Error due to DEM sources in catchment area and river network using D8 algorithm

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Abstract

Digital elevation models (DEMs) are considered as an important spatial input parameter for hydrological models and have an inherent source of uncertainties which could be due to grid size or data sources. The acceptability of the DEM source for the research objective and appropriate resolution has to be properly examined before any hydrologic application. These impact the results of the SWAT hydrological model, which predominantly relies on DEMs for the hydrological variables derived. Four popularly used DEMs namely AW3D30 DEM, CartoDEM, SRTM DEM and ASTER GDEM have been considered for the present study in identifying the error in river network extraction using deterministic eight neighborhood (D8) method and error in automatic basin boundary delineation. It was found that newly released AW3D30 global DEM had the best river network extraction capability compared with the digitized river network from google earth imagery. For stream network extraction, the delineation accuracy for AW3D30 was best compared to other DEMs whereas ASTER GDEM showed poor river network extraction capability. On the other hand, SRTM and CartoDEM showed good river network extraction ability. For basin boundary delineation, ASTER GDEM showed the maximum total error of 167.46 km^2 with AW3D30 basin boundary as reference boundary. The foremost question of applicability of dataset for the study area has been examined through this case study.

Keywords: *Digital elevation model (DEM), River network, Automatic delineation, D-8 method, SWAT.*

1. Introduction

The ability of any hydrologic model to produce reliable hydrologic components depends on the spatial input parameters. One important source of uncertainty is associated due to DEM. In hydrologic modeling Digital elevation models (DEMs) are used for the basin boundary extraction, river network delineation and extraction of physical characteristics of a catchment including area, shape, slope of the catchment. Past studies have underlined the importance of DEM in hydrologic simulations in Soil and Water Assessment Tool (Lin et al. 2012; Reddy and Reddy 2015; Tan et al. 2018). This study utilizes physically distributed hydrological SWAT model. In SWAT, each watershed is lumped into hydrologic response units (HRUs) with a homogenous combinations of soil, slope and land cover. Different DEM source and resolutions results in different HRUs and thus eventually yields deviations in the resulting hydrologic components.

DEM accuracy assessment is important for extraction of reliable watershed characteristics and thus ensuring further effective hydrologic applications. Substantial amount of studies has been put in to assess DEM and its impact on watershed. Hammond (2006) explored two important issues in Bruce catchment, England, concluding that the basin area generated by the computer failed to delineate the boundary accurately mainly due to anthropogenic activities in addition to quality of data and algorithms. The study also explored the limit up to which coarser resolution delineates the boundary reliably than fine resolution data. Vladimir J. Alarcon and Chuck O' Hara (2006) studied the basin boundary delineation capability of DEMs namely Shuttle Radar Topographic Mission (SRTM), Interferometric Synthetic Aperture Radar (IFSAR), National Elevation Data (NED) and United States Geological Service Digital Elevation Model (USGS DEM) and concluded that SRTM DEM produced optimum basin boundary delineation results than NED. Paz, Collischonn, Risso, & Mendes, (2008) considered the application of automatic river network in Uruguay River basin comparing the results with digitized drainage lines from satellite images and concluded that relative error was higher than 30% in flat regions with coarse DEM resolution, though stream burning and distance transforms minimized the error range.

Rahman et al. (2010) carried out the study in twelve catchments of varying geomorphology from the five hydrological zones of Bangladesh with SRTM 90 m DEM and explored the limitation of SRTM 90 m in river network extraction with slope of 1:3600 and more. Also, he concluded that the catchment with slope 1:2850 and more steep catchments were delineated correctly. The study also showed how slope is significantly related to network delineation error. Kumar, Patra, & Lakshmi, (2017) considered three widely used DEMs namely, ASTER DEM, SRTM (90 m) and SRTM (30 m) and found a significant error in SRTM 30 m and ASTER DEM while comparing with the reference boundary also the stream network delineation error was least for SRTM 90 m in a case study in Gandak basin.

The flow routing model in Digital elevation model (DEM) is based on popularly used D8 method which was introduced by O'Callaghan and Mark (1984). Initially this method was problematic considering the lack of down slope called sink thus creating a discontinuous flow pattern. This led Jenson, Dominque, & Domingue, (1988) to develop a method so as to eliminate the sinks before computing flow direction. This later was followed in widely used ESRI products like ArcView, ArcGIS, Arc Info. Fairfield and Leymarie (1991) argued about the limitation of flow discretization into only one of the eight possible directions at 45° in D8 method.

After this, many studies were carried out in developing flow direction algorithms, though it was not implemented due to practical reasons excluding D8 method. Therefore, In the present study investigates the error in basin boundary delineation and river network delineation using the widely implemented D8 method and their relation to various popularly used different DEM sources.

2. Description of the Study Area

In the present study, Jeraikela catchment in India is selected as the case study to perform the analysis. Jeraikela catchment is the sub-basin of Brahmani River Basin. The geographical setting of the basin is shown in the figure 1. The catchment covers areas in the states of Jharkhand and Odisha and drains an area of about 10,201 km^2. While most of the Brahmani basin comprises of agricultural areas with reasonably high mountainous terrain, this region, Jeraikela sub basin is the only part of the Brahmani basin that is characterized by a wide variation in topography with elevations ranging from 198 to 1089 m, thus making it an interesting case study for DEM related study.

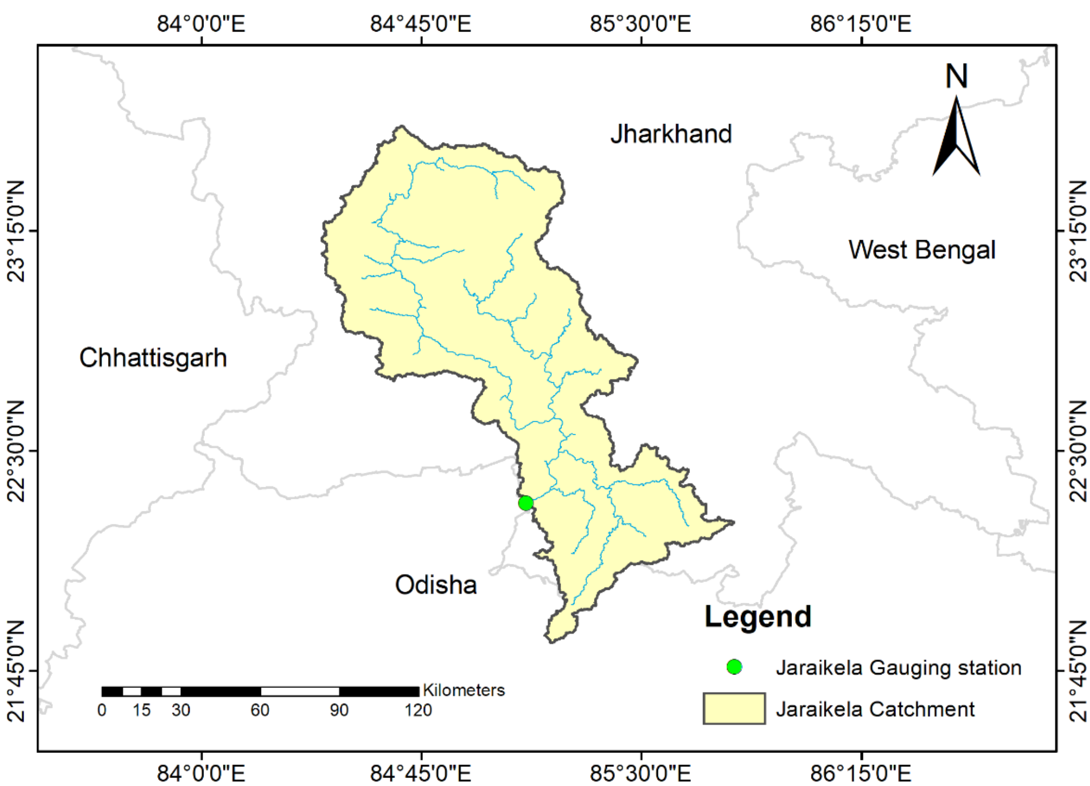

Figure 1. Location of Jeraikela basin, India

3. Description of data sets used

Four popularly used DEM data products namely CartoDEM, AW3D30 global DEM, SRTM DEM and ASTER GDEM were selected for this study. The details of the different DEM datasets are listed in Table 1. CartoDEM is a DEM dataset generated using cartosat-1 stereo data, developed by Indian Space research organization (ISRO). CartoDEM was made available from 2005 onwards and can be accessed through Bhuvan geoportal, ISRO. AW3D30 global DEM was launched in

2016 by Japan Aerospace Agency (JAXA) and can be procured through the ALOS website free of cost. ASTER GDEM was released under joint collaboration between National Aeronautics and Space Administration (NASA) and Japan's ministry of Economy, Trade, and Industry (METI) and was made available to public from 2009 onwards and can be downloaded from USGS earth explorer website. SRTM was released by National Geospatial-Intelligence Agency (NGA) and National Aeronautics and Space Administration (NASA) and was initially available at 90 m. SRTM DEM data of 30 m resolution was made available to public in 2015 for Southeast Asian region and can be downloaded free of cost from USGS earth explorer website.

Table 1. Details of different DEMs used in the study.

S.No	DEM dataset	Resolution	Source
1	CartoDEM	30 m	Indian space research Organization (ISRO)
2	AW3D30 global DEM	30 m	Japan Aerospace Agency (JAXA)
3	SRTM DEM	30 m	National Geospatial-Intelligence Agency (NGA) and National Aeronautics and Space Administration (NASA)
4	ASTER GDEM	30 m	United States National Aeronautics and Space Administration (NASA) and Japan's ministry of Economy, Trade, and Industry (METI)

4. Methodology

In the present study, two types of error are examined. That is,

- Error due to different DEM sources in digital river network extraction using the traditional deterministic eight neighborhood (D8) method and,
- Error due to different DEM sources in catchment area using automatic basin boundary delineation.

The assessment of error in digital river network was delineated using ArcSWAT which is generated by the popular D8 algorithm through processing the depression, flow direction calculation and the flow accumulation calculation. The delineated river network is then compared with the river network digitized from google earth which is considered as the reference river network for spatial agreement. The distance from the reference river network to the automatically delineated river network is measured at equal interval of 1 km in ArcGIS 10.1 in the catchment. The spatial disagreement between the reference river network and the automatically delineated river network is the alignment error. Error is considered as positive when automatically delineated river network is on the right side of the reference network and negative otherwise when measured from gauging station (outlet) to remote point.

For quantifying the error in the river network two statistical parameters namely mean absolute error (MAE) and standard deviation (SD) were considered. MAE is reliable since measures of absolute error are less dominated by large numbers of small errors (Rahman et al. 2010).

MAE is calculated by using the formula,

$$MAE = \frac{1}{n}\sum_{i=1}^{n} |O(x_i y_i) - D(x_i y_i)| \tag{1}$$

where, n is the number of intervals, $O(x_i y_i)$ is the alignment of digitized river network at i^{th} interval and $D(x_i y_i)$ is the location of the delineated river network at i^{th} interval.

The error due to automatic basin boundary delineation is examined by assessing three error parameters, namely, overestimated area, underestimated area and the total error which is the sum of the overestimated and underestimated area. The automatically delineated basin boundary by AW3D30 DEM was assumed to be the reference basin boundary area since it had the best river network delineation capability compared with all the other DEMs. The overestimated area is the area which lies outside the reference basin boundary whereas the underestimated area is the area which shortfalls within the reference AW3D30 basin boundary. To clarify the statement, set notation can be used. If X is the catchment boundary that needs to be assessed (CartoDEM, ASTER GDEM, and SRTM automatically delineated catchment area) and Y is the catchment area that is considered as a reference (AW3D30 DEM) then in set notation, the overestimated and the underestimated areas can be expressed as,

$$overestimated\ area = X - X \cap Y \tag{2}$$

$$underestimated\ area = Y - X \cap Y \tag{3}$$

where $X \cap Y$ is the intersection of areas which is under consideration (CartoDEM, ASTER GDEM, and SRTM) and reference area (AW3D30 DEM). The total error is analogous to the mean absolute error which is the essentially the sum of overestimated area and underestimated area.

5. Results and discussions

5.1 *Error in extraction of river network using D8 method*

The river network extraction is evaluated by considering total stream length and the tributaries. Spatial disagreement of the delineated river network by the DEMs considered and reference river network digitized from the google earth imagery is shown in figure 2.

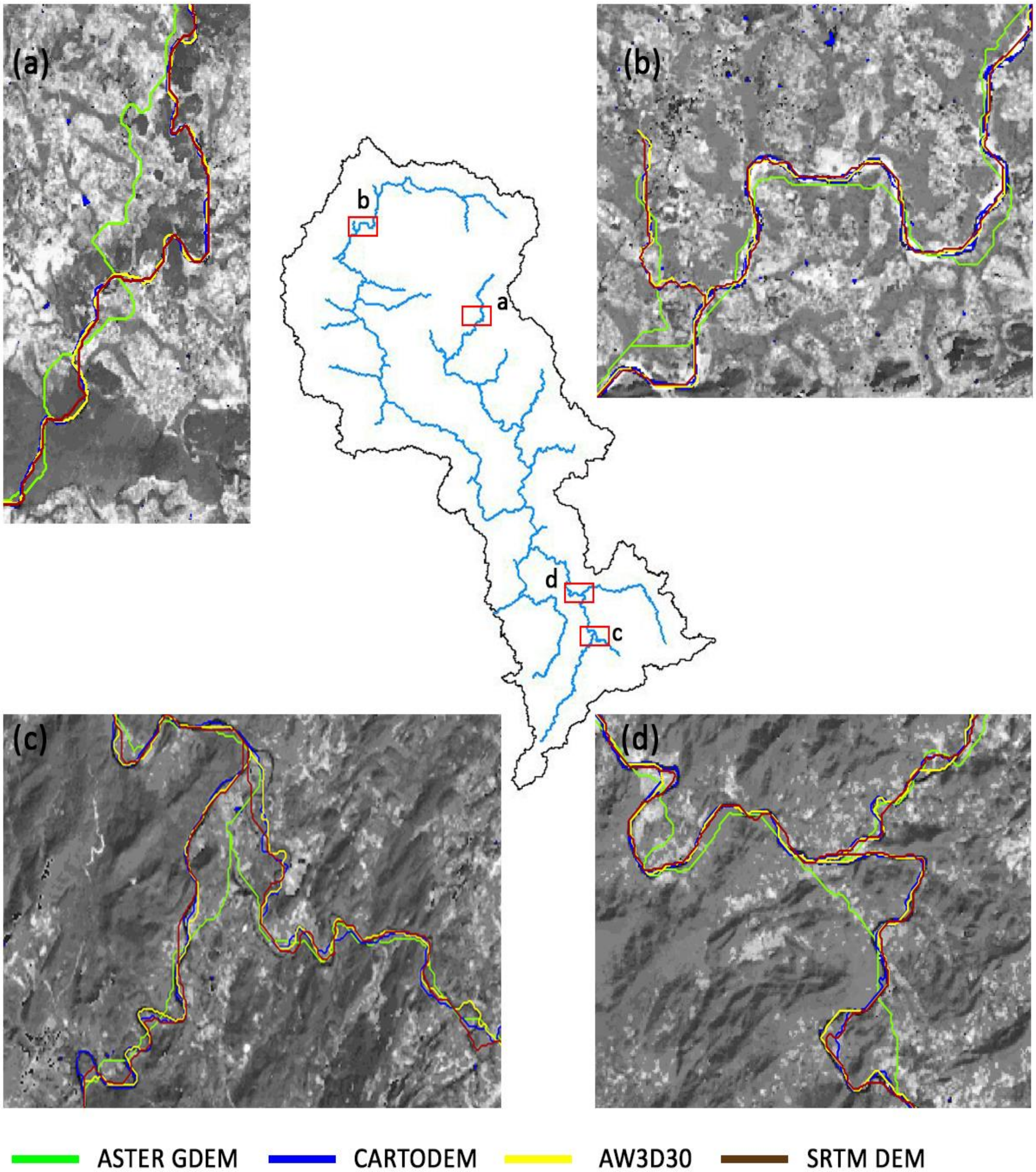

Figure 2. River network delineation by different DEM sources.

Based on visual based inspection AW3D30 global DEM showed the best river network extraction capability compared with all the other DEMs considered. It was observed that total stream length was found to be greater in AW3D30 global DEM. In contrast, ASTER GDEM showed poor digital river network extraction ability in the Jeraikela catchment whereas Cartosat-1 showed better river network extraction ability over the considered SRTM DEM.

River characteristics namely total river length extracted, average slope, average width and average depth extracted from various DEM sources considered is listed in Table 2. The highest range of the total river length 68.79 m for a particular constant area threshold value (1% of the total threshold area - 10000 Ha).

Table 2. River characteristics for DEM considered

S.No	DEM source	Total river length (km)	Average slope (%)	Average width (m)	Average depth (m)
1.	AW3D30 global DEM	935.62	0.25	91.65	2.05
2.	CartoDEM	922.97	0.22	96.92	2.14
3.	SRTM DEM	895.07	0.23	96.94	2.14
4.	ASTER GDEM	866.83	0.33	93.90	2.09

In general, ASTER GDEM was not able to generate reliable river network in the outlet and low lying regions. A similar finding at the outlet was observed by Tan, Ramli, & Tam, (2018). The poor river network ability by ASTER GDEM may be due to local blunders and artefacts which are sometimes inherent in the ASTER GDEM data (Hirt et al. 2010). Figure 3. Shows the behavior of MAE due to selected due to selected DEMs in Jeraikela catchment.

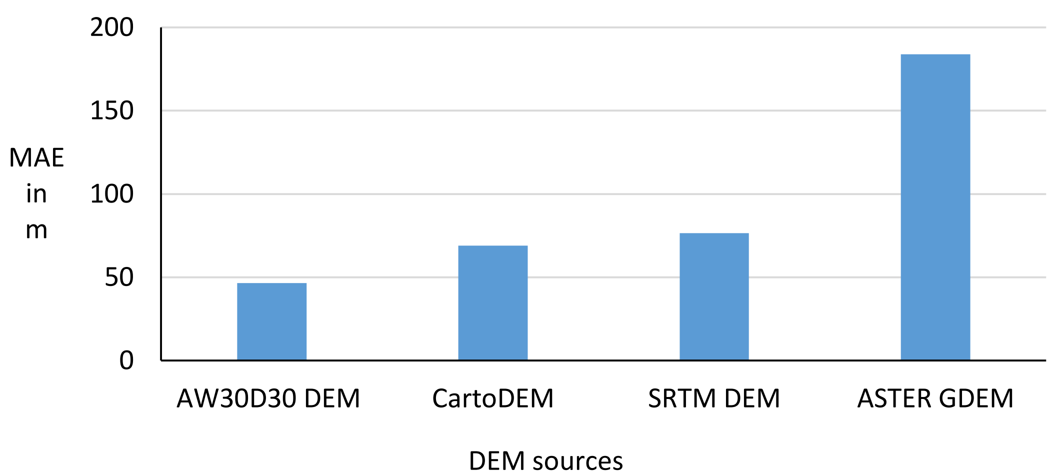

Figure 3. MAE error due to DEM sources in Jeraikela catchment

5.2 ***Error in automatic basin boundary delineation***

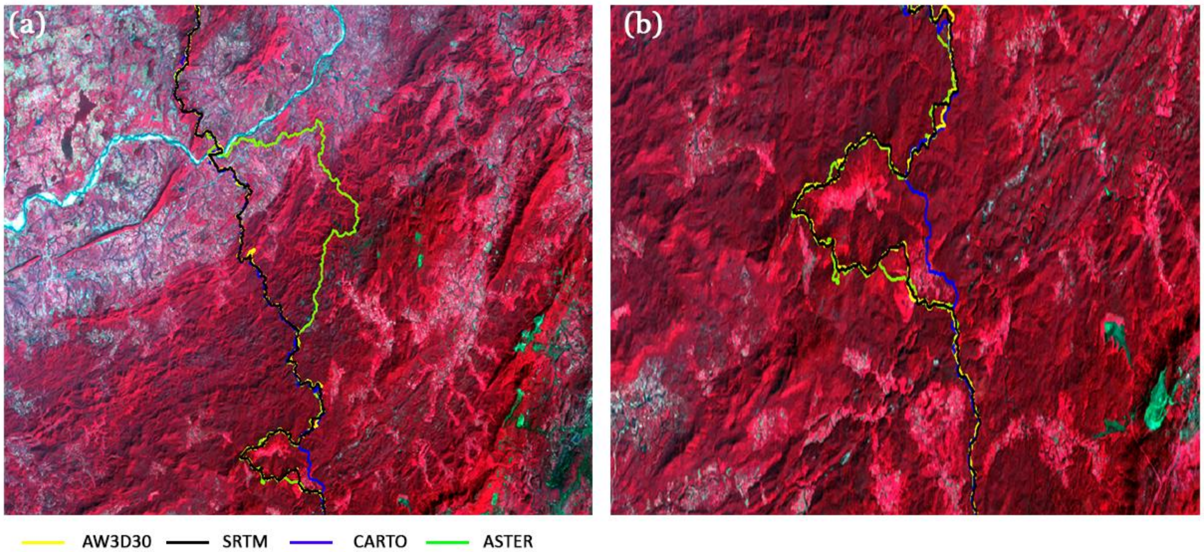

Figure 4. Differences in basin boundary delineation of DEMs considered in the study.

The basin delineation which is typically executed as a single step algorithmic process was observed. All the DEMs except ASTER GDEM delineated a similar basin boundary. The figure 3 shows the sub basins delineated by different DEM sources. The difference in the basin boundary in ASTER GDEM observed at the outlet region is shown in figure 4. The automatically delineated basin boundary by AW3D30 DEM was assumed to be the reference basin boundary area since it had the best river network delineation capability compared with all the other DEMs.

Table 3 lists the total error due to different DEMs in basin boundary delineation. The highest total error in basin boundary delineation was found in ASTER DEM is 167.46 km^2, therefore in the hydrologic analysis may respond differently in terms of quantification of discharge and other hydrological variables.

Table 3. Overestimated, underestimated and total error due to DEM sources

DEM sources	Total area (km^2)	Overestimated area (km^2)	Underestimated area (km^2)	Total error (km^2)
AW3D30 DEM	10494.95	0.00	0.00	0.00
ASTER GDEM	10413.49	124.46	43.00	167.46
CartoDEM	10484.21	25.86	15.12	40.98
SRTM DEM	10492.98	17.84	15.88	33.72

5.3 ***Topographic and basin characteristics***

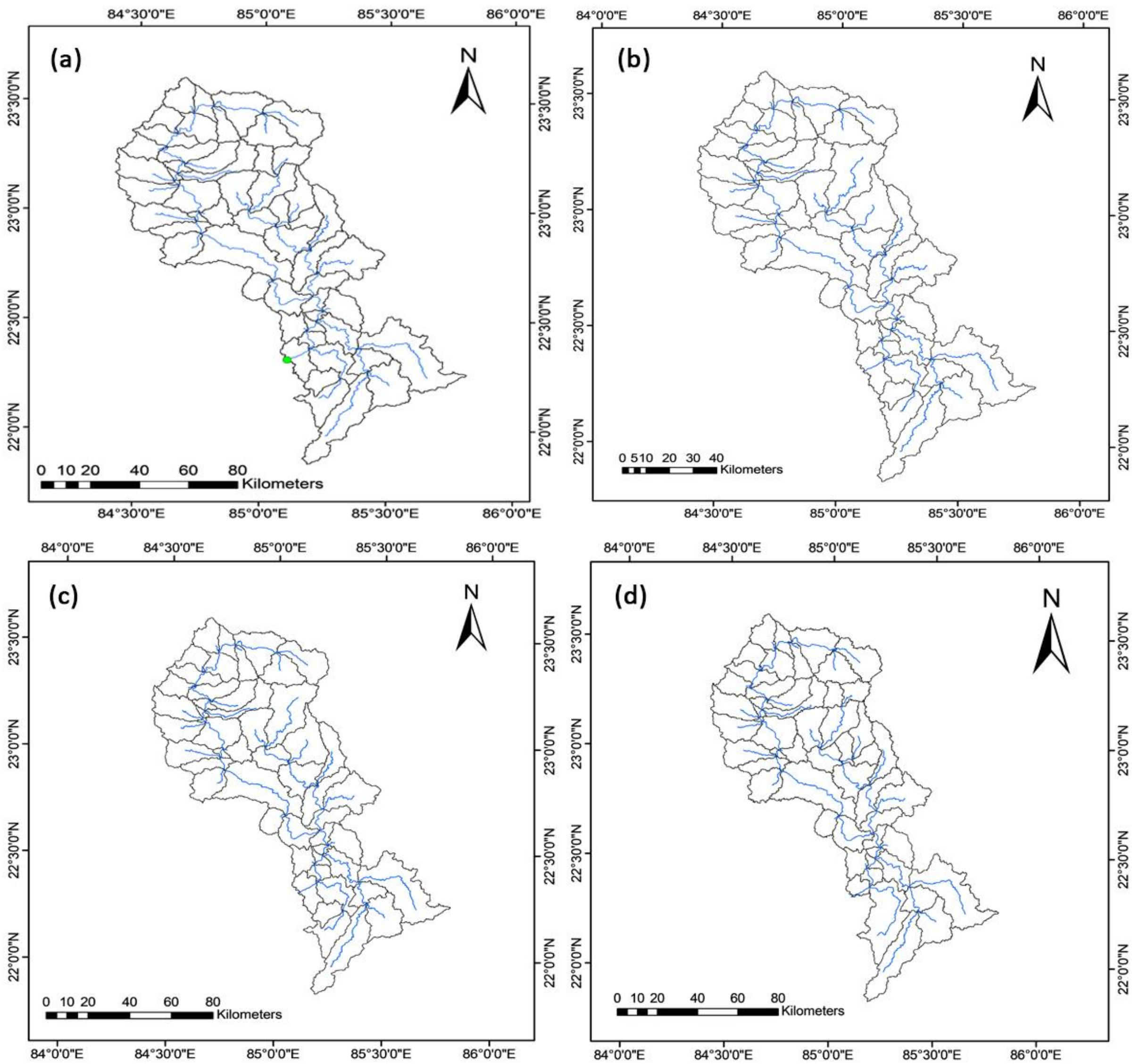

Figure 5. Sub basins derived from (a) AW3D30 DEM (b) CartoDEM (c) SRTM (d) ASTER DEM

Figure 5 shows the sub basin derived and the variation of shape in basin boundary due to different DEM sources. A difference in the number of HRU units were found due to different DEM sources with highest being AW3D30 DEM (252 HRUs), CartoDEM (237 HRUs), SRTM DEM (234 HRUs), ASTER GDEM (203 HRUs). Thus AW3D30 could possibly provide more detailed basin characteristics in the form of topographic information and void conditioned treatment of DEM sources. For the catchment, maximum elevation and the minimum elevation was underestimated by CartoDEM. Similar results was reported by Goyal & Panchariya, (2018) for upper Teesta and upper Narmada catchments.

The total basin area variation was found to be less between CartoDEM, AW3D30 DEM, and SRTM DEM with areas 10484.21 km^2, 10494.95 km^2, and 10492.98 km^2 respectively. The basin area delineated for ASTERGDEM was 10413.49 km^2. Table 4 lists the information about elevation and basin characteristics due to different DEM sources selected for the study. The obtained inferences are applicable in this catchment alone and should not be generalized. In a flat region or hilly mountainous regions, the results may be drastically different.

Table 4. Elevation information and basin characteristics

SI. No	DEM source	Elevation			Basin			
		Min elevation	Max elevation	Mean elevation	Sub basin	HRU	Area (km^2)	Perimeter (km)
1.	AW3D30 DEM	198	1088	541.82	55	252	10494.95	1173.77
2.	CartoDEM	140	1032	486.94	51	237	10484.21	1171.01
3.	SRTM DEM	200	1088	542.76	51	234	10492.98	1165.76
4.	ASTER GDEM	171	1097	541.51	53	203	10413.49	1041.34

6. Conclusions

The study is conducted on Jeraikela catchment to evaluate the performance of the different DEM sources in deriving the physical characteristics of the watershed. The study found that out of the freely available DEMs, AW3D30 DEM provided better river network extraction capability and derived the longest stream for a particular threshold area. The HRU distribution also was found to be more thus representing detailed topographic information in hydrological analysis.

On contrary ASTER DEM had poor river network extraction capability and major miss matches were found whereas CartoDEM showed underestimation in both maximum and minimum elevation in the catchment. Thus in essence, care should be taken while considering different DEM sources before its applicability in the study area. This study shows that AW3D30 DEM was best considering the basin boundary delineation and river network extraction criteria and thus it is recommended for future use of hydrological studies using SWAT in Jeraikela.

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