The numbers of streams of various orders in a sub watershed were counted and length measured. Generally, the total length of stream segments decrease with stream order.

Deviation from its general behavior indicate that the terrain is characterized by high relief and or moderately steep slope underlain by varying lithology and probable uplift across the basin (Singh,1997).

In the present study, the selected three watersheds does not show any deviation from the general observation.ie, the stream length decreases with stream order. The above observation was confirmed by the report of Magesh (2012).





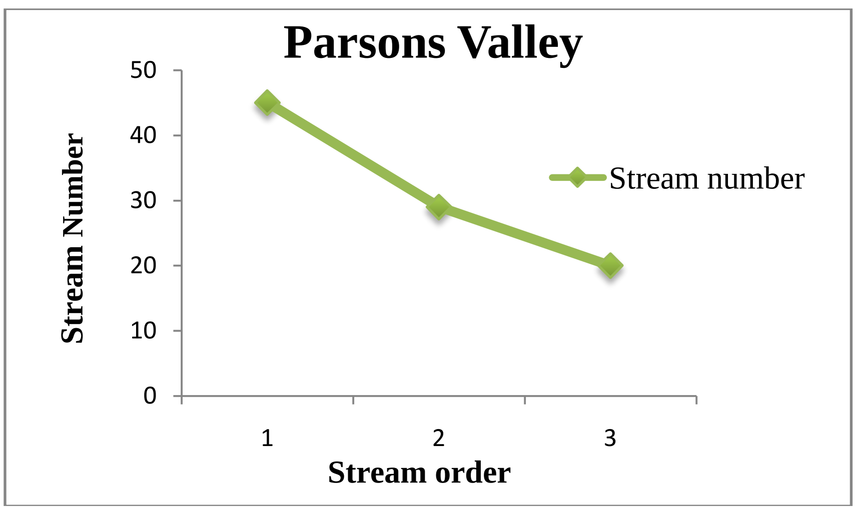


Figure.5.Stream number-stream order relationship

4.3.1.4 Mean stream length (Lsm)

Mean stream length (Lsm) is a characteristic property related to the size of drainage network components and its contributing basin surfaces (Strahler, 1964). This has been calculated by dividing the total stream length of order ‘‘u’’ by the number of streams of segments in the order (Table 5). Generally, Lsm of any given order is greater than that of the lower order and less than that of its next higher order. In the present work, Lsm is always less than one for all selected three sub-watersheds which might be due to variations in slope and topography. Althaf (2013) has also reported the similar results.

4.3.1.5 Stream length ratio (RL): Stream length ratio (RL) is the ratio of the mean length of the one order to the next lower order of the stream segments (Horton 1945). The RL between streams of different order in the study area reveals that there is a different variation trend showing all the three watersheds. This variation might be due to changes in slope and topography, (Table 5). Observation of the present investigation coincides with the results obtained by Althaf (2013).

4.3.1.6 Bifurcation ratio (Rb): Bifurcation ratio (Rb) may be defined as the ratio of the number of stream segments of given order to the number of segments of the next higher order (Schumm 1956). Horton (1945) considered the bifurcation ratio as an index of relief and dissections. Strahler (1957) demonstrated that the bifurcation ratio shows a small range of variation for different regions or different environmental conditions, except where the geology dominates. From the Table 5, it seem that the bifurcation ratio values for Devarshola, Pykara and Parsons Valley vary from 0.8 to 3.4, 0.5 to 3.4 and 1.4 to 1.5 respectively, because of possibility of variations in basin geometry and lithology. It is observed that Rb is not the same from one order to its next order. These irregularities depend upon the geological and lithological development of the drainage basin. The lower values of Rb are characteristics of the sub-watersheds which have suffered less structural disturbances (Strahler, 1964) and the drainage patterns has not been distorted because of the structural disturbances (Nag, 1998). Similar results have been reported by Hajam(2013)and Althaf (2013). The mean bifurcation ratios of Devar shola, Pykara and Parsons Valley reservoir watersheds are respectively 1.63, 1.49 and 1 which indicates that these watersheds are not affected by structural disturbances (Table 5).

4.3.1.7 Length of overland flow (Lg): Length of overland flow is one of the most important independent variables affecting both hydrologic and physiographic development of drainage basins (Horton, 1932). Overland flow is significantly affected by infiltration/percolation through the soil that varies in time and space (Schmid, 1997; Kanth and Hassan, 2012). This factor basically relates inversely to the average slope of the channel and is quite synonymous with the length of sheet flow to a large degree. The length of overland flow (Lg) approximately equals to half of the reciprocal of drainage density (Horton, 1945). The present work revealed that the Lg is less in all the three sub-watersheds. The computed value of Lg for all the three sub-watersheds varies from 0.21 to 0.23.This results are agreement with the findings of Aravinda (2013).

Table .3. Linear morphometric parameters of the three sub watersheds

Watershed name	Stream order	Stream number	Length of stream	Mean stream length	Stream length ratio	Bifuration ratio	Mean bifurcation ratio	Length of overland flow
Devar shola	1	361	66.1	0.18	0.58	1.679		0.21
	2	215	38.5	0.17	0.34	3.467		
	3	62	13.2	0.21	0.53	2.214	1.63	
	4	28	7.1	0.25	0.92	0.8		
	5	35	6.6	0.18	-	-		
Pyakara	1	80	12.5	0.15	1.92	3.478		0.21
	2	23	6.9	0.30	0.34	0.534	1.49	
	3	43	4.4	0.10	1.07	1.954		
	4	22	2.4	0.11	-	-		
Parsons Valley reservoir	1	45	10.5	0.23	0.86	1.551		0.23
	2	29	9.1	0.31	0.49	1.45	1.00	
	3	20	4.5	0.22	-	-		

5. CONCLUSION

The purpose of the present study is collecting, comparing, processing and analysing the DEM data in a GIS environment for delineation of watershed boundary and determination of morphological parameters of selected sub watersheds in Nilgiris district, Tamil Nadu. For the analysis, the DEM extracted from 1:25,000 scale Survey of India (SOI) toposheet and satellite derived DEM viz., ASTER, SRTM and CARTOSAT were used. ASTER, SRTM and Cartosat are collected from http://www.gdem.aster.er sdac.or.jp. Morphometric analysis relating to linear aspects of the selected watersheds has been carried out using the standard mathematical formulae in three sub watersheds from three different DEMs. Linear aspects of the basins are closely linked with the channel patterns of the drainage network wherein the topological characteristics of the stream segments in terms of open links of the network system are analyzed. The designation of stream orders is the first step in drainage basin analysis, the highest stream order among the three sub watersheds is five in Devarshola watershed. While the remaining sub watersheds namely, Pykara and Parsons Valley showing four and three order respectively. The numbers of streams of various orders in a sub watershed were counted and length measured. The selected three sub watersheds does not show any deviation from the general observation.ie, the stream length decreases with stream order. The stream length ratio between streams of different order in the study area reveals that there is a different variation trend showing all the three watersheds. This variation might be due to changes in slope and topography. The lower values of bifurcation ratio shown the watersheds which have suffered less structural disturbances and the drainage patterns has not been distorted because of the structural disturbances.

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