

Cartosat-1 derived DEM (CartoDEM) towards Parameter Estimation of Microwatersheds and Comparison with ALTM DEM

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Abstract Hydrologic analysis of microwatersheds is essential for water resources planning at large scale. Space based input for decentralized planning at panchayat level use high resolution DEM. Drainage and slope play important role in planning and Digital Elevations Models (DEM) are widely being used for estimation of hydrologic parameters which are useful as input for hydrologic models. The estimates vary as per resolution and type of DEM. This paper evaluates the suitability of DEM derived through Cartosat-1 satellite stereo data (CartoDEM) for hydrologic parameter estimation of microwatersheds and compares the results with Airborne Laser Terrain Mapper (ALTM) based DEM data. Comparison is based on the hydrologic parameters delineated in Geographical Information System. Microwatersheds are delineated and drainage length extracted using two different cell sizes for both DEMs. Correctness Index, Figure of Merit, visual comparison, Percent within buffer and Junction comparison method, compared extracted river network. Average watershed slope is calculated using three different methods. CartoDEM derived drainage is comparable with ALTM

derived drainage. There is high correlation between Carto5 and Carto10 DEMs in terms of drainage delineation and slope calculation. Average watershed slope vary as per calculation methods but average channel slope value (S3) although less, is comparable across DEMs.

Keywords Hydrology · Digital Elevation Model · CartoDEM · ALTM · Microwatershed · Slope

Introduction

Availability of Digital Elevation Models has opened many doors for hydrologic modeling of the Earth and DEMs generated from different sources are being made available day by day. The process of DEM generation is undergoing changes and more automation is coming in the process of generation of DEM from newer sources. Easily available SRTM DEM data has widely been used by researchers (Ling et al., 1998, Martza & Garbrecht, 1999, Schumann et al., 2008). SRTM standard data products are provided by resampling the raw data at 30 m (Sanders, 2007) and SRTM DEM is available at 90 m resolution for Indian sub continent (<http://www.cgiar-csi.org/data/elevation/item/45-srtm-90m-digital-elevation-database-v41>) which limits its utilization to study watersheds at large scale. The availability of ALTM DEM is very limited. There is a need for better resolution, easily available DEM for hydrological applications of all areas. CARTOSAT-1 satellite launched by ISRO for cartography applications, urban development

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and disaster management provides along track stereoscopic data for generation of Digital Surface Model and is available at Bhuvan website at 30m resolution (<http://bhuvan.nrsc.gov.in>). Satellite has a spatial resolution of 2.5 m. The high-resolution stereo data beamed from twin cameras onboard Cartosat-1 mission facilitates topographic mapping upto 1:25,000 scale (Srivastava et al. 2006). The primary advantage of Cartosat-1 mission is seen as generation of Digital DEM derived from Cartosat-1 data called as CartoDEM, which has planimetric accuracy of 15m (CEP90) and vertical accuracy of 8m (LE 90) (Krishnamurthy et al. 2008). When compared to SRTM over Indian landmass, 90% of pixels of CartDEM reported were within ± 8 m difference. The drainage delineation shows better accuracy and clear demarcation of catchment ridgeline and more reliable flow-path prediction in comparison with ASTER (Muralikrishnan et al., 2012).

Assessing the accuracy of DEMs has always been difficult (Gong et al., 2000).

DEM accuracy by single global Root Mean Squared Error (RMSE) is not sufficient to assess the spatial variability of DEM errors, especially for extensive regions as pointed out by Carlisle (2005). He also mentioned that it is necessary to do comparison in smaller regions. Another important parameter to access is the vertical accuracy of DEM which depends upon grid size, data sources and processing methods (US Geological Survey 2008).

Since the objective is to utilize DEM data for different applications, quality of DEM can be judged by evaluating the derivatives resulted from different sources DEM or DEM at different grid size. Numerous researchers have worked in this area. To see the applicability of DEM in hydrologic analysis, it is necessary to see the impact on flow lines/drainage extraction and average slope calculation, the parameters which affect the modeling procedure. Hydrological models rely on Digital Elevation Models to get information about different attributes needed for analysis (Moore et al., 1991) viz., slope, watershed boundary extraction, water flow lines etc. Drainage length and slope are important parameters in watershed analysis. Different hydrological models which convert rainfall into runoff are function of watershed slope. Wu et al. (2008) took 10 m USGS DEM and produced series of DEMs up to 200m grid size using three commonly used resampling methods. No systematic trend was observed for corresponding changes of flow path and watershed area.

Most comparisons were done using a single source of DEM with changing grid size to lower the resolution.

Slope along flow lines have an influence on stream flow and the hydrologic response of the watershed (Chang, 2006). Armstrong & Martz (2003) have shown that average watershed slope varies inversely with DEM grid size. Change in grid size smoothens the image. There are many algorithms which have been used by different researchers to calculate the slope. Hill & Vincent (2005) did Y slope estimate using three different methods with LIDAR data and confirmed that Y slope is inversely proportional to DEM grid size. Irfan et al. (2011) evaluated two slope calculation methods to determine their suitability with respect to estimating slopes along flow lines. Automatically extracting drainage networks from digital elevation models coupled with the constant stream threshold value is a regular method for drainage extraction. Two algorithms for drainage network identification were discussed and illustrated by Mark (1984). A comparison can be made with reference drainage by calculating correctness index (Li and Wong 2010). Davies & Bell (2009) suggested mean distance method, percent within buffer, catchment area and visual comparison methods for measurement of performance.

ALTM LiDAR data availability is very limited. National Remote Sensing Centre (NRSC) in India has acquired ALTM LiDAR data for few sample areas in the country. LiDAR data at 5m resampling was made available for the analysis which covered 16 sq km area.

Objective of the present study is to find the suitability of Cartosat data towards hydrologic applications for microwatersheds by comparing the derived parameters with ALTM LiDAR DEM derived parameters. The study aimed at comparing delineated potential flow lines for CartoDEM at two resolutions and estimating the error and sensitivity of average watershed slope associated to the grid size, and calculation methods.

Methodology

Present study is aimed at utilization and comparison of CartoDEM derived hydrologic products with ALTM LiDAR DEM derived products. CartoDEM is generated from Cartosat-1 stereo pair data at 5m and 10 m resolution. The 10m DEM grid was generated by subsampling the 5 m grid which is acceptable method of decreasing DEM resolution (Moore et al, 1993). Potential flow

lines/river network were delineated for different DEM and grid size. The extracted network was compared keeping 5m ALTM DEM as reference. Average watershed slope values were calculated using three different methods and compared.

Study Area

Availability of ALTM LiDAR data was the deciding factor to choose the study area. The area is located along Tapi river, which is a major river in Western India. The river divides states of Maharashtra and Madhya Pradesh. ALTM DEM data was obtained from National Remote Sensing Centre(NRSC) Hyderabad. Figure 1 shows the index map of the study area with CartoDEM 5m.

Generation of CartoDEM

The LPS 2011, which is a complete suite of photogrammetric production tools for triangulation, generating terrain models, producing orthomosaics and extracting 3D features (ERDAS) was used for the identification of horizontal and vertical GCPs and tie points. One cartosat stereo pair (531/297) which was sufficient for area covered by ALTM DEM was analysed. Cartosat-1 stereo pairs were added to the block and the respective Rational Polynomial Coefficient (RPCs) were attached to the images followed by computation of pyramid layer for each image. Block (or aerial) triangulation is the process of establishing a mathematical relationship between the images contained in a project, the camera or sensor model, and the ground. High resolution DEM chip was used for

taking vertical and horizontal control points. One ground control point is sufficient for restitution of the Cartosat model as per Sadasive Rao et al. (2006). Baltsavias et al. (2007) suggested use of minimum six well distributed GCPs for a Cartosat-1 scene. Accordingly 6 GCPS and 128 Tie points were taken and the block was triangulated with rmse of 0.498. DEM at 5 m resolution was extracted in Leica Terrain Format (LTF). Editing was carried out using mass points and breaklines. Care was taken to ensure that all the mass points lie on the ground. Any mass point lying on tree was deleted and brought to adjacent ground. Edited LTF was used to generate final DEM at 5m and 10m. The study area is devoid of forests and is dominated by agriculture so for all practical purpose, DSM generated after editing the LTF was considered as Digital Terrain Model.

Identification of Microwatershed Boundaries

Watershed delineation was done using hydrologic analysis tool of Arc/INFO GIS software (ESRI 2011). Appropriate pour points were selected for boundary identification and 17 watershed boundaries were identified. The watershed areas range from 5 Ha to 75 Ha. Watershed wise minimum, maximum, range and average elevation values were calculated for ALTM DEM and CartoDEMs. Elevation range in the area is between 220.45m to 275.9m which varied slightly with DEM source and resolution.

Figure 2 shows the percent variation in average watershed elevation between ALTM LiDAR DEM and other DEMs. A negligible variation of 0.5% was observed between ALTM and CartoDEM values.

Fig. 1 Index map of the study area showing CartoDEM at 5 m resolution

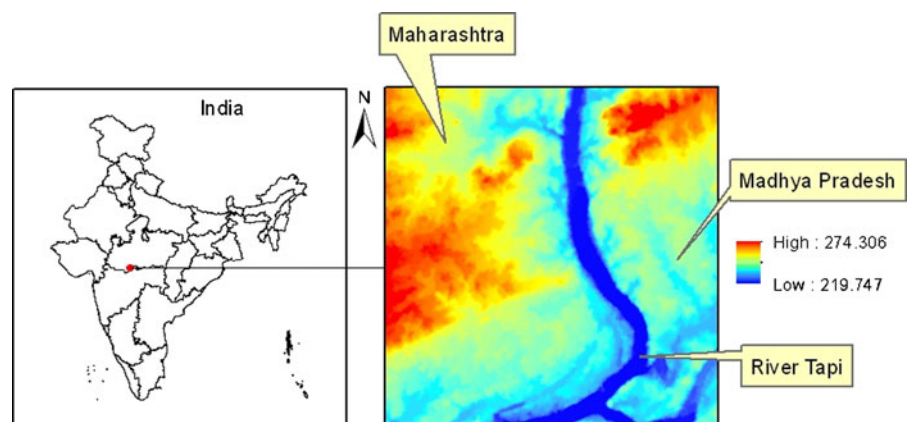
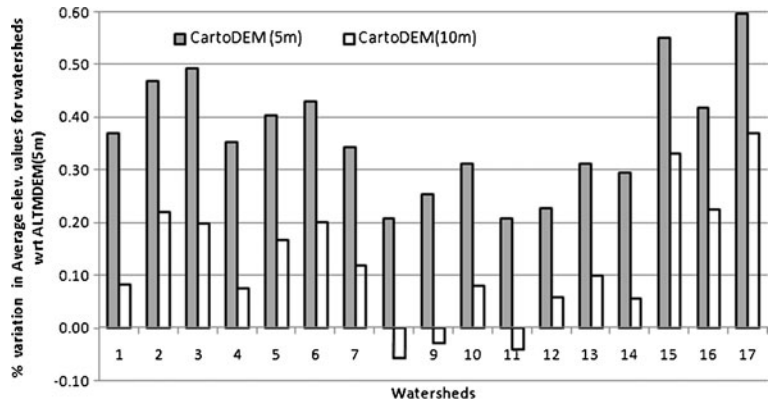


Fig. 2 Percent variation in average elevation values for watersheds with respect to ALTM DEM (5m)



CartoDEM(10m) elevation values showed better comparison to ALTM derived elevation values.

Demarcation of Potential Flow Lines/Drainage Lines

Stream networks can be delineated from a DEM using the output from the Flow Accumulation function. After identification of sinks, depressionless DEM is generated which is hydrologically adjusted and flow

direction is calculated from this DEM. Using the corrected flow direction grid, flow accumulation grid is calculated, which in its simplest form is the number of upslope cells that flow into each cell (ESRI 2011). By applying a threshold value to the results of the Flow Accumulation function using Map Algebra (or the Con tool in geoprocessing)(ESRI, 2011), a stream network can be delineated which is affected by threshold value (Tarboton et al. 1992).

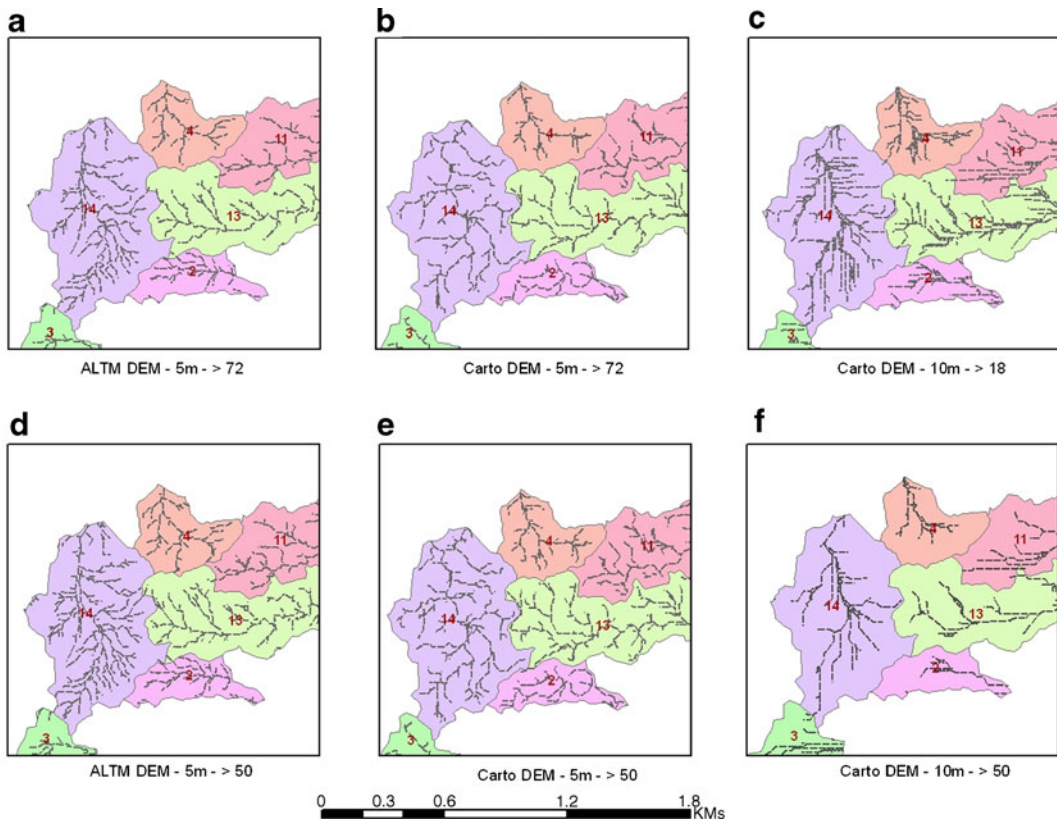


Fig. 3 Extracted drainage network for different case studies. **a,b,c** Constant contributing cell area (1800 sq m) **d,e,f** Constant threshold

A larger threshold reduces the number of extracted streams, avoiding redundant or artificial streams, whereas applying a smaller threshold creates more stream features, some of which may not actually exist (Tarboton, 1997, Tarboton & Ames, 2001). Determining a threshold value that represents where a permanent stream or stream channel begins is affected not only by contributing area but also by climate, slope, and soil characteristics (Tarboton et al., 1991). Since CartoDEM data has been used in the analysis which aims at generation of output at 1:10,000 scale (Radhadevi et al.) and grid size of 10m, an area threshold of 1800 sq m was selected which equals to double the mapping unit at this scale.

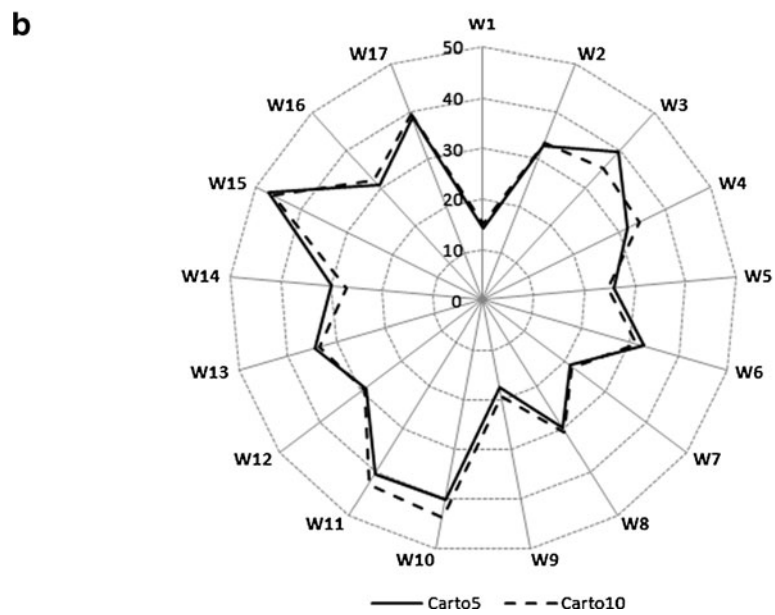
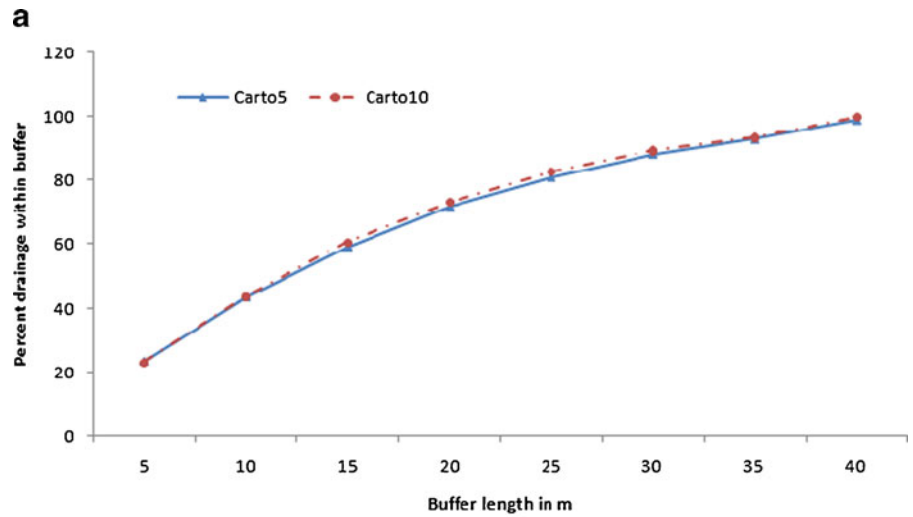
Calculation of Slope

Average watershed slope was calculated using three methods in the analysis. S_1 slope is the average of local slope values at every point in the watershed and is calculated by

$$S_1 = (1/n) \sum_{i=1}^n S_i \tag{1}$$

Where S_i is the local slope at cell i and n is number of cells in each watershed.

Fig. 4 a Percent drainage of Carto5 and carto10 within variable buffer around ALTM derived drain. **b** Result of junction comparison method showing the average distance of drainage from reference drainage on error circle within each watershed



Black (1996) has suggested a method for calculation of slope based on contours. S_2 slope is calculated as:

$$S_2 = C * I / A \tag{2}$$

Where C is total length of contour within watershed (m), I is contour interval and A is watershed area in sq m.

S_3 slope is calculated based on slope of longest flow path on channel slope as given by Olivera & Maidment (1998) and Moglen & Hartman (2001), where

$$S_3 = \Delta H / L \tag{3}$$

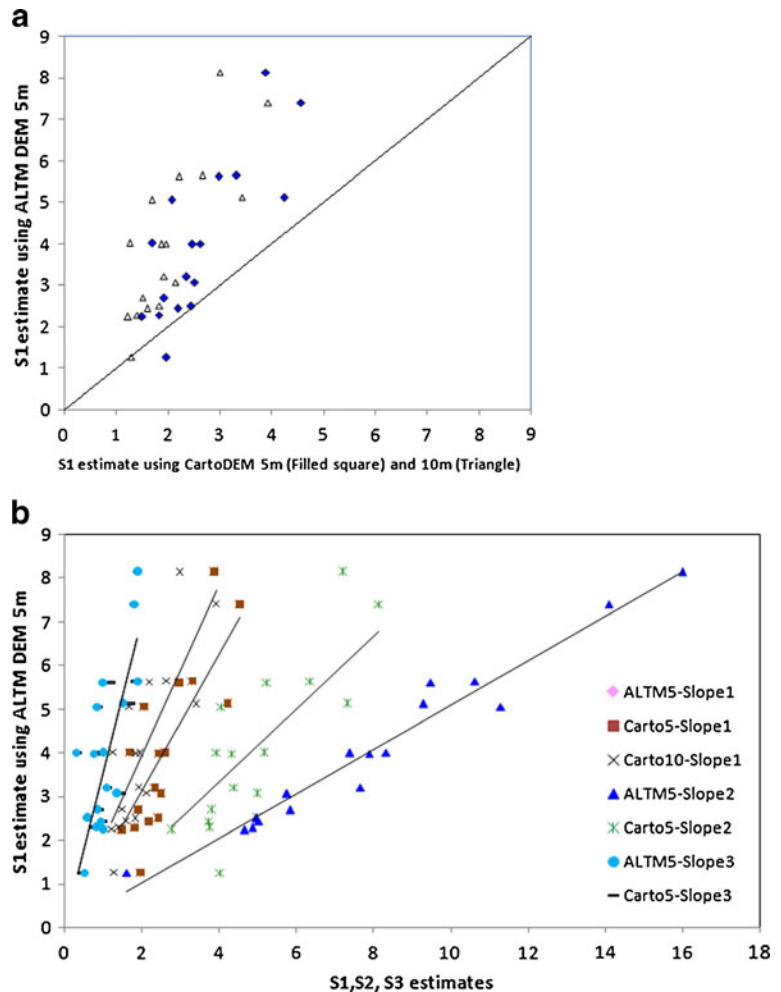
Where ΔH is change in elevation along the longest flow path and L is the length of longest flow path. This method also gives average watershed slope generally used in watershed analysis.

Evaluation/Comparison

Extracted river network was compared with network delineated from ALTM LiDAR DEM of 5 m grid size. In the present study to compare the drainages, the indices Correctness Index (CI) and Figure of Merit (FM) suggested by Jing Li (2010) and Pontius et al. (2008) have been used. Value of CI lies between 0 and 1 with value close to 1 for close resemblance of DEM. The Figure of Merit (FM) can range from 0%, meaning no overlap between observed and predicted change, to 100%, meaning perfect overlap between observed and predicted change. It gives a better understanding of the extracted drainage network.

Percent within buffer suggested by Davies (2009) was used to reduce the effect of mis-registration of DEMs of different data sources. Percent drainage

Fig. 5 **a** Comparison of S1 estimates from ALTM DEM (Reference DEM), Carto5m and Carto10m DEM. *Filled symbol* is for Carto5m and *triangles* represent Carto10m. **b** Comparison of different slope estimates with reference ALTM S1 estimate



length of CartoDEM derived drainage within buffer around the reference drainage was calculated and compared. In another method of comparison called ‘Junction comparison, the distance between junction points of drainages was compared. This is particularly useful for watershed as the changed location of outlet points can change the results. Prominent junction points were numbered on each DEM and distance between them was calculated and compared.

Results

Potential Flow Lines Extraction

Extracted river network for all case studies are shown in Fig. 3.

Drainage network was extracted for constant contributing cell area and constant threshold value. From the visual observation of potential drainages it is clear that keeping the threshold value corresponding to constant contributing area results in almost similar drainage extraction (Fig. 3a, b and c). The length of extracted drainage reduces with DEM grid size for same threshold value (Fig. 3e, f). Effect of changing threshold values can be seen in the extraction of small first order drainages. The drainage lines appear similar and seem to be matching visually, but statistically they are apart. The delineation is different from both DEMs but follow a similar trend in same source DEM at different resolutions.

To check the positional accuracy of extracted lines, CI and FM values were calculated for all the microwatersheds for ALTM5-Carto5, ALTM5-Carto10 and Carto5-Carto10 combinations where 5 and 10 are grid sizes. Lowest CI and FM values are observed between ALTM5-Carto5 combination. Lower CI values between ALTM5 and CartoDEM5 may be attributed to positional errors in the data, which can also be concluded from increasing CI values between ALTM5 and Carto10. FM values are overall lower than CI values.

To understand the effect of positional mismatch between reference DEM and other DEMs, buffer masks with variable buffer length (5m to 40m) were generated around ALTM DEM derived drainage. Percent length of drainage extracted using other DEMs falling within each buffer area was calculated. Figure 4a shows the variation in drainage within

buffer area for two DEMs at various buffer length. Around 20 to 25% of drainage extracted from cartoDEM fall within 5m buffer of ALTM derived drain. As evident from Fig. 4a, entire extracted drainage fall within buffer of 40m.

For junction comparison method, around 85 major junction points were identified on each drainage output. The junctions which belong to different flow path were not chosen in this analysis. Absolute distance between junction points was calculated to know the positional displacement of junctions. An average distance value of 31.5m was observed between junctions of ALTM5 and Carto5 drainage which marginally increased to 31.84 between ALTM5 and Carto10. Figure 4b shows the results of junction comparison method for 17 watersheds on error circles. The circles represent the distance between the junctions on reference DEM and other DEMs (10m to 50m).

Comparison of Slopes

Slope estimates for (i) ALTM5m-S1, S2 and S3 (ii) Carto5m-S1, S2 and S3 and (iii) Carto10m-S1 for all

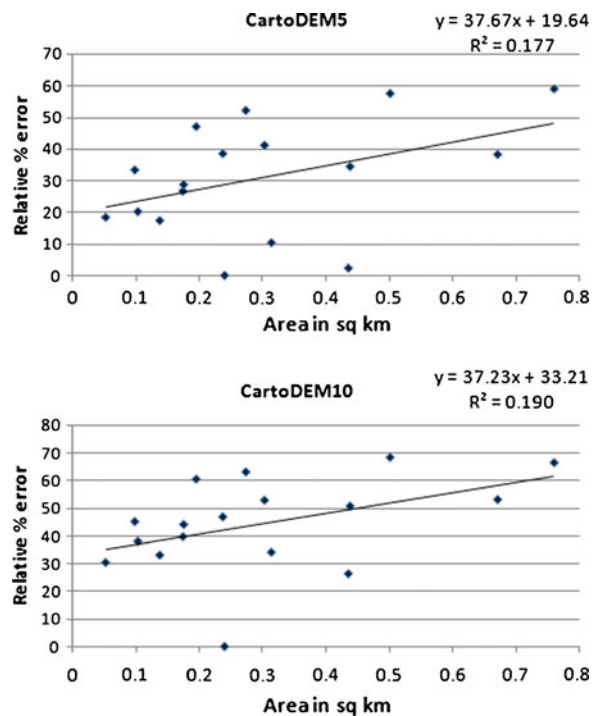


Fig. 6 Graph showing relation between relative percent error in S1 estimate and watershed area for (i) Carto5-ALTM and (ii) Carto10-ALTM

the 17 watersheds were carried out. ALTM S2 estimate gives highest estimate of slope in comparison to other estimates. If we plot ALTM S1 slope estimate with Carto5 and Carto10 S1 estimates (Fig. 5a) then the points lie on the west side of the line indicating under biasness in the S1 estimate using Carto5 and Carto10 DEMs. The average difference between S1 estimates was 34.2% for Carto5 and 42.5% for Carto10.

Keeping ALTM S1 estimate as reference on Y axis, all the other estimates are plotted on X axis as shown in Fig. 5b. From the Fig. 5b it is clear that S3 estimates are lower than all the other estimates. The estimates considerably vary due to different methodologies and one can not replace one estimate for the other. The variability is S3 estimate is very low between different DEMs making it source independent. The model results will vary considerably with different slope estimates.

In order to correlate the difference in slope estimate with elevation, difference between maximum and minimum elevation for each watershed was found out. A correlation of 0.826 was obtained between difference in slope estimates and elevation difference. The variation in S2 estimate is very high. More variation is seen in watershed 9, 10 and 11 which have undulating topography with large elevation difference between hill to pour point of watershed.

To understand the impact of watershed area on slope estimate, a graph was plotted between relative percent error in S1 estimate between Carto5-ALTM and Carto10m-ALTM and watershed area (Fig. 6).

Although the graph shows a positive trend of increase in relative error with area, a correlation of 0.42 and 0.44 was found between these two parameters for Carto5 and Cart10. A low correlation of 0.257 was also found between difference in slope estimates for watershed and watershed area.

Conclusions

Evaluation of two grid size of cartoDEM was carried out towards hydrological parameter estimation and the results were compared with reference ALTM DEM. DEM grid size of 5m and 10m was selected for CartoDEM for direct comparison with ALTM and direct applicability to various thematic applications.

Extracted drainage network is visually comparable between DEMs and the drainage lines follow similar

path. Minor changes are observed in the orientation of first order tributaries on different DEMs. The extracted drainage density is similar when same contributing area is used for threshold calculation.

Carto5 and Carto10 were comparable for positional accuracy and high value of correctness index was found between these two observations. Carto10 derived drainage performed better in comparison to Carto5 when positional accuracy of drainage was mapped between ALTM and CartoDEM. Around 30 to 40m positional shift was observed between derived drainage and their junctions as evident from buffer and junction comparison analysis.

All the three methods of slope calculation yielded different results but within same method, high correlation in slope estimates was obtained between different DEM sources. A correlation between S3 estimates yielded a value of 0.982, whereas the same value for S1 estimate was 0.81. S2 estimation is affected by topographic undulations and the results vary from watershed to watershed. Variability in S3 estimation is very low and the results across DEMs are comparable.

The study showed that CartoDEM derived drainages are comparable with ALTM derived drainages with a positional shift of around 40m. Although S3 slope estimates differ from S1 and S2 estimates, S3 estimates are comparable across DEM sources and hence are insensitive to DEM source. CartoDEM data finds usability in hydrologic analysis of small microwatersheds.

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