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Comparative Performance Evaluation of Different Digital Elevation Models

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ABSTRACT
Digital elevation model (DEM) represents the terrain of the earth. The open source DEM involves systematic errors and unknown errors that are geographically dependent on terrain conditions. The performance evaluation of these DEM's against the global positioning system (GPS) surveyed elevation data becomes essential for better delineation of watershed boundary. Therefore, this study was conducted in Lohawati watershed of Champawat district, Uttarakhand, to assess the accuracy of ASTER, SRTM and Cartosat DEM's with respect to GPS surveyed elevation data of 58 location points. The elevation from DEM's were extracted to these points in ArcGIS environment. MAE, RMSE and PI were the statistical indices used for accuracy assessment. The analysis revealed that ASTER-DEM was most accurate with least MAE (15.22), RMSE (18.48) and PI (0.01223), followed by SRTM-DEM. Cartosat-DEM was least accurate with MAE, RMSE and PI values as 34.36, 37.41 and 0.01227, respectively. The coefficient of determination (R^2 = 0.98) was similar for the three DEM's. However, the slope and intercept for ASTER-DEM regression line was closest to 1 and 0, respectively. Thus, ASTER-DEM performed better for mountainous terrain and may be used for watershed delineation.
Keywords: Digital Elevation Model, ArcGIS Software, Statistical Indices, Watershed

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INTRODUCTION
It is essential to divide the basin into lesser hydrological units such as watersheds and sub-watersheds for effective implementation of management practices. Thus, for any watershed study the first and prior most requirement is to know its boundary i.e. watershed delineation. As in earlier days the delineation of watershed was performed using topographic sheets which was a cumbersome task. Now, with the advancement in technology it can be easily achieved by processing the freely available digital elevation model (DEM) in GIS software such as ArcGIS, QGIS etc. The DEM's are available in various spatial resolutions and can be downloaded free of cost from various sources such as USGS Earth Explorer, Bhuvan a geo-platform of Indian Space Research Organization (ISRO), JAXA Global ALOS portal etc. However, the downloaded DEM's from different sources, having same spatial resolution, have different degree of accuracy as far as elevation is considered. Therefore, this study was carried out to access the elevation accuracy of the three DEM's; Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER), Shuttle Radar Topography Mission (SRTM) and digital elevation model generated using the stereo images of Indian Remote Sensing Satellite Cartosat-1 (Cartosat).

Study Area
The study was carried out in Lohawati watershed of Champawat district of Uttarakhand state in India, which is situated in the lesser Himalayas. Fig 1. It lies in the eastern part of the Kumaon division with longitude 80° 00' 00"to 80° 06' 00" E and latitude 29° 16' 48" to

29° 25' 48" N. The watershed has an area of 1,07.91 km^2. The region is drained by Lohawati and Ladhiya rivers and its tributaries. The average mean sea level elevation varies from 1222 to 2123 m.

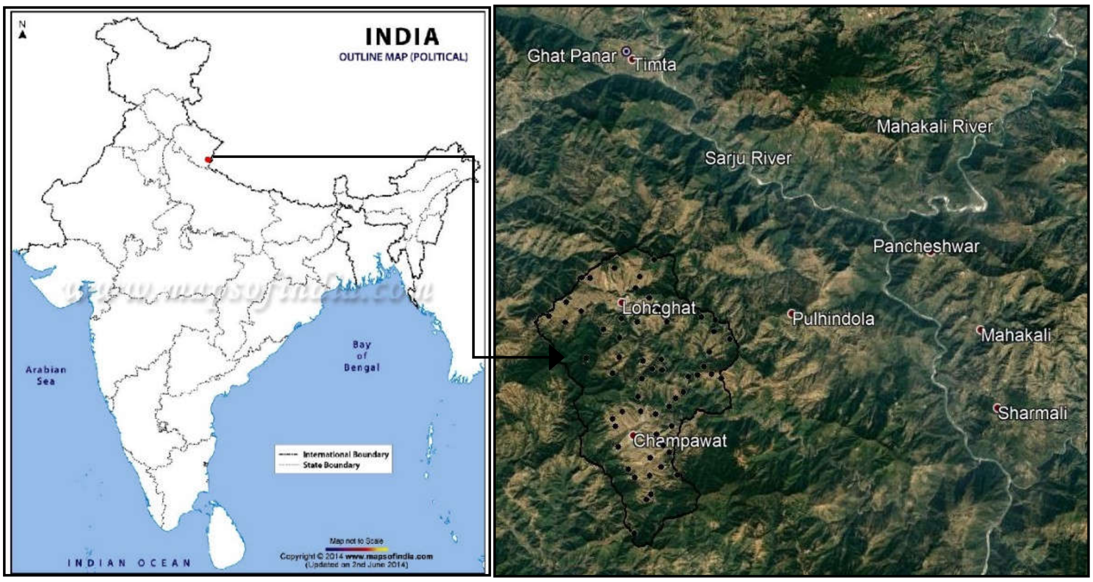

Fig. 1. Index map of Lohawati watershed.

MATERIAL AND METHODS

The SRTM and ASTER DEM's of 30 m spatial resolution were downloaded from USGS Earth Explorer [8] and Cartosat-1 DEM of 30 m spatial resolution was downloaded from Bhuvan [6]. The source and details of DEM's are given in Table 1. The elevation data was recorded for 58 locations in the study area, using global positioning system (GPS) model Garmin- 10 (UTM 44N, WGS84), as shown in Fig. 2. ArcMap the main component of ArcGIS software was used for processing and analysis of DEM's. The error in DEM elevation is assessed using higher accuracy field surveyed data [1, 2]. The stepwise procedure for extracting the elevation data without any interpolation corresponding to the 58 locations from digital elevation model is as follows:

1. Add DEM to ArcMap
2. Add the survey location points as shapefile.
3. ArcToolbox > Spatial Analyst Tools > Extraction > Extract Values to Points
4. The values from the DEM are represented in Attribute Table as RasterValue
5. ArcToolbox > Conversion Tools > Excel > Table to Excel

The extracted elevation data, without interpolation from DEM's, and recorded data for survey locations was statistically analyzed using the statistical indices such as Mean Absolute Error (MAE), Root Mean Square Error (RMSE) and Performance Index (PI) defined as:

$$RMSE = \sqrt{1/n \sum_{i=1}^{n} (e_i)^2}$$

$$MAE = 1/n \sum_{i=1}^{n} |e_i|$$

$$PI = \frac{\left(RMSE/\overline{H}_{GPS}\right)}{1 + \left(\sum_{i=1}^{n} \left(H_{GPS} - \overline{H}_{GPS}\right)\left(H_{DEM} - \overline{H}_{DEM}\right) \Big/ \sqrt{\left(H_{GPS} - \overline{H}_{GPS}\right)^2 \left(H_{DEM} - \overline{H}_{DEM}\right)^2}\right)}$$

$$PI = \frac{RMSE/\overline{H}_{GPS}}{1 + r}$$

where, $e_i = H_{GPS} - H_{DEM}$, H_{GPS} and H_{DEM} are elevations recorded by GPS and that extracted from DEM, and r is correlation coefficient, square of which is the coefficient of determination (R^2). MAE value ranges between zero to infinity based on the prediction [7]. The RMSE value ranges from zero for an exact estimate to large positive values for poor estimates [5]. The performance index value ranges between 0 and infinity, with lower values showing better accuracy [4].

Table 1. Description of digital elevation models for the study area.

DEM	Satellite	Name of Dataset	Spatial Resolution (m)	Datum	Site
ASTER	ASTER GDEM	ASTGDEMV2_0N29E080	30	WGS_1984	https://earthexplorer.usgs.gov/
SRTM	Shuttle Radar	SRTM1N29E080V3	30	WGS_1984	https://earthexplorer.usgs.gov/
Cartosat	Cartosat-1	C1_DEM_16b_2005-2014_v3r1_80E29N_h44o	30	WGS-1984	https://bhuvan-app3.nrsc.gov.in/data/download/index.php

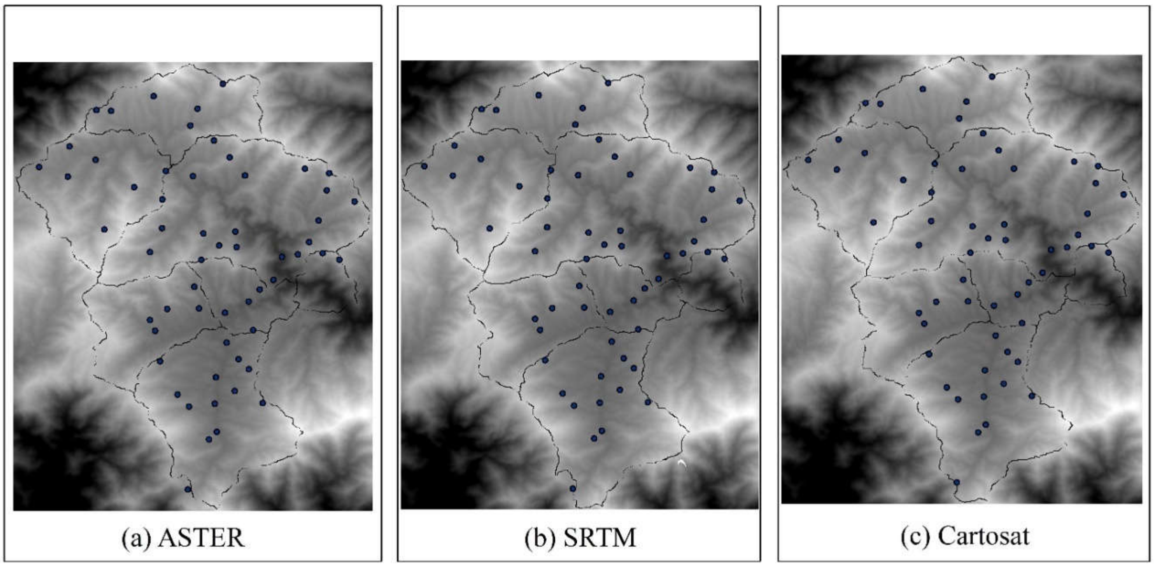

Fig. 2. Study area with points used for GPS recording and superimposed on DEM's.

RESULTS AND DISCUSSION

The performance comparison of the three DEM's (ASTER, SRTM and Cartosat) was carried out for the 58 locations' elevation data without any interpolation method. The statistical analysis revealed that RMSE is minimum for ASTER-DEM with a value of 18.48 followed by SRTM-DEM and Cartosat-DEM with values 19.95 and 37.41, respectively (Table 2). The MAE was found to be 15.22, 17.09 and 34.36 for ASTER-DEM, SRTM-DEM and Cartosat-DEM, respectively. The computed PI value of 0.01223 for ASTER-DEM was found to be least and a maximum of 0.01227 for Cartosat-DEM and that for SRTM-DEM, it was 0.01226. On the basis of these statistical indices ASTER-DEM, which gave lowest values of MAE, RMSE and PI, resulted the most closer elevation values to the recorded GPS readings.

Table 2. Statistical indices of the three DEM's without interpolation.

	MAE	RMSE	PI
ASTER-DEM	15.22	18.48	0.01223
SRTM-DEM	17.09	19.95	0.01226
Cartosat-DEM	34.36	37.41	0.01227

The coefficients of determination (R^2) for best linear regression line fitted to DEM's and GPS elevation data were almost similar with a value of 0.98, as shown in Fig. 3. The slope and intercept of regression lines for ASTER-DEM, SRTM-DEM and Carto-DEM were (0.996, 16.19), (0.984, 40.14) and (0.989, -16.90), respectively. The slope and intercept of best fit linear regression line, are 1 and 0, respectively [3]. The ASETER-DEM was better fitted as the slope and intercept were closer to 1 and 0, respectively.

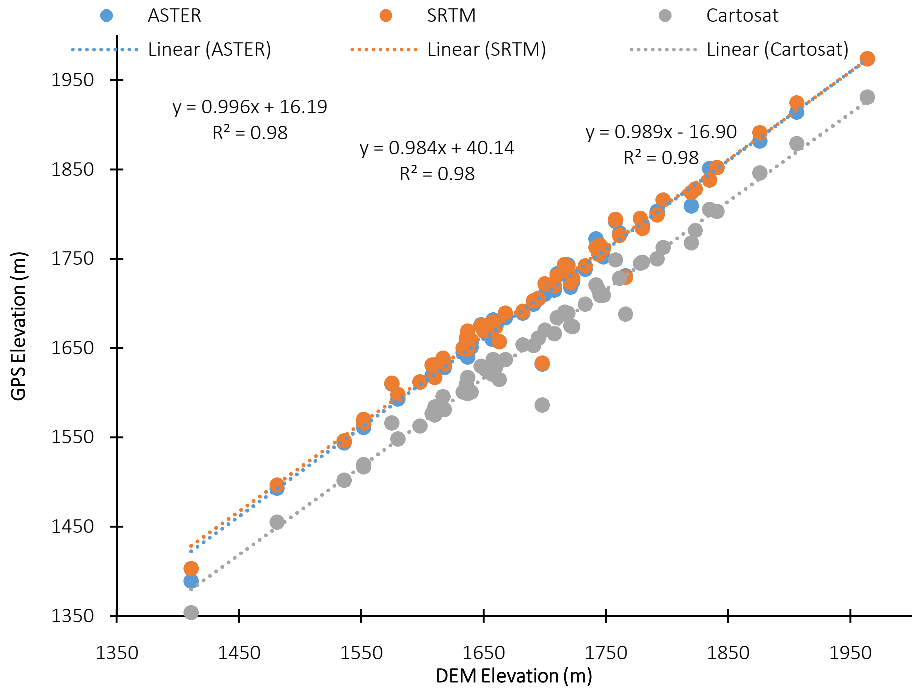

Fig.3. Scatter plot of DEM's (ASTER, SRTM, Cartosat) elevation vs GPS elevation.

CONCLUSION

The 58 points with elevation data, recorded with the help of GPS, were superimposed on DEM's in ArcGIS environment. The elevation values, corresponding to these points, were extracted and statistical indices MAE, RMSE and PI were computed. The Aster-Dem elevation data were in close proximity to the recorded GPS elevations as indicated by a PI value of 0.01223, which is closest to 0 than others. The MAE and RMSE were also minimum for ASTER-DEM. The Cartosat-DEM performed badly based on these statistical parameters followed by SRTM-DEM. With almost similar R^2 value, ASTER-DEM elevations were in close resemblance to that recorded by GPS as the slope and intercept of regression line was closer to 1 and 0, respectively. Thus, the ASTER-DEM performed better for a mountainous rugged terrain and may be used for watershed delineation for further planning and management studies.

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