



Comparison of Open Source DEM's for Morphometric Analysis of Micro Watersheds: A Case Study from the Midlands of Kerala

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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ABSTRACT

Morphometric analysis with the help of remote sensing and GIS is now widely used to prioritise micro watersheds for planning interventions for soil and water conservation. DEM is the main digital data used to perform the morphometric analysis. There are different types of DEMs available to perform morphometric analysis using GIS techniques. But, no authentic information is available on the degree of accuracy levels of these DEMs to quantitatively determine various morphometric parameters for the watersheds in Kerala, with typical undulating and sloping terrain features. Hence, this research has been initiated to evaluate the quality of three popular DEMs viz. SRTM(Shuttle Radar Topography Mission), CARTOSAT(Cartography and satellite) and ASTER(Advanced spaceborne thermal emission and reflection Radiometer), each with 30 m spatial resolution. Two small sub watershed of Bharathapuzha river basin have been chosen for the study which are lying near to Valanchery town in Malappuram district. More than 21 morphometric parameters including drainage network, basin geometry, basin texture and basin relief characteristics were computed using these three types of DEMs and the outputs compared with google earth map. The results shows that the SRTM 30m DEM is characterized by higher accuracy compared to CARTOSAT and ASTER and has got better matching with google earth map data sources.

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1. INTRODUCTION

DEMs are very widely used to study and quantify the physical features and hydrologic behaviour (responses) of the watersheds. At the same time, they are available from different sources such as SRTM, ASTER, and CARTOSAT, to name a few. So, there is an important question to be addressed regarding the accuracy of these open source datasets which are acquired from different data sources. This study envisages to evaluate the accuracy levels of deals with three types of most commonly used DEMs viz., SRTM, CARTOSAT and ASTER, all of them with 30 m resolution.

Watershed based planning is very important for management and sustainable development of natural resources. Watershed is an area contributing water to a common outlet. Drainage characteristics of the watershed need to be understood on micro watershed scale and the same can be done through morphometric analysis. Morphometric analysis of a watershed provides a quantitative description of the land form, drainage system, and relief all of which are important parameters for the characterisation of watersheds [1]. It is also an important indicator of the hydrologic processes for characterization of watershed [2]. Proper planning and management of watershed is very necessary for sustainable development of all life forms. Geomorphological analysis of a watershed is also used for evolving the regional hydrological models for resolving different hydrological uncertainties of the ungauged watersheds in the absence of data accessibility conditions [3]. Morphometric parameters mainly depends upon relief, lithology, bedrock and geological conditions. Hence, the information of geomorphology, hydrology, geology and land use pattern is highly informative for reliable study of drainage pattern of the watershed [4].

Morphometric analysis is the measurement of three dimensional geometry of landforms and has traditionally been applied to watersheds, drainage channels, hill slopes, and other group of terrain features [5]. In traditional methods, it is difficult to examine all drainage networks from field observations due to their area extent through rough terrains. In the past, drainage characteristics of many river basins and sub basins in different parts of the globe have been studied using conventional methods [6]. A

number of researchers have reported that using remote sensing and GIS a detailed and updated information of drainage basin can be generated in a systematic way [7,8,9]. The most important digital data for geomorphological analysis is the DEM which is a remote sensing product. There are different kinds of DEMs available in the world depending upon the sensors used in capturing the images of the earth surfaces, spatial resolution of the grids of the DEM etc.

Recently, morphometric analysis using GIS and remote sensing techniques have emerged as a powerful and promising method. Determination of morphometric parameters necessitates the analysis of various drainage parameters such as ordering of the various streams, measurement of basin area and perimeter, length of drainage channels, drainage density, stream frequency, bifurcation ratio, basin relief and Ruggedness number. Different sources of DEMs are available for morphometric analysis, however, very little knowledge is available on their reliability and accuracy. Hence, it is important that different DEMs need to be evaluated to assess their suitability for geomorphologic analysis. In this context, this study has been carried out to evaluate different DEM sources for their effectiveness in carrying out morphometric analysis of watersheds in Kerala context.

2. MATERIALS AND METHODS

2.1 Description of Study Area

Two small sub watersheds of the Bharthapuzha river basin which are located near to Valanchery town of Malappuram District, Kerala State was taken for the study and they are nomenclatured as W1 and W2. The first sub watershed (W1) geographically lies between 10°51' North latitude, 76°02' East longitude and 10°56' North latitude, 76°04' East longitude. The second sub-watershed (W2) lies between 10°54' North latitude, 76°04' East longitude and 10°56' North latitude, 76°06' East longitude. Using the available three DEMs, viz., SRTM, CARTOSAT and ASTER watershed boundary and stream channels are extracted and then used to calculate morphometric parameters. These calculated parameters for each data source are then compared with those of other data sources to determine the most accurate DEM for the study. The watersheds W1 and W2 lies between 11 to 164 m and 23 to 140 m above mean sea level

respectively. The main streams are flowing from the North to South of the watersheds and plays an important role in social and economic scenario of the locality.

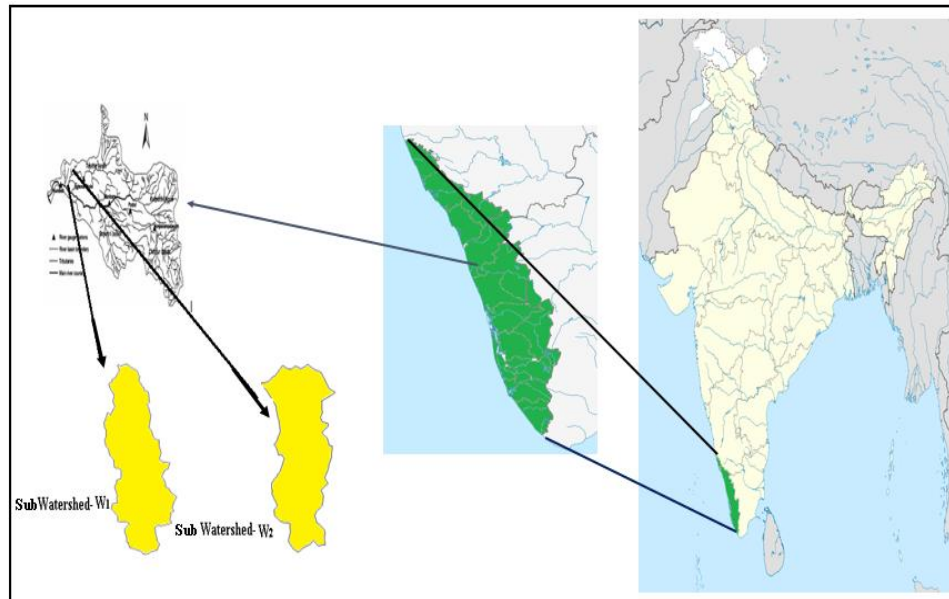


Fig. 1. Location Map of Study Area

Table 1. Equations adopted for estimating the morphometric analysis

Sl. No.	Morphometric Parameter	Equations	Reference
1	Bifurcation ratio (Rb)	$R_b = \frac{N_u}{N_{u+1}}$ Nu = Number of streams of the given order Nu+1 = Number of streams of the next higher order	Schumn (1956)
2	Stream frequency (Sf)	$S_f = \frac{N_u}{A}$ Nu = Number of streams of order u A = Area of basin km ²	Horton [13]
3	Form factor (Rf)	$R_f = \frac{A}{L_b^2}$ A = Area of watershed, km ² L _b = Length of basin, km	Horton [14]
4	Elongation ratio (RL)	$R_L = \left(\frac{1}{L_b}\right) \sqrt{\frac{A}{\pi}}$ L _b = Main channel length A = Area of the basin	Schumn (1956)
5	Shape factor (S)	$S = \frac{L^2}{A}$ S= Shape factor in km A= Area of the basin km ²	Horton [14]
6	Circulatory ratio (Rf)	$R_f = \frac{4\pi A}{P^2}$ A= Area of basian km ² P= Perimeter of basin km	Miller [15]
7	Elliptical Index (Ei)	$E_i = \frac{\pi L^2}{4A}$ L= Length of Basin A = Area of watershed, km ²	

Sl. No.	Morphometric Parameter	Equations	Reference
8	Drainage Density (Dd)	$D_d = \frac{N_1}{A}$ N ₁ = Length of streams of all orders A= Area of the basin	Horton [14]
9	Drainage texture (Dt)	$D_t = \frac{N_u}{P}$ N _u = Number order of stream u P = Perimeter of basin in km	Horton [14]
10	Infiltration number (In)	$I_n = D_d * S_f$ D _d =Drainage density S _f =Stream frequency	Faniran [16]
11	Length of overland flow (Lf)	$L_f = \frac{0.5}{D_d}$ L _f = Length of overland flow D _d = Drainage density	Horton [13]
12	Constant of channel maintenance (Cc)	$C_c = \frac{1}{D_d}$ C _c = Constant channel maintenance D _d = Drainage density	Schumn (1956)
13	Basin relief (Rb)	$R_b = E_{max} - E_{min}$ E _{max} = Maximum elevation, E _{min} = Minimum elevation	Strahler [1],
14	Relief ratio (Rr)	$R_r = \frac{R_b}{L}$ R _b = Basin relief L= Channel length in km	Schumn (1956)
16	Ruggedness number (Rn)	$R_n = R_b * D_d$ R _b = Basin relief D _d = Drainage density	Melton [17]
17	Hypsometric Intergral (E)	$E \approx HI_{si} = \frac{Elev_{mean} - Elev_{min}}{Elev_{max} - Elev_{min}}$ Elev _{mean} is the mean elevation, Elev _{max} is the maximum elevation and Elev _{min} is the minimum elevation	Pike and Wilson [18]

Table 2. Indication of stream frequency and ruggedness number value

Stream frequency	Number of streams per (km ²)	Ruggedness Number	Prone to soil erosion
Low	0-5	<0.18	Less
Moderate	5-10	0.18-0.36	Moderately low
Moderate high	10-15	0.36-0.54	Moderate
high	15-20	0.54-0.79	Moderately high
Very high	20-25	>0.79	High

Table 3. Indication of drainage density and drainage texture value

Drainage density	Explanation	Drainage texture	Significant
<1	Less	<2	Very coarse
1-2	Moderate	2-4	Coarse
2-3	High	4-6	Moderate
3-4	Very high	6-8	Fine
		>8	Very fine

Table 4. Indication of form factor value

Form factor	Shape	Nature of flow
0	Highly elongated	Low peak for longer duration
0-0.6	Slightly elongated	Flatted peak flow for longer duration
0.6-0.8	Perfectly circular	Moderate to high peak flow for short duration
0.8-1.0	Circular	High peak flow for short duration

2.2 Source of Data Collection and Analysis

- 1) SRTM DEM of 30 m resolution: SRTM DEM which is freely downloadable form the url <https://earthexplorer.usgs.gov> is used in the study. It is freely available since the US government stated on Sep 23, 2014 in a UN summit that the NASA’s shuttle radar topography mission (SRTM) 1arc-second resolution topographic data will be made available freely for public use.
- 2) CARTOSATDEM of 30 m resolution: It is an Indian satellite which was launched May 5, 2005, by Indian space research organization (ISRO). CARTOSAT-1 satellite consists of a panchromatic camera which gives a long track of stereo, with a tilt in flight direction of ± 26° and ± 5°. CARTOSAT spacecraft gives the stereo images which can be used in different applications like largescale mapping and terrain modelling. It has a coverage of 1arc degree. It can befreely downloaded from <https://bhuvan.nrsc.gov.in>.
- 3) ASTER DEM of 30 m resolution: In June 2009, the data of advanced spaceborne thermal emission and reflection radiometer, global digital elevation model (ASTER GDEM) was made accessible by NASA for research and academic use (USGS and Japanese ASTER Program 2003). It was downloaded from the url <https://earthexplorer.usgs.gov/>

For both the sub watersheds W1 and W2the boundary delineation, and generation of stream features and respective spatial computations were done by using Arc GIS 10.4. version software and Microsoft excel was also used for derivation of some primary and derived morphometric parameters by using basic attributes computed from spatial data.

The parameters computed in the present study using GIS techniques includes drainage texture, relief characteristics, drainage network and basin geometry. The input parameters for the present study such as area, perimeter, elevation, stream

length etc. were obtained from digitized coverage of drainage network map in GIS environment. The morphometric parameters were computed using the standard equations presented in Table 1.

3. RESULTS AND DISCUSSION

3.1 Area, Perimeter and Length of Basin

The quantitative linear, shape and relief morphometric parameters of the watersheds were extracted from different DEMs. The sub watersheds W1 and W2 were having an area of 15.13 & 4.61 km², perimeter21.71 & 12.14 km, length of basin 8.82 &3.61 km respectively when the SRTM DEM was used. The corresponding values were15.06 & 4.80 km² for area,22.27& 14.75 km for perimeter, and length of basin 6.74&3.65km for CARTOSAT DEM. In the case of ASTER DEM also the values were close to that of SRTM and CARTOSAT as shown in Table 6.

3.2 Stream Order and Stream Lengths

Table 5 shows the comparison of number of streams numbers and stream lengths respectively, derived from different DEMs. It shows that the longest stream lengths and maximum number of streams was obtained from SRTM followed by CARTOSATDEMs which means that the finer the resolution, the more stream counts will be found. Moreover, the SRTM gave the 4th order stream in both watershed W1and W2, CARTOSAT gave the fourth order stream in only W1 watershed and third order stream generated in W2 watershed. The ASTER DEM gave the 3rd order stream in both W1 and W2 watersheds. From the result, it appears that SRTM DEM is producing more streams and stream orders.

3.3 Bifurcation Ratio (R_b)

Bifurcation ratio is a function of geological structure and permeability of the surface strata [17,18]. The bifurcation ratio between the first

and second order streams obtained from all DEMs values ranges between 4 and 6, indicating that the streams formed in similar rock with minimal or no influence of geological structures. Variation in the number of streams on account of variations in DEM used have been reflected in bifurcation ratio also.

3.4 Relief Parameters

Different relief parameters viz., basin relief, relative relief and relief ratio have been determined and presented in table 6 and provides an estimate of the overall steepness of the basin [12]. It can be taken as a measure of the intensity of erosion process. The relief ratios generated from different DEMs shows variations in both of the watershed W1 and W2 (Table. 6)

3.5 Ruggedness Number (R_n)

It is a nondimensional parameter obtained as the product of drainage density and relative relief. R_n captures slope steepness and length and represents the structural complexity of the terrain [1]. High values of R_n would occur when both variables, relative relief and drainage density are large and for such basins, the slopes are not only steep but are also long. Basins with high R_n values are susceptible to an increased peak discharge and therefore, highly susceptible to erosion. Among the sub watersheds under considerations, the ruggedness number is having moderate values as resulted by all DEMs.

3.6 Elongation Ratio

The elongation ratio values vary between 0.6 and 1 depending on the morphology of the Watershed. For the study watersheds W1 and W2 the elongation ratios varied between 0.32 to 0.36 which indicates that both of the watershed are elongated in shapes. R_e values resulting from different DEMs shows close comparison.

3.7 Stream Frequency (F_s)

According to Horton [11], it is the total number of streams of all orders per unit area of the catchment. Stream frequency is directly related to runoff and degree of dissection and inversely related to infiltration and mean annual rainfall [19]. Generally, the sub watersheds showed high

stream frequency variation between different DEMs used. In the case of W1, the stream frequency was more close to each other. But, wider variation was seen in the case of W2.

3.8 Drainage Density (D_d)

Drainage density is having direct relationship with rock resistivity, mean annual rainfall, rainfall intensity, an inverse relationship with infiltration capacity and vegetation cover [19,20]. The lower values of D_d suggest permeable subsoil material or high resistant, low relief and dense vegetation. On the other hand, higher values of D_d correspond to catchment having a more significant number of streams and thus result in rapid stream response. The results from the study showed that all the DEMs gave high drainage density. Variations in drainage density with respect to different sources of DEM were less.

3.9 Drainage Texture (T)

Infiltration capacity can be recognized as the single critical factor which influences drainage texture and considered drainage texture to comprise both drainage density and stream frequency [11]. Drainage texture depends on several physical factors such as rainfall, climate, soil type, vegetation, relief, infiltration capacity, and stage of development of the basin. From the values for drainage texture presented in Table 6, it shows that the SRTM DEM has high drainage texture for both of the watersheds. When CARTOSAT DEM is used W1 shows the fine drainage texture and W2 shows the coarse drainage texture. In the case of ASTER DEM W1 and W2 shows the moderate drainage texture.

3.10 Form Factor

The form factor is one of the critical parameters which represents the shape of the catchment area. Higher form factor values leads to a peak flow with shorter duration, whereas the basins with lower form factor have an elongated shape, and lower peaks flow for longer durations. In this study, form factor values are seen in between 0.32 – 0.42 for both of the watersheds. Variation in form factors between the DEMs were not very significant.

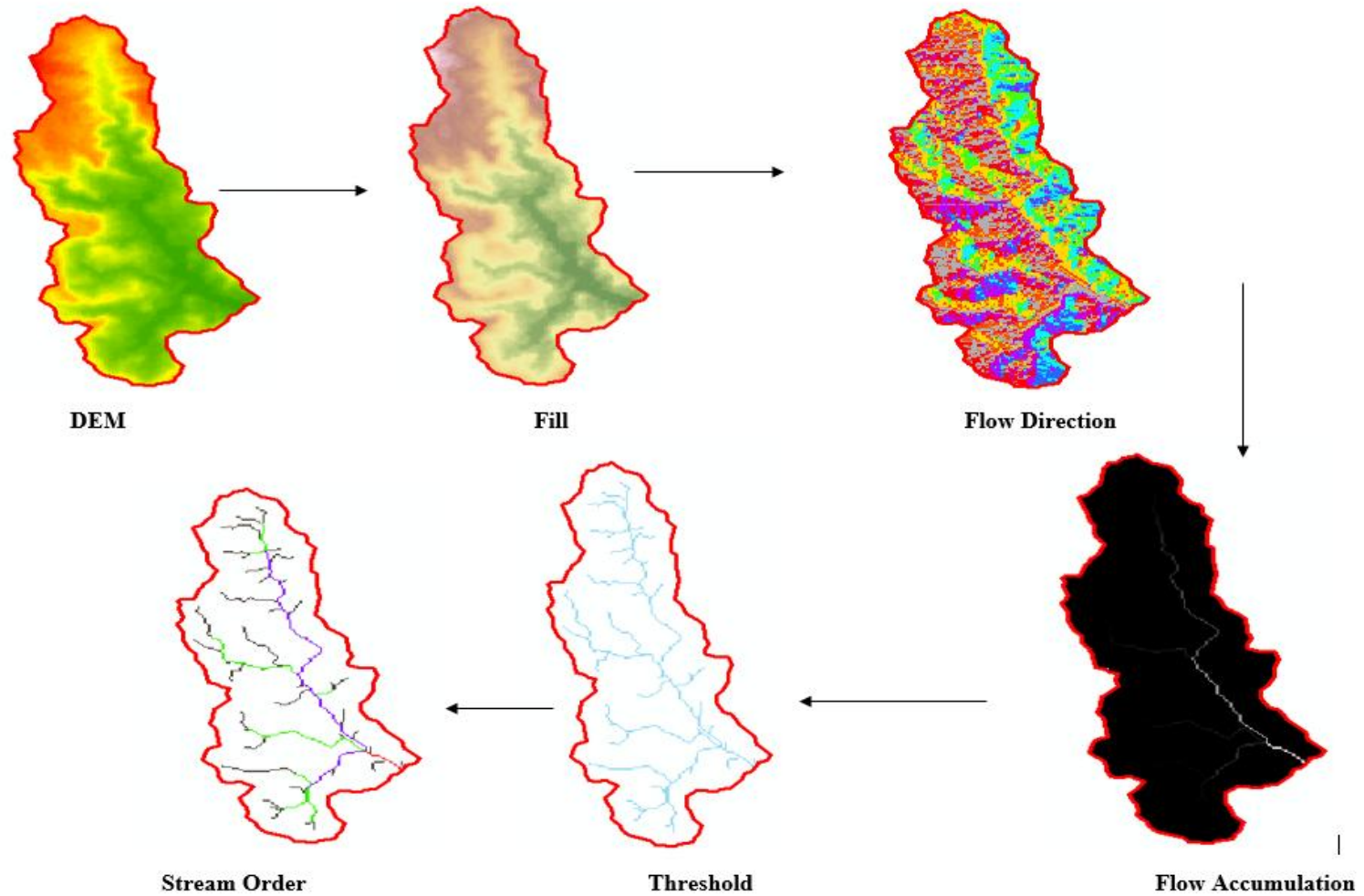


Fig. 2. Procedure for getting stream order from the different open source DEMs for a sub watershed

Table 5. Linear parameters of W1 and W2subwatershedsusing different DEMs

Watershed	Stream order	No. of Stream Order	SRTM 30m		CARTOSAT 30 m			ASTER 30 m		
			Total stream Length(km)	Bifurcation Ration	No. of Stream Order	Total stream Length(km)	Bifurcation Ration	No. of Stream Order	Total stream Length(km)	Bifurcation Ration
W1	1	73	14.99	-	85	15.53	-	88	16.28	-
	2	61	7.75	1.19	37	7.41	2.29	44	9.53	2
	3	25	6.96	2.44	19	7.04	1.94	1	6.65	44
	4	1	0.66	25	1	0.96	19	-	-	-
	Total	160	30.36	-	142	30.94	-	133	32.46	-
W2	1	47	5.35	-	24	5.18	-	41	7.89	-
	2	30	3.19	1.56	19	3.02	1.26	39	3	1.05
	3	13	1.79	2.30	1	1.28	19	1	3.04	39
	4	1	1.23	13	-	-	-	-	-	-
	Total	78	10.33	-	44	9.48	-	81	13.93	-

Table 6. Morphometric analysis of W1 and W2sub watersheds using different DEMs

Sl. No.	Morphometric characteristics	SRTM 30m		CARTOSAT 30 m		ASTER 30 m	
		W1	W2	W1	W2	W1	W2
1	Area (km ²)	15.13	4.61	15.06	4.80	15.73	5.51
2	Perimeter (km)	21.71	12.14	22.27	14.75	23.86	13.8
3	Length of basin (km)	6.82	3.61	6.74	3.65	7.73	3.58
4	Bifurcation ratio	9.54	5.62	7.74	10.13	23	20.02
5	Stream frequency (km ⁻²)	10.57	19.73	9.42	9.16	8.45	14.70
6	Form factor (km ² /km)	0.32	0.35	0.33	0.36	0.31	0.42
7	Elongation ratio (km ² /km)	0.32	0.33	0.32	0.33	0.31	0.36
8	Shape factor (Km/km ²)	3.07	2.82	3.01	2.77	3.14	2.32
9	Circulatory ratio (Km ² /km)	0.40	0.39	0.37	0.27	0.34	0.36
10	Elliptical Index	2.41	2.22	2.36	2.18	2.46	1.82
11	Compactness coefficient	1.57	1.59	1.62	1.89	1.69	1.65
12	Drainage Density (km/km ²)	2.006	2.50	2.05	1.95	2.06	2.52
13	Drainage texture	7.36	7.49	6.34	2.98	5.57	5.86
14	Infiltration number	21.21	49.49	19.37	18.10	17.44	37.16
15	Length of overland flow (km)	0.24	0.19	0.24	0.25	0.24	0.19
16	Constant of channel maintenance	0.49	0.39	0.48	0.50	0.48	0.39
17	Stream Slope (%)	2.24	3.24	2.27	3.20	2.21	3.04
18	Basin relief (km)	0.15	0.11	0.15	0.11	0.15	0.10
19	Relative relief	0.70	0.96	0.68	0.79	0.65	0.78
20	Relief ratio	0.022	0.032	0.022	0.032	0.021	0.030
21	Ruggedness number	0.30	0.29	0.31	0.23	0.32	0.275
22	Hypsometric Integral	0.49	0.495	0.46	0.47	0.496	0.50

Table 7. Stream length ratios of sub watershed W1 and W2 using Different DEMs

Watershed	Stream order	SRTM 30m		CARTOSAT 30 m		ASTER 30 m	
		Mean stream length	Stream length ratio (L_u)	Mean stream length	Stream length ratio (L_u)	Mean stream length	Stream length ratio (L_u)
W1	1	0.21	-	0.18	-	0.19	-
	2	0.13	0.62	0.20	1.09	0.22	1.17
	3	0.28	2.19	0.37	1.85	6.65	30.70
	4	0.66	2.37	0.96	2.59	-	-
	1	0.11	-	0.22	-	0.19	-
W2	2	0.11	0.93	0.16	0.74	0.08	2.50
	3	0.14	16.83	1.28	8.05	3.04	0.025
	4	1.23	8.93	-	-	-	-

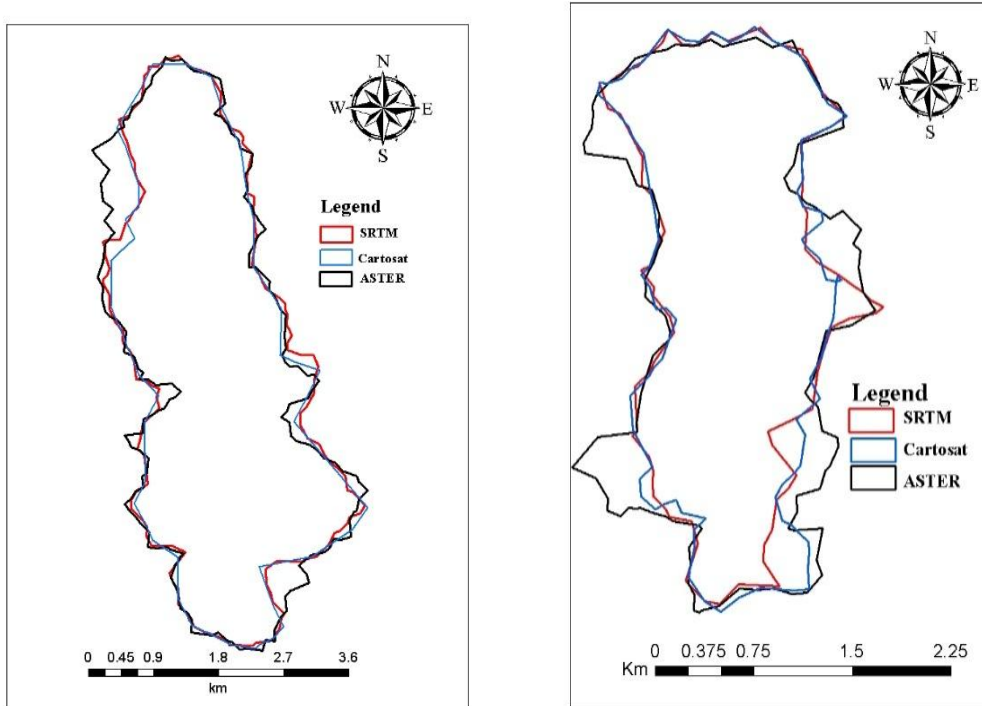


Fig. 3. Watershed boundary delineated using different sources of DEM

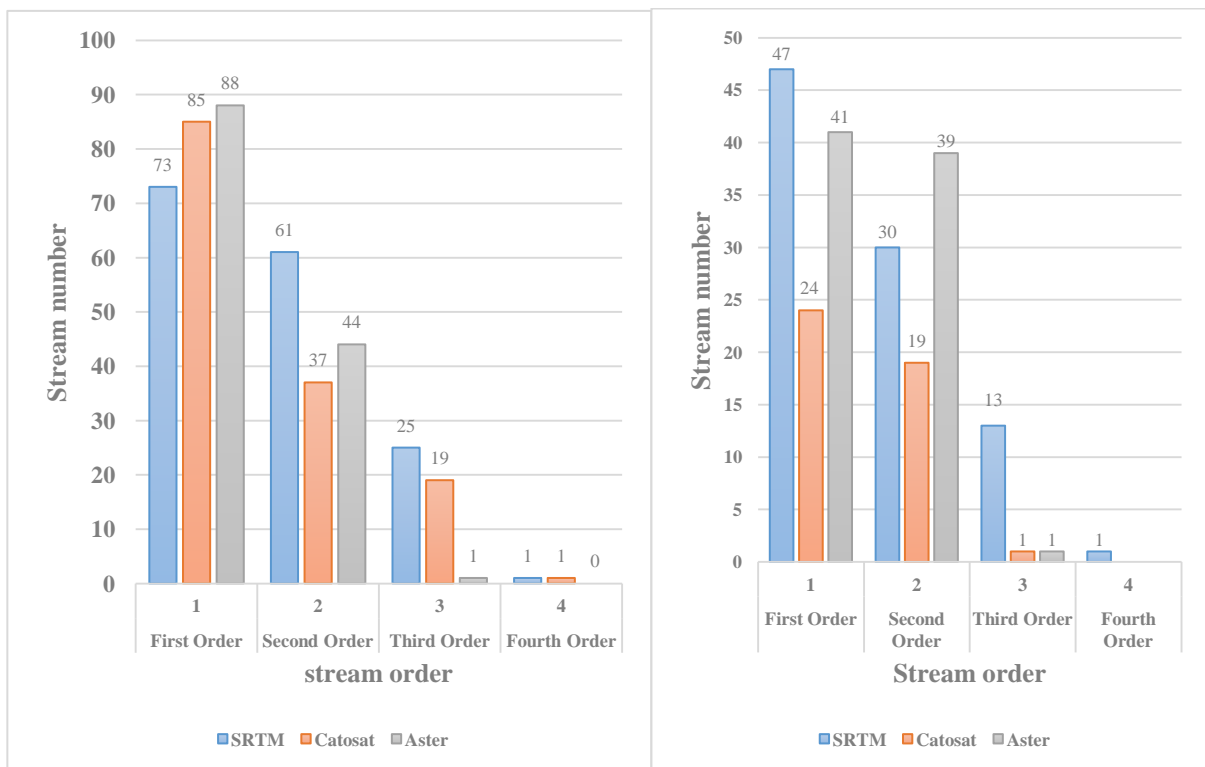


Fig. 4. Comparison of stream numbers and stream order for sub watersheds W1 and W2 for different DEMs

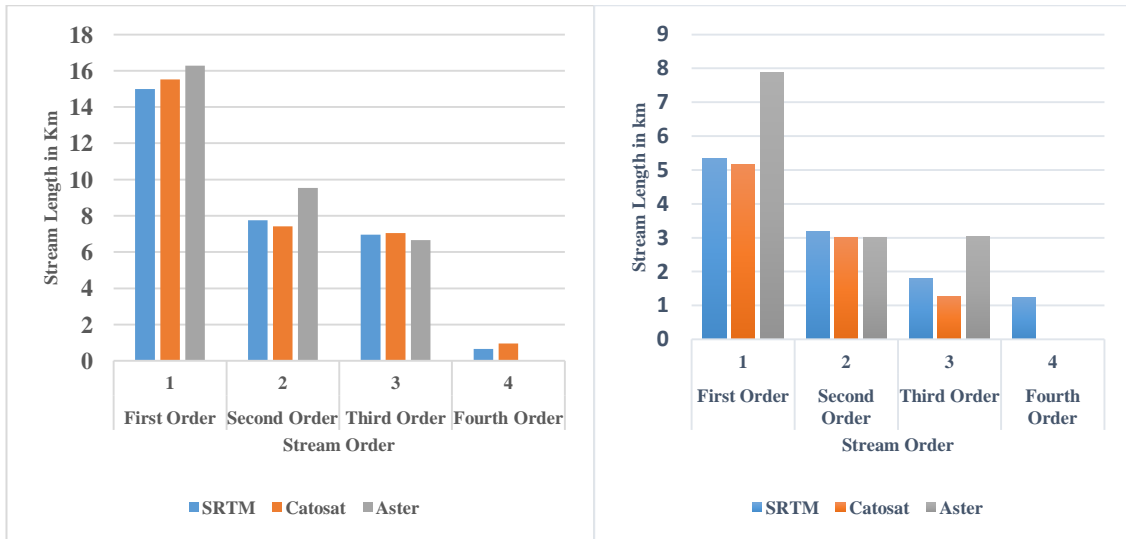
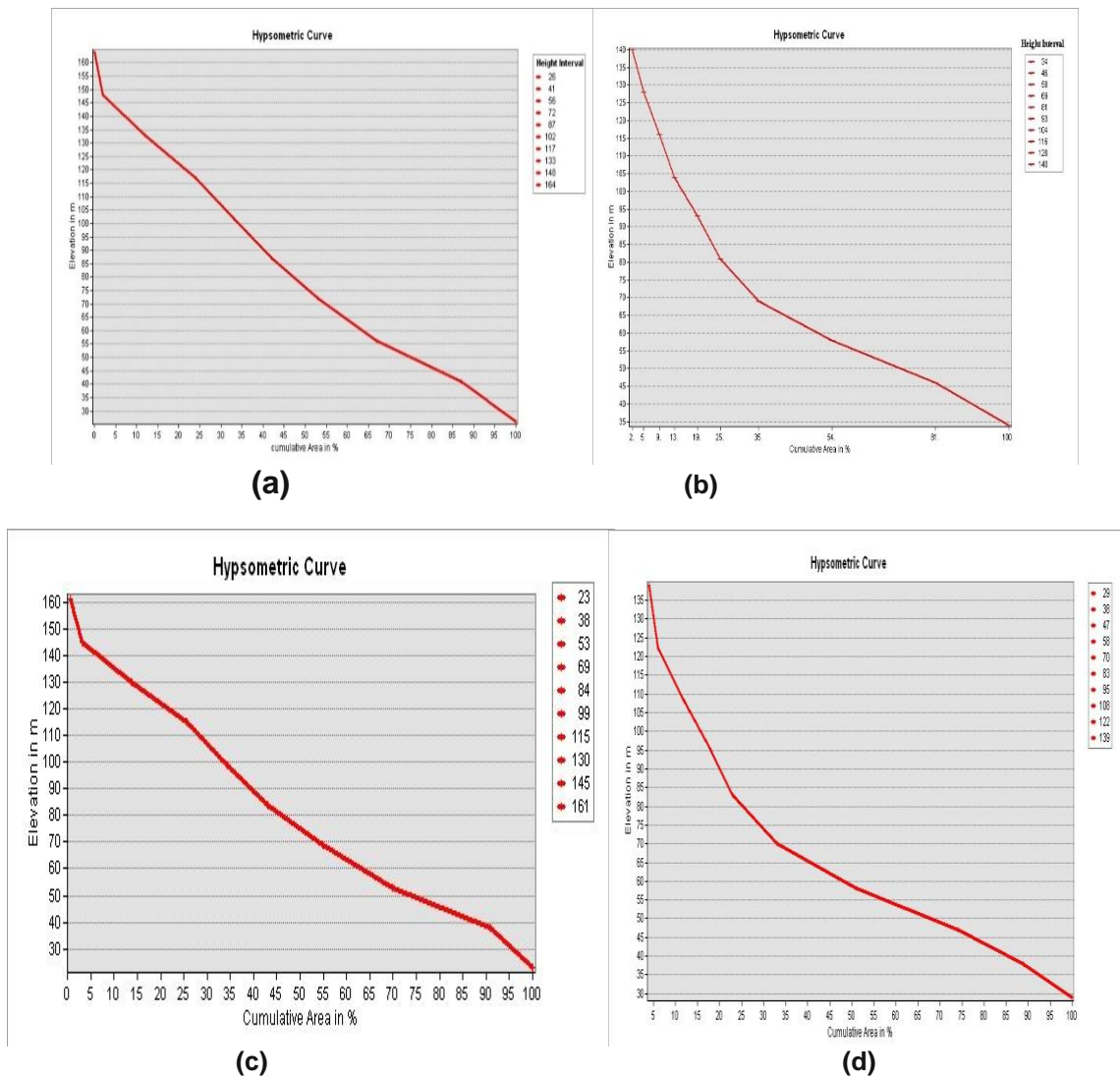


Fig. 5. Comparison of stream length and stream order for watersheds W1 and W2 for different DEMs



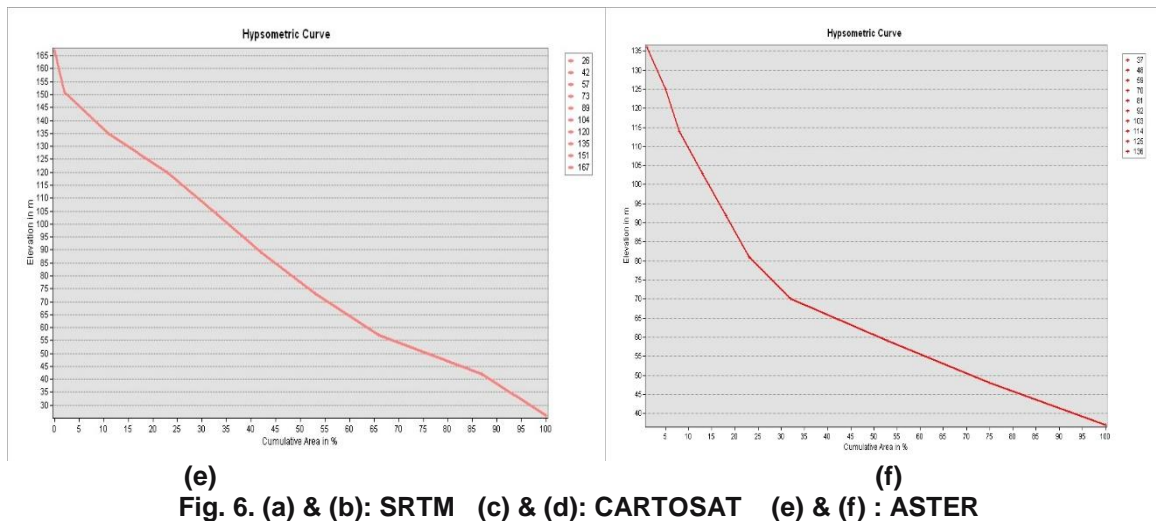


Fig.6 Hypsometric curve of the sub watersheds W1 and W2 by using different DEMs datasets

3.11 Circulatory Ratio

The circulatory ratio is the ratio of the basin area to the area of the circle having the circumference as the perimeter of the basin [13]. The parameters such as length, land use/land cover, climate, relief, frequency of the streams, and geological feature of the basin will influence the circulatory ratio. The higher the circulatory ratio indicates that the catchment is circular and will indicate higher peak runoff during short duration and vice versa. The SRTM DEM gave the highest value of circulatory ratio for both W1 and W2.

other in the case of SRTM and Cartosat DEMs when compared to the Aster DEM. After Superimposing of the all the boundaries of the watershed on the common platform like google earth it shows that the boundary and streams and outlet generated by SRTM DEM were in more matching compared to the other DEMs.

Ragheb [21] have reported that the google earth is one of the important reference and base maps for calibration and for studies with high degree of accuracy (less than 2 meters). Therefore, it can be inferred that the SRTM 30 m is more accurate than the other DEM used for comparison.

3.12 Hypsometric Integral

Hypsometric curve representing the elevation values and their corresponding areas which also reflect the age behaviour and activity of the basin. Hypsometric curve shape is considered the best parameter to select the suitable DEM for studying the hydrologic behaviour of the basin.

The hypsometric curves have been plotted between the cumulative percentage of the surface areas with respect to the elevation of the study watersheds W1 and W2 by using all the three DEMs in arc GIS. The hypsometric integral (HI) was estimated using the elevation relief ratio method. The HI values of the W1 and W2 Watersheds for all the three DEMs are seen lying in equilibrium stages.

Most of the morphometric characteristics of both of the watersheds W1 and W2 such as area, basin length and elevations are close to each

4. CONCLUSION

Soil and water conservation related research, to a great extent, depends on the accuracy of topographic information. Digital topographic data is made available through DEMs which are created by different agencies based on a different data sources due to which the accuracy of each DEM differs from others. This research focus on the comparison of the morphometric parameters of the watershed generated from different types of DEM. The study conducted on two sub watersheds of Bharathapuzha have revealed that certain basic parameters of the watershed such as area, perimeter and basin length are not changing appreciably with respect to different DEMs used viz. SRTM, CARTOSAT and ASTER, all with 30 m spatial resolution. Other shape parameters such as form factor, elongation ratio are also not varying considerably with respect to different DEMs applied. Elevation related parameters

such as basin relief, relief ratio were too showed close comparison between different DEMs used.

On the other hand, linear parameters, such as stream numbers, bifurcation ratio were changing remarkably in respect of different DEMs used. Hence, any watershed analysis done with the help of DEM and GIS techniques should also consider the type of DEMs used and the likely errors that may arise out of it. The study reveals that the SRTM 30 m is the best DEM for studying and investigating watershed hydrology and water resources as it matches more closely with the data of google map products.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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