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Comparative assessment of different digital elevation models for morphometric analysis of Godavari river sub basin

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ABSTRACT

The present study was undertaken to carry out morphometric analysis of the Godavari river sub basin using three types of digital elevation models (DEMs) *viz.,* CARTOSAT, shuttle radar topographic mission (SRTM, 30 m resolution) and advanced space-borne thermal emission and reflection radiometer (ASTER 30 m resolution). The delineated area of sub-basin was obtained as 3654.79, 3621 and 3529.3 km^2 using CARTOSAT, SRTM and ASTER DEM, respectively. The delineated area of the sub basin using CARTOSAT, and SRTM DEM were nearly the same, whereas ASTER DEM showed small deviation. Total number of streams of all orders delineated from CARTOSAT, SRTM and ASTER DEM were 23593, 21682 and 22969, respectively, indicating a small deviation. The total stream length of the sub basin using CARTOSAT, SRTM and ASTER DEM were 9755.49 km, 6645.11km, and 9752.63 km, respectively. The CARTOSAT, SRTM and ASTER DEMs showed similar results for the elongation ratio and length of overland flow. The CARTOSAT and SRTM DEM exhibited the same relief as 501 m, whereas ASTER DEM resulted in 512 m relief. The logarithmic plotting position of a number of streams against stream orders indicated a decrease in the number of streams in geometric progression with an increase in stream order in all DEMs. The form factor (R_f) ranges from 0.05, 0.03 and 0.02 in CARTOSAT, SRTM and ASTER DEM, respectively of the sub-basin indicating an elongated shape. The circularity ratio (R_c) of the whole basin was computed as 0.32, 0.28 and 0.26 in CARTOSAT, SRTM and ASTER DEM, respectively indicating the dendritic stage of the basin. The value of the constant of channel maintenance (C) was computed as 0.37, 0.37 and 0.36 using CARTOSAT, SRTM and ASTER DEM, respectively, indicating high structural disturbance, low permeability, steep to very steep slopes and high surface runoff in the sub-basin. The drainage density (D_d) of the whole basin was computed to be 2.67, 2.69 and 2.76 km km^{-2} using CARTOSAT, SRTM and ASTER DEM, respectively. The closeness of results through all the DEMs indicates the acceptability of all the DEMs for morphometric analysis.

1. INTRODUCTION

In recent years, there has been a huge demand for using the geospatial datasets of different digital elevation models (DEMs) to study and assess the physiographic features and hydrologic behaviour of the hydrographic basin. So, there is an important question about the accuracy and sensitivity of these datasets which are acquired from different DEMs. DEMs are an important form of satellite or remote sensing (RS) data used in hydrological, hydraulic, climate change, agricultural management, and water resources development studies (Guiamel and Lee, 2020). The sources and resolution of DEMs impact the results obtained from hydraulic and hydrology models (Ali *et al*., 2015). For example, flood inundation mapping of river channels was affected by DEM sources (Williams *et al*., 2000; Dodov and Foufoula-Georgiou, 2006; Nardi *et al*., 2006) and the hydrological modelling of a watershed using the so-called Soil and water assessment tool (SWAT) was influenced by DEM sources and resolution (Lin *et al*., 2010; Tan *et al*., 2018; Ficklin *et al*., 2013). Furthermore, DEMs have been frequently used for morphometric analysis of river basins by extracting topographic parameters such as stream networks that can be derived from flow directions and flow accumulations (Vaze *et al*., 2010; Ariza-Villaverde *et al*., 2015). A DEM is a regular gridded matrix representation of the land surface, including various topographical features, over time and space (Burrough, 1986). The fundamental features of any DEM data are accuracy and resolution (Sefercik and Alkan, 2009). Ghumman *et al*. (2017) tested the DEM efficiency at lower and higher resolution for a large (100 km^2) area of the watershed; according to his report, the efficiency was similar for both tested resolution levels. However, for a smaller watershed of less than 1 km^2 researchers found that model efficiency was affected by DEM resolution for flood risk analysis and drainage pattern mapping (Sampson *et al*., 2015 and Woodrow *et al*., 2016). The sources and accuracy of DEMs also impact morphometric parameter analysis, even for DEMs with identical resolution (Weydahl *et al*., 2007; Cook *et al*., 2012). Niyazi *et al*. (2019) used DEMs such as the SRTM 30 m, the ASTER, 30 m, and the advanced land observation system (ALOS) (Takaku *et al.,* 2014) (ALOS, 30 m) and found that the morphometric parameter results differed, with the exception of some parameters. During morphometric parameter analysis, Niyazi *et al*. (2019) found that stream order and stream length were the main controlling parameters. According to the authors, these parameters are reported in different result outputs for each DEM type. However, this study also stated that CARTOSAT (30 m), SRTM (30 m) and ASTER (30 m) provide closer morphometric parameters. These types of DEM data have also been used by other researchers; for example, ASTER 30 m (Evangelin *et al*., 2015), SRTM 30 m (Choudhari *et al*., 2018), and ALOS 30 m (Bayik *et al*., 2018; Tesema, 2021).

Morphometric parameter analysis plays a significant role in understanding watersheds, including erosion characteristics, flood conditions, sediments, and runoff behaviour (Singh *et al*., 2021). For instance, authors have computed morphometric parameters using Arc-GIS software and mathematical equations in order to analyse linear, areal, and relief aspects of Earth's surface with the use of DEM data from different sources with the same resolution, or the same sources with different resolutions (Niyazi *et al*., 2019; Rai *et al*., 2014; Singh *et al*., 2023a). The results of morphometric watershed parameters can be used directly or indirectly to prioritize sub-watersheds for forms of watershed management, such as soil conservation practice (Abdeta *et al*., 2020; Evangelin *et al*., 2015; Waiyasusri and Chotpantarat, 2020). Morphometry is a quantification of morphology in geomorphology. It is the measurement and mathematical analysis of the configuration of the earth's surface, shape and dimension of its landforms (Agarwal, 1988). In geomorphology, a major emphasis has been given to the development of quantitative physiographic methods to describe the evolution and behaviour of surface drainage networks during the past several decades (Horton 1945). Morphometric analysis of watershed/catchment is the best method to identify the relationship between various linear, areal and relief aspects (Abboud and Nofal, 2017) in the area. It is a relatively simple approach to describe the hydro-geological behaviour, landform processes, soil physical properties and erosion characteristics and thus, provides a holistic insight into the hydrologic behaviour of the catchments. 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; Esper, 2008). The watershed morphometric parameters or indices can help to interpret the shape and hydrological characteristics of a river basin (Rai *et al.,* 2017). The most common morphometric parameters to be studied of a watershed include stream order, stream number, stream length, mean stream length, stream length ratio, bifurcation ratio, mean bifurcation ratio, stream frequency, drainage density, drainage texture, relief ratio, form factor, circularity ratio elongation ratio and length of overland flow (Vinutha and Janardhana, 2014; Yangchan *et al*., 2015; Singh *et al.,* 2021).

It is a vital tool in any hydrological investigation like assessment of groundwater potential and management, pedology and environmental assessment and is a subject of interest to both geomorphologists and hydrologists. Physiographic characteristics of drainage basins like the size, shape, slope, drainage density, size and length of streams can be correlated with various important hydrologic phenomena (Chorley, 1969; Gregory and Walling, 1973; Rastogi and Sharma, 1976). The morphometric parameters describe and compare the basin characteristics and its processes explaining the geologic and geomorphic history of the drainage basin (Strahler, 1964). Morphometric analysis is a crucial step in understanding the watershed dynamics. Drainage basin morphometry attempts to explain and predict the long-term aspects of basin dynamics resulting in morphological changes within the basin (Thomas *et al*., 2011) and also delineate physical changes in the drainage system with time in response to natural or anthropogenic disturbances (Thompson *et al*., 2001).

The RS and GIS techniques are the appropriate tools / techniques for morphometric analysis as the satellite images provide a synoptic view of a large area which is very useful in the morphometric analysis of a drainage basin. RS and GIS tools have proved to be proficient tools for the morphometric characterization of sub-watersheds and prioritization of watersheds with respect to soil erosion (Aher *et al*., 2014; Waikar and Nilawar, 2014; Sharma and Thakur, 2016; Singh *et al.,* 2023b). Keeping this in view, a study was undertaken to study the morphometry of the sub basin in upper catchment of Godavari river basin using three different DEMs (ASTER, CARTOSAT, and SRTM). These DEMs were used for their varying spatial resolutions, accuracy levels, and global availability, ensuring a comprehensive comparative assessment of terrain features and elevations for robust morphometric analysis. The general topography of this upper catchment is hilly. The morphometric analysis will help the decision makers to check the erosion status and application of soil and water conservation measures.

2. MATERIALS AND METHODS

Study Area

Godavari river rises at an elevation of 1,067 m in the western ghats near Thriambak hills in the Nashik district of Maharashtra. After flowing for about 1,465 km, generally in south-east direction, it falls into the Bay of Bengal. The Godavari is the biggest of the east flowing rivers of the peninsular India and the second largest river draining in India. Godavari basin drains about 9.5% of India's total geographical area. The catchment area of the basin is 3,12,812 sq km extending over the states of Maharashtra (48.6%), Telangana (20% approx.), Madhya Pradesh (10%), Andhra Pradesh (3.4% approx.), Chhattisgarh (10.9%), Odisha (5.7%) and Karnataka (1.4%).The Godavari basin falls in Deccan plateau. Around 32% of the Godavari basin area lies in the elevation zone of 500-750 m. The basin is bounded on the north by the Mahadeo hills, the Satmala hills comprising a series of table lands varying from 600-1200 m in elevation. The western edge of the basin is formed by an almost unbroken line of the north Sahyadri range of the western ghats, from 600-2100 m height (SANDRP, 2017). The eastern area of the basin is majorly covered by the Dandakaranya range with the eastern ghats rising from the plains of east Godavari and Vishakhapatnam. Eastern ghats are not as prominent as western ghats. The southern boundary of the basin follows the Harishchandra range in the west, the Balaghat range in the centre and the Telangana plateau in the East. The basin is broadly divided into the Maharashtra plateau, Vidarbha plains and Dandakaranya region. Except for the hills forming the watershed around the basin, the entire drainage basin of the river Godavari comprises undulating country, a series of ridges and valleys interspersed with low hill ranges. Large flat areas which are characteristic of the Indo Gangetic plains are scarce except in the delta. The Pravara, the Manjra are the main tributaries joining on the right bank of the river and the Purna, the Pranhita, the Indravati, the Sabari are the main tributaries joining on the left bank. The Pravara rises in the western ghats flowing in an easterly direction and falls into the Godavari with its drainage area falling entirely in Maharashtra (SANDRP, 2017). In the present study, sub basin was selected for the morphometric analysis using CARTOSAT DEM (30 m resolution, 29/04/2015), SRTM DEM (30 m resolution, 23/09/2014) and ASTER DEM (30 m resolution, 30/11/2013). The sub basin lies between longitude $74^{0}00'18.72''$E to $74^{0}59'55.68''$E and latitude $19^{0}34'49.44''$N to $19^{0}59'42''$N which is shown in Fig. 1.

Fig. 1. Location map of the study area

A study was undertaken to carry out morphometric analysis of Godavari river sub basin using different DEMs *viz.,* CARTOSAT DEM of Indian Space Research Organization, SRTM and ASTER (Fig. 2a-c). Delineation of boundaries, drainage network and extraction of terrain features like slope was done using DEM. GIS was used for the hydrospatial analysis. The drainage characteristic of sub-basin was studied to describe and evaluate its hydrological characteristics by analysing data. The present investigation can be used to prepare a comprehensive watershed plan for the development of integrating topography and erosion status with the drainage characteristics of the region.

Morphometric Analysis

Geomorphological analysis is the systematic description of watershed's geometry and its stream channel system to measure the linear aspects of drainage network, aerial aspects of watershed and relief aspects of channel network. The morphological parameters directly or indirectly reflect the entire watershed based causative factors affecting runoff and sediment loss. The geomorphological parameters were determined by using different formulae as shown in Table 1.

3. RESULTS AND DISCUSSION

The different thematic maps such as drainage, topographical elevation and slope were prepared under the GIS environment. The results are described under the following sub-heads:

Analysis of linear parameters

The linear aspects of the basin, such as stream order (N), stream length (L) and bifurcation ratio (R_b) were determined and results are given in Table 2. In the present study ranking of streams has been carried out based on the method proposed by Strahler (1964). The basin is an eighth order basin. The order wise total number of stream segments is known as the stream number. Horton's (1945) law of stream numbers states that the number of stream segments of each order form an inverse geometric sequence with order number. Most drainage networks show linear relationships, with small deviations. The logarithmic plotting position of number of streams against stream order in CARTOSAT,

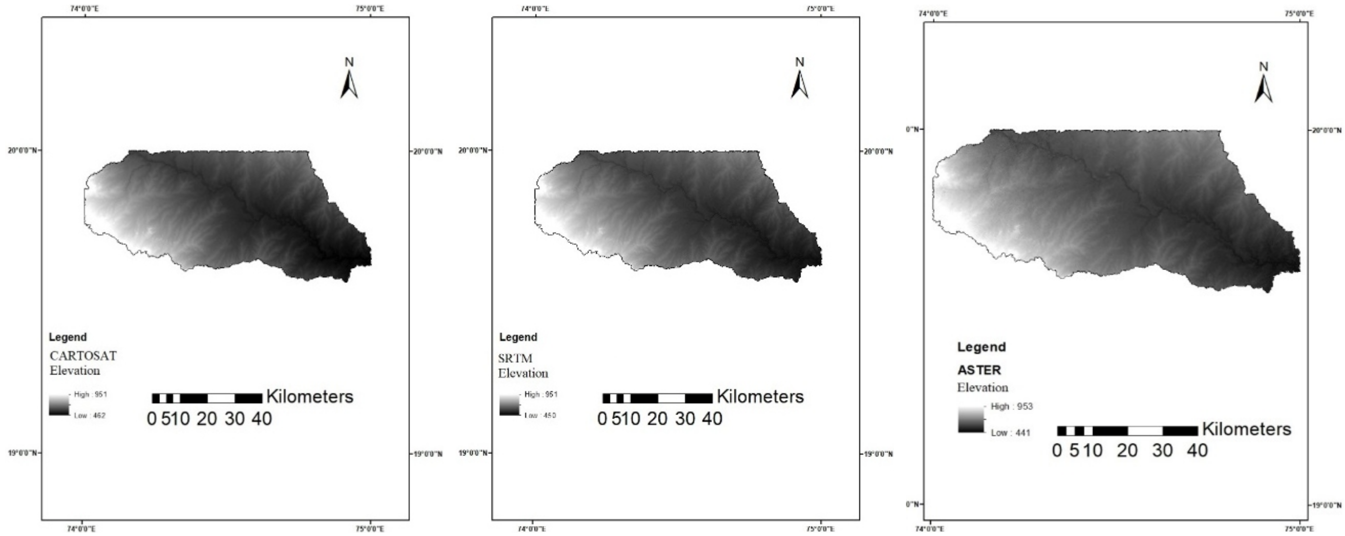

Fig. 2. CARTOSAT DEM, SRTM DEM and ASTER DEM

Table: 1
Formulae for different morphometric parameters used in analysis

Morphometric parameters	Formula	Reference
Linear parameters		
Length (L)	$L = 1.31*2A^{0.568}$ where, L = Basin length (km) A = Area of the basin (km^2)	Nooka *et al.* (2005)
Stream order (u)	Hierarchical rank	Strahler (1964)
Stream length (L_u)	Length of the stream	Horton (1945)
Mean stream length (L_{sm})	$L_{sm} = L_u/N_u$ where, L_{sm} = Mean stream length L_u = Total stream length of order 'u' N_u = Total no. of stream segments of order 'u'	Strahler (1964)
Stream length ratio (R_L)	$R = L_u/L_{u-1}$ where, R_L = Stream length ratio L_u = Total stream length of order 'u' L_{u-1} = The total stream length of its next lower order	Horton (1945)
Bifurcation ratio (R_b)	$R_b = N_u/N_{u+1}$ where, R_b = Bifurcation ratio N_u = Total no. of stream segments of order 'u' N_{u+1} = Number of segments of the next higher order	Schumm (1956)
Mean bifurcation ratio(R_{bm})	R_{bm} = Average of bifurcation ratios of all orders	Strahler (1957)
Aerial parameters		
Form factor (F_f)	$F = A/L^2$ where, F = Form factor A = Area of the basin (km^2) L = Basin length (km)	Horton (1932, 1945)
Elongation ratio (R_e)	$R = 1.128\sqrt{A/L}$ where, R = Elongation ratio A = Area of the basin (km^2) L = Basin length (km)	Schumm(1956)
Circularity ratio (R_c)	$R = 4\pi A/P^2$ where R = Circularity ratio $\pi = 3.14$ A = Area of the basin (km^2), P = Perimeter (km)	Miller (1953), Strahler(1964)
Shape factor (S)	$S = L^2/A$ where S = Shape factor L = Basin length (km) A = Area of the basin (km^2)	Horton (1932)
Compactness co-efficient (C)	$C = 0.2821* P/A^{0.5}$ where C = Compactness coefficient P = Perimeter (km) A = Area of the basin (km^2)	Gravelius (1914)
Drainage density (D_d)	$D_d = L_u/A$ where D_d = Drainage density L_u = Total stream length of all orders A = Area of the basin (km^2)	Horton (1932, 1945)
Streamfrequency (F_s)	$Fs = \Sigma N_u/A$ where F_s = Streamfrequency ΣN_u = Total no. of streams of all orders A = Area of the Basin (km^2)	Horton (1932, 1945)
Drainage texture (T)	$T = D_d*F_s$ where T = Drainage texture D_d = Drainage density F_s = Stream frequency	Horton (1945)
Textureratio (T_r)	$T_r = N_1/PN_1$ = Total number of first order streams P = Perimeter of watershed	Horton (1945)
Constant of channel maintenance (C)	$C = 1/D_d$ where, C = Constant of channel maintenance D_d = Drainage density	Schumm (1956)
Length of overland flow (L_g)	$L_g = 1/2D_d$ where, L_g = Length of overland flow D_d = Drainage density	Horton (1945)
Relief parameters		
Basin relief (R)	R = H-h where, R = Basin relief H = Maximum elevation in meter H = Minimum elevation in meter	Hadley & Schumm (1961)
Relief ratio (R_r)	$R_r = R/L$ where R_r = Relief ratio R = Basin relief L = Longest axis in kilometre	Schumm (1956)
Ruggedness number (R_n)	$R_n = H*D_d$ where R_n = Ruggedness number H = Basin relief D_d = Drainage density	Schumm (1956)

Table: 2
Linear aspects of the sub basin

DEM	Area (km^2)	Perimeter (km)	Stream numbers of different orders								Total	Order wise total stream length (km)								Total
			1	2	3	4	5	6	7	8		1	2	3	4	5	6	7	8	
CARTOSAT	3654.79	377.9	11901	5321	3070	1762	809	335	125	270	23593	5160.926	2250.33	1162.88	636.81	300.88	112.16	42.19	89.20	9755.49
SRTM	3621.00	404.00	9939	5353	3067	1791	819	318	124	271	21682	4304.90	2250.50	1158.64	642.87	300.58	106.82	42.19	89.11	6645.11
ASTER	3529.3	413.61	11649	5326	2987	1627	928	201	76	175	22969	4991.71	2339.9	1196.46	679.85	379.63	76.56	28.53	59.99	9752.63

DEM	Average stream length (km)								Total	Stream length ratio							Mean
	1	2	3	4	5	6	7	8		1	2	3	4	5	6	7	
CARTOSAT	0.43	0.42	0.38	0.36	0.37	0.33	0.34	0.33	2.97	0.98	0.90	0.95	1.03	0.90	1.01	0.98	0.96
SRTM	0.40	0.39	0.35	0.33	0.34	0.31	0.31	0.3	2.73	0.98	0.90	0.94	1.03	0.91	1.00	0.97	0.96
ASTER	0.39	0.40	0.37	0.38	0.38	0.35	0.34	0.32	2.93	1.03	0.93	1.03	1.00	0.92	0.97	0.94	0.97

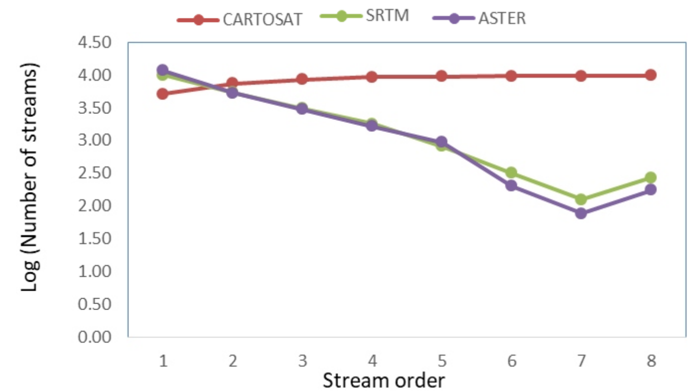

Fig. 3. Relationship between stream order and stream number

SRTM and ASTER DEM presented in Fig. 3 shows the number of streams usually decreases in geometric progression as the stream order increases.

The stream lengths for sub-basin of various orders were measured on a digitized map with the help of GIS using CARTOSAT, SRTM and ASTER DEM. The total length of stream segments is maximum in first order streams and decreases as the stream order increases. The total stream length in the sub-basin is 9755.49 km, 6645.11 km and 9752.63 km using CARTOSAT, SRTM and ASTER DEM respectively (Table 2). The values of the stream length ratio (R_L) are 0.96, 0.96 and 0.97 using CARTOSAT, SRTM and ASTER DEM, respectively. Same length ratio (R_L) was observed in CARTOSAT, SRTM DEM. It is noticed that the R_L between successive stream orders of the basin vary due to differences in slope and topographic conditions (Sreedevi, 2005). The stream length ratio (R_L) has an important relationship with the surface flow discharge and erosional stage of the basin. In the present study, it was observed that the plot of logarithm of the cumulative stream length as ordinate and stream order as abscissa is almost a straight line fit. The straight-line fit indicates that the ratio between cumulative length and order is constant throughout the successive orders of a basin (Fig. 4).

The mean bifurcation ratio value of the basin is 1.92, 1.87 and 2.17 using CARTOSAT, SRTM and ASTER DEM, indicating that the basin is falling under normal basin category (Strahler, 1957). The bifurcation ratio is also an indicative tool of the shape of the basin. Elongated basins have low R_b value, while circular basins have high R_b value (Morisawa, 1985). In this study area, the higher value of R_b indicates a strong structural control in the drainage pattern whereas the lower value indicates that the sub-basins are less affected by structural disturbances (Strahler, 1964; Vittala, 2004 and Chopra, 2005). CARTOSAT and SRTM DEM shows nearly the same value for bifurcation ratio (Table 3).

Analysis of areal parameters

The aerial aspects of the basin like drainage density (D_d),

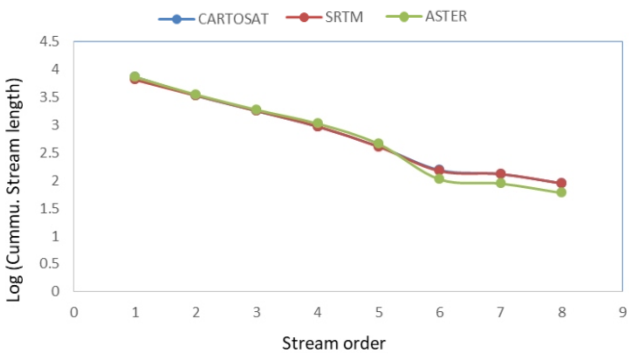

Fig. 4. Relationship between stream order and cumulative stream length

stream frequency (F_s) elongation ratio (R_e), circularity ratio (R_c), form factor (R_f) etc. were calculated and results are presented in Table 4. Drainage density is one of the often-used morphometric parameters in the analysis of various environmental variables. It is a measure of the degree of fluvial dissection and depends on a number of factors like topography, lithology, climate, pedology and vegetation (Nag, 1998; Mesa, 2006; Thomas *et al*., 2011). The drainage density in the whole basin is 2.67, 2.69 and 2.76 km km^{-2}, using CARTOSAT, SRTM and ASTER DEM, respectively suggesting high drainage density. It is indicating that the region is composed of weak or impermeable subsurface materials; sparse vegetation, mountainous relief and fine drainage texture (Reddy, 2004). CARTOSAT and SRTM DEM showed nearly the same results for the drainage density. The stream frequency (F_s) mainly depends on the lithology of the basin and reflects the texture of the drainage network. The stream frequency (F_s) value of the basin of the study area is 6.46, 6.52 and 6.68. Generally, High value of stream frequency (F_s) is related to impermeable subsurface material, sparse vegetation, high relief conditions and low infiltration capacity (Reddy, 2004). CARTOSAT and SRTM DEM shows nearly the same results for the stream frequency.

The form Factor (R_f) proposed by Horton (1945) is to predict the flow intensity of the basin of a defined area. The index of R shows the inverse relationship with the square of the axial length and a direct relationship with peak discharge. The value of form factor would always be greater than 0.78 for a perfectly circular basin. Smaller the value of

Table: 3
Bifurcation of the sub basin

DEM	Bifurcation ratio							Mean
CARTOSAT	2.24	1.73	1.74	2.18	2.41	2.68	0.46	1.92
SRTM	1.86	1.75	1.71	2.19	2.58	2.56	0.46	1.87
ASTER	2.19	1.78	1.84	1.75	4.62	2.64	0.43	2.17

form factor, more elongated will be the basin. Form Factor (R_f) value of basin of the study area is 0.05, 0.03 and 0.02 using CARTOSAT, SRTM and ASTER DEM, respectively, which indicate that the basin is sub circular and elongated in shape. The elongated basin with a low form factor indicates that the basin will have a flatter peak of flow for a longer duration. Flood flows of such elongated basins are easier to manage than of the circular basin (Nautiyal, 1994). All the DEMs show nearly the same result.

The circularity ratio (R_c) is affected by the lithological character of the basin. Its values approaching one indicate that the basin shapes are circular and as a result, it gets scope for uniform infiltration and takes a long time to reach excess water at basin outlet, which further depends on the prevalent geology, slope and land cover. The ratio is more influenced by length, frequency (F) and gradient of various orders rather than slope conditions and drainage pattern of the basin. The $R_c$of the whole basin is 0.32, 0.28 and 0.26 using CARTOSAT, SRTM and ASTER DEM, respectively which indicates the dentritic stage of a basin.

The elongation ratio (R_e) is a very significant index in the analysis of basin shape, which helps to give an idea about the hydrological character of a drainage basin. elongation ratio (R_e) for the study area using the CARTOSAT, SRTM and ASTER shows the same value as 0.26 as shown in Table 4. The value near 1 is typical of regions of very low relief, whereas values in the range of 0.6 to 0.8 are generally associated with strong relief and steep ground slopes (Strahler, 1968).

Schumm (1956) used the inverse of drainage density as a property known as the constant of channel maintenance (C). It is the area of basin surface needed to sustain a unit length of stream channel and depends on the rock type, permeability, climatic regime, vegetation cover as well as duration of erosion. In areas of close dissection, its value will be very low. The value of constant channel maintenance

Table: 4
Aspects of the sub basin

DEM	Form factor	Shape factor	Circularity ratio	Elongation ratio	Texture ratio	Compactness constant	Drainage density (km km^{-2})	Stream frequency	Constant of channel maintenance	Length of flow overland
CARTOSAT	0.05	20.95	0.32	0.26	31.49	1.76	2.67	6.46	0.37	0.18
SRTM	0.03	39.19	0.28	0.26	24.60	1.89	2.69	6.52	0.37	0.18
ASTER	0.02	42.09	0.26	0.26	28.16	1.96	2.76	6.68	0.36	0.18

(C) of the study area is 0.37,0.37 and 0.36 using CARTOSAT, SRTM and ASTER DEM, respectively which indicates that sub-basins are under the influence of high structural disturbance, low permeability, steps to very steep slopes and high surface runoff. All the DEMs show nearly the same result.

The length of overland flow (L_g) is the length of water over the ground before it gets concentrated into definite stream channels. It is approximately equals to half of the reciprocal of drainage density (Horton, 1945). This factor relates inversely to the average slope of the channel and is synonymous with the length of the sheet flow to the large degree. The length of overland flow (L_g) is one of the most important independent variables, affecting both the hydrological and physiographical development of the drainage basins (Horton, 1945). The computed value of L for the study area using CARTOSAT, SRTM and ASTER DEM is 0.18.The low L_g values of basin and sub-basins indicating short flow paths, with steep ground slopes, reflecting the areas associated with more runoff and less infiltration. The drainage maps of the sub basin using three different DEMs are shown in Fig. 5a-c.

Thakur *et al.* (2022) prioritized watershed in Bhopal lake catchment, Madhya Pradesh using a multi-criteria decision analysis tool. In this study SRTM DEM (30 m) was used for morphometric analysis. The drainage density, channel frequency, form factor and circulatory ratio value ranges from 0.95-1.72, 0.41-1.87,0.21-0.93 and 0.14-0.39, respectively.

Analysis of relief parameters

The relief aspects of the sub basin are shown in Table 5. Relief aspect of the watershed plays an important role in drainage development, surface and subsurface water flow, permeability, landform development and associated features of the terrain. Relief is the maximum vertical distance between the lowest and the highest points of a basin. The relief of the basin is 501 m, 501 m and 512 m using CARTOSAT, SRTM and ASTER DEM (Fig. 6a-c).

Table: 5
Relief and slope of area

DEM	Maximum Elevation (m)	Minimum Elevation	Relief	Relief Ratio	Ruggedness Number
		Relief Aspects			
CARTOSAT	951	450	501	0.0046	1.25
SRTM	951	450	501	0.00464	1.002
ASTER	953	441	512	0.004726	1.38
		Slope (%)			
CARTOSAT	Area (km^2)	SRTM	Area	ASTER	Area
2-5	2959.51	0-3	1958.17	0-3	1202.39
5-9	2684.47	3-7	3502.61	3-11	3994.84
9-41	680.57	7-24	1673.92	11-37	955.80
41-105	15.48	24-105	141.71	37-115	36.86

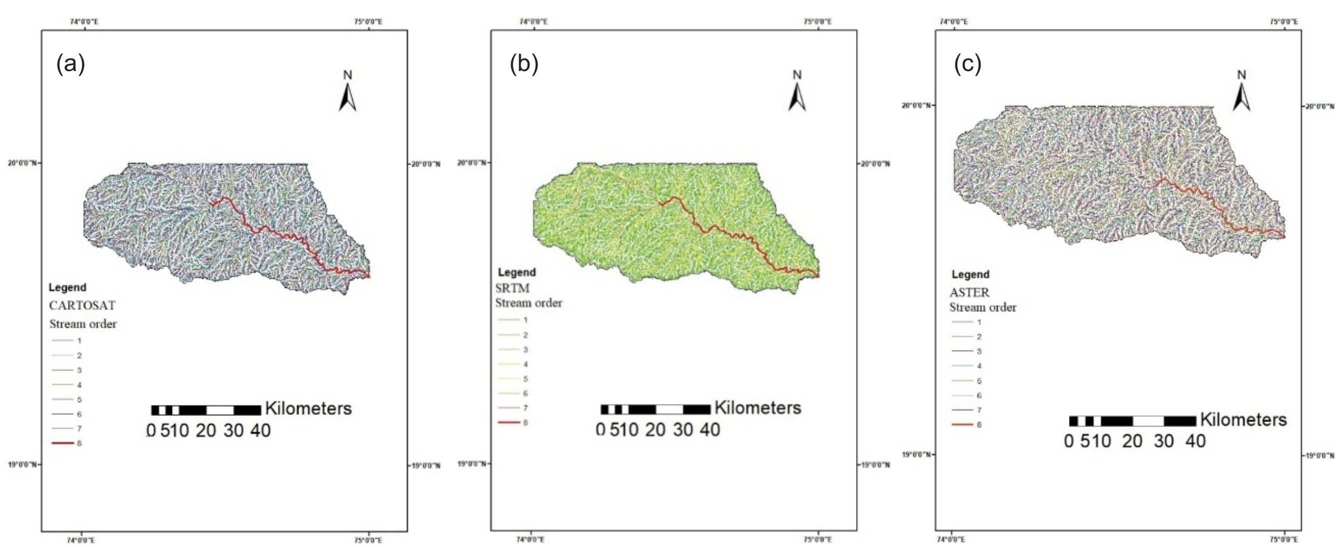

Fig. 5. Drainage map of (a) CARTOSAT DEM, (b) SRTM DEM and (c) ASTER DEM

The high relief value indicates the gravity of water flow, low infiltration and high runoff conditions of the study area. Relief ratio has a direct relationship between the relief and channel gradient. The relief ratio normally increases with decreasing drainage area and size of the watersheds of a given drainage basin. The relief ratio of the basin is 0.0046, 0.0046 and 0.0047 using CARTOSAT, SRTM and ASTER DEM, respectively. The relief ratio of the basin shows the characteristic features of less resistant rocks of the area (Sreedevi, 1999). All DEMs show same results for the relief ratio. Ruggedness number is the product of relief and drainage density in order to define the slope steepness and length. It is a dimensionless term and indicates the structural complexity of the terrain. The ruggedness number of the basin is 1.25,1.002 and 1.38 using CARTOSAT, SRTM and ASTER DEM, respectively which shows the deviation in the result.

Slope of the basin varies from 0 to 105% (Fig. 7a-c) and the 2959 km^2 areas which is about 80 percent of the basin area shows the slope ranges from 2 to 5% using CARTOSAT DEM. The 54 per cent area shows the slope ranges from 0-3% using SRTM DEM and the 34% area shows the slope ranges from 0-3% using ASTER DEM. All the DEMs show the deviations in the slope.

Niyazi *et al.* (2019) compared different types of the Digital Elevation Models on the basis of drainage morphometric properties. In this study SRTM DEM (90 m), SRTM DEM (30 m), Aster DEM (30 m) and ALOS DEM (30 m) was used. The analysis of the DEMs indicated that all

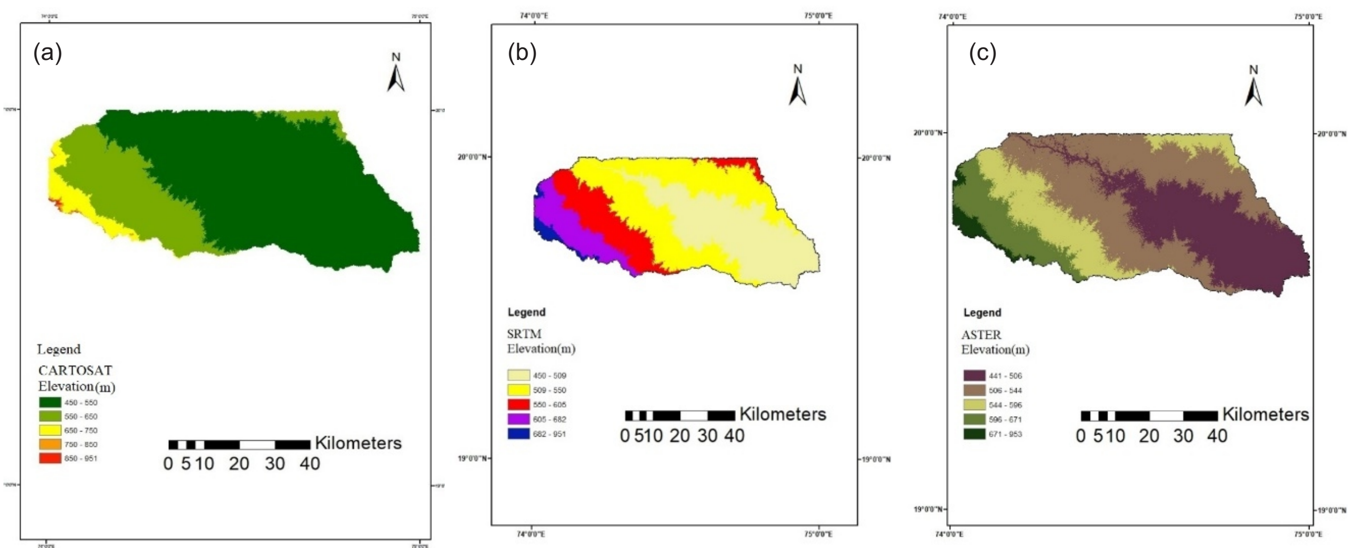

Fig. 6. Topographical elevation map of (a) CARTOSAT DEM, (b) SRTM DEM and (c) ASTER DEM

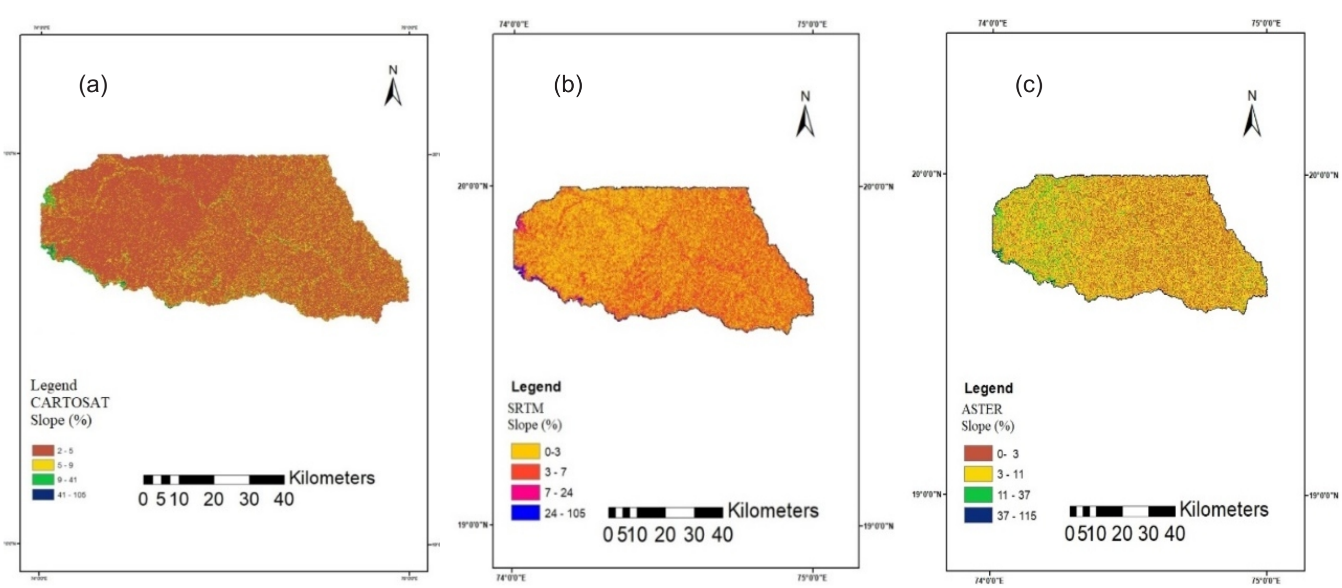

Fig. 7. Slope map of (a) CARTOSAT DEM, (b) SRTM DEM and (c) ASTER DEM

DEMs show eight order streams, except SRTM DEM (90 m) which shows seventh order stream of study area. The circularity ratio of SRTM DEM (90 m), SRTM DEM (30 m), Aster DEM (30 m) and ALOS DEM (30 m) was 0.16, 0.13, 0.15 and 0.14, respectively. The drainage density values of SRTM DEM (90 m), SRTM DEM (30 m), Aster DEM (30 m) and ALOS DEM (30 m) was 0.86, 2.42, 2.25 and 2.53, respectively. The results show that the longest stream lengths and maximum number of streams was obtained from SRTM 30, ASTER 30 and ALOS 30. It shows that the finer the resolution there will be more number of streams obtained.

4. CONCLUSIONS

The comparative assessment of three types of DEMs was carried out in Godavari sub basin. The analysis of study shows that the delineated study area using CARTOSAT, SRTM DEM gives nearly the same result whereas ASTER DEM shows small deviation. All DEMs show deviation in stream order. The CARTOSAT and SRTM DEM show the same relief as 501 m whereas ASTER DEM shows 512 m relief. All the DEMs show the deviations of slope in the study area. The linear, areal, shape and relief parameters analysed using CARTOSAT, SRTM and ASTER DEM and results are almost same with small deviation so it is concluded that all the three DEMs are acceptable for morphometric analysis for all the regions. It is also concluded that the basin is falling under the normal basin category. The relief ratio of the basin shows the characteristic features of less resistant rocks of the area. The low value of L_g indicates short flow paths with steep ground slopes reflecting the areas associated with more runoff and less infiltration.

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