Comparison of Cartosat, ASTER and SRTM DEMs of Different Terrains

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Abstract
In last few years, Digital Elevation Models have established much more imperative due to their diverse applications and utility in the fields of Terrain analyses, in geomorphology etc. Because of their inevitability, DEMs with reasonable accuracy and at higher spatial resolutions are being generated by different organizations worldwide, e.g. Cartosat DEM of Indian Space Research Organization (30m), Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Global Digital Elevation Model (30m) and SRTM (90m and 30m). In the present study, specific areas have been selected based upon the terrain ruggedness i.e. Himalayan Kanchenjunga area (highly rugged terrain), Lalitpur area of Uttar Pradesh district (Moderately rugged terrain) and Roorkee area of Uttarakhand (almost flat terrain). Followed by a statistical comparison made between Cartosat-DEM (30m), ASTER-GDEM (30m) and SRTM DEM (30m) for the three regions of India. Topographic maps for the three regions have also been used to compare spots height with corresponding values in Cartosat-DEM, ASTER-GDEM and SRTM-DEM.

Key words: Digital Elevation Model (DEM); Comparison; Cartosat-DEM; ASTER-GDEM; SRTM-DEM.

1. Introduction
Digital Elevation Model (DEM) is a digital representation of terrain as a raster (a grid of squares) of the earth's surface that stores Earth’s elevation information. DEMs represent a convenient way of storing elevation information and of making such information available to applications programs such as GIS. Most frequently the term is used to refer to a set of elevation data. Hence due to its expanding utilization and importance many national cartographic organizations are putting their efforts to generate DEMs of different characteristics. Remote sensing has the ability to cover a large area in a short time which leads remote sensing to be a very dominant tool in the modern-day geosciences. There are many applications of remote sensing techniques in various fields, such as natural disasters, mineral and groundwater exploration, environmental studies, land use, forest studies etc. DEMs are used often in geographic information systems. DEM can also be obtained from direct topographic surveys but now are being obtained through remote sensing (Sharma et al., 2010). In the last few years interferometry synthetic aperture RADAR is found to be of extensive use for generating DEM. Two passes of a radar satellite (such as RADARSAT-1), or a single pass if the satellite is equipped with two antennas used to generate a DEM. Alternatively, stereoscopic satellite image pairs can be employed using the digital image correlation method (Sharma et al.,2010 and Marks et al.,1984). Where two optical images acquired with different angles taken from the same pass of a satellite (such as the HRS instrument of
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Figure 1. Location of study areas.

SPOT5, the VNIR band of ASTER, Cartosat-PAN stereo etc.).

In this paper, Cartosat-DEM, ASTER-GDEM and SRTM-DEM for three different terrains of India have been studied and compared for suitability study.

a) Kanchenjunga (Himalaya) which is highly rugged terrain.

b) Lalitpur (Uttar Pradesh) which is a moderately rugged terrain.

c) Roorkee (Uttarakhand) of Indo-gangatic plane (near flat terrain).

2. Data Used

In the study topographic maps, Cartosat DEM (30m), ASTER-GDEM (30m) and SRTM-DEM (30m) have been used and discussed briefly in subsequent sections.

2.1 Topographic Map

A topographic map is a detailed and accurate graphic representation of cultural and natural features on the ground. The feature that most distinguishes topographic maps from maps of other types is the use of contour lines to portray the shape and elevation of the land. Topographic maps render the three-dimensional ups and downs of the terrain on a two-dimensional surface. The following topographic maps were used in the present study, which have been produced by Survey of India for Government of India.

(a) Kanchenjunga (Sikkim Himalaya 1:50,000 scale)
(b) Lalitpur (Uttar Pradesh 1:50,000 scale)
(c) Roorkee (Uttarakhand 1:50,000 scale)

2.2 Cartosat-DEM Characteristics and Accuracy

Indian Space Research Organization (ISRO) has launched Cartosat-1 on May 5, 2005 with prime objective of delivering high-resolution satellite data of 2.5 m in-track stereo. One of its mission goals is to generate a DEM and corresponding ortho-image for the entire country to facilitate large scale mapping and terrain modelling applications. Cartosat-1 has completed nine years of its operation successfully and has acquired images over India and across the globe. Cartosat-1 satellite has two panchromatic cameras with 2.5 m spatial resolution, to acquire two images simultaneously, one forward looking (Fore) at +26 degrees and another rear looking (Aft) -5 degrees for near instantaneous stereo data. The time difference between the acquisitions of the same
scene by two cameras is about 52 seconds. The spacecraft body is steerable to compensate the earth rotation effect and to force both Fore and Aft cameras to look at the same ground strip when operated in stereo mode. Simultaneous stereo pair acquisitions are of immense advantage since the radiometric parameters of the images are identical. The stereo pairs have a swath of 26 km and a fixed B/H ratio of 0.62. The satellite covers the same area in a specified interval of 126 days. The roll and tilt capability of Cartosat-1 can be used to increase the viewing frequency, which varies with latitude. The revisit capability at equator is 5 days.

### 2.3 SRTM-DEM Characteristics and Accuracy

The SRTM-DEM (30m) has been acquired from the Consultative Group on International Agricultural Research and Consortium for Spatial Information. The Shuttle Radar Topography Mission (SRTM) 1-arc second DEM (approx. 30m resolution) is the result of a collaborative effort by the National Aeronautics and Space Administration (NASA), the National Imagery and Mapping Agency (NIMA), the German Aerospace Centre (DLR), and Italian Space Agency (ASI) (Foni et al., 2004, Jenson et al., 1998 and Sharma et al., 2010). The mission was launched on 11 February 2000 aboard the Space Shuttle Endeavour. Using radar interferometry, a 3-arc second (SRTM-3) DEM was produced covering almost 80% globe excluding polar regions (Table 1). Initially a 1-arc second data product was also produced, but was not available for all countries. However since January 2015 NASA is providing the 1-arc second data freely for many countries including India. The data currently is being distributed by NASA/USGS (finished product) contains ‘no-data’ termed as voids where water or heavy shadow prevented the quantification of elevation. These are generally small holes, which nevertheless render the ‘no-data’ especially in fields of hydrological modelling. Later, through further processing the original DEMs were filled in these no-data voids. Data were collected using two interferometers, C-band (American) and X-band (German) systems, at 1-arc second (30 m) (Foni et al., 2004, Jenson et al., 1998 and Sharma et al., 2010).

### 2.4 ASTER-GDEM Characteristics and Accuracy

The ASTER instrument was launched on-board NASA’s Terra spacecraft in December 1999. The ASTER GDEM, made available in June 2009, was generated using stereo-pair image collected by the ASTER instrument onboard Terra. ASTER GDEM coverage spans from 83° north latitude to 83° south, encompassing 99 percent of Earth's landmass. It has an along-track stereoscopic capability using its near infrared spectral band and its nadir-viewing and backward viewing telescope to acquire stereo image data with a base-to-height ratio of 0.6. One nadir-looking ASTER visible and near-infrared (VNIR) scene consists of 4,100 samples by 4,200 lines corresponding about 60 km x 60 km ground area. The accuracies estimated for the ASTER-GDEM are 20m for the elevation values and 30m for horizontal positioning. This assessment concluded that the actual elevation accuracy of GDEM tiles is within or close to the stated accuracy of 20 meter at 95% confidence.

### 3. Methodology

Topographic maps for the three study areas were scanned and georeferenced. DEMs were generated, digitizing the contour lines on the topographic maps. The point elevation information (spot heights) present in the topographic maps were digitized (Figure: 2). Slope and aspect map of Kanchenjunga, Lalitpur and Roorkee areas are generated using Cartosat-DEM, ASTER-GDEM and SRTM-DEM which showed almost uniform trend for these three locations. The number of spot heights i.e. 147 points for Kanchenjunga, 91 points for Lalitpur and 151 points for Roorkee present in the topographical map are digitized and corresponding values of these points from topographic map (DEM from contour) Cartosat-DEM, ASTER-GDEM and SRTM-DEM of study areas were extracted. Later, statistical comparisons are made between spot heights and corresponding cell values of Cartosat-DEM, ASTER-GDEM and SRTM-DEM (Table 2 and 3).

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**Table 1. Characteristics of Cartosat-DEM, ASTER-GDEM and SRTM-DEM.**

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Cartosat-DEM</th>
<th>ASTER-GDEM</th>
<th>SRTM-DEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tile size</td>
<td>7.5’ x 7.5’ ~ 13.5km x13.5km (1º)</td>
<td>3601’ x3601 cells (1º x1º)</td>
<td>1 arc second (1º x1º)</td>
</tr>
<tr>
<td>Spatial resolution</td>
<td>1 arc-second (30m)</td>
<td>1 arc-second (30m)</td>
<td>1 arc-second (30m)</td>
</tr>
<tr>
<td>Geographic Coordinates</td>
<td>Latitude and longitude</td>
<td>Latitude and longitude</td>
<td>Latitude and longitude</td>
</tr>
<tr>
<td>DEM format</td>
<td>Geo-Tiff, Referenced to the WGS 84</td>
<td>Geo TIFF, signed integer 16 bits and 1m/DN Referenced to the geoid</td>
<td>Geo TIFF, signed integer 16 bits and Referenced to the WGS 84</td>
</tr>
<tr>
<td>No Data Values</td>
<td>-999</td>
<td>-9999</td>
<td>-32768</td>
</tr>
<tr>
<td>Coverage</td>
<td>North 83° - South 83°</td>
<td>North 83° - South 83°</td>
<td>North 60° - South 60°</td>
</tr>
</tbody>
</table>
Table 2. Statistical comparison of point elevation values extracted from different DEMs.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Kanchenjunga (in m)</th>
<th>Lalitpur (in m)</th>
<th>Roorkee (in m)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Topographical map</td>
<td>ASTER</td>
<td>Cartosat</td>
</tr>
<tr>
<td>Mean</td>
<td>5508.7</td>
<td>5470</td>
<td>5410</td>
</tr>
<tr>
<td>Std. Dev.</td>
<td>680.83</td>
<td>671.93</td>
<td>671.06</td>
</tr>
</tbody>
</table>

Table 3. Comparison of slope and aspect mean values extracted from slope and aspect maps derived from three different DEMs.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Kanchenjunga</th>
<th>Lalitpur</th>
<th>Roorkee</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slope Mean</td>
<td>89.53</td>
<td>89.99</td>
<td>89.58</td>
</tr>
<tr>
<td></td>
<td>87.19</td>
<td>89.97</td>
<td>87.25</td>
</tr>
<tr>
<td>Aspect Mean</td>
<td>170.14</td>
<td>170.59</td>
<td>170.18</td>
</tr>
<tr>
<td></td>
<td>150.94</td>
<td>160.11</td>
<td>152.89</td>
</tr>
<tr>
<td></td>
<td>167.50</td>
<td>169.93</td>
<td>168.52</td>
</tr>
</tbody>
</table>

Figure 2. Spot heights derived from topographic map top to bottom (along column) Kanchenjunga, Lalitpur and Roorkee. Left to right (along row) ASTER-GDEM, Cartosat-DEM and SRTM-DEM.
Figure 3. Distribution of Spot Heights for Kanchenjunga area. (Total number of spot heights is 147)

Figure 4. Distribution of Spot Heights for Lalitpur area. (Total number of spot heights is 91)

Figure 5. Distribution of Spot Heights for Roorkee area. (Total number of spot heights is 151)
4. Results and Discussion

The present study gives an idea about choosing suitable DEM based upon ruggedness of terrain. Here the remote sensing technique of generation for both Cartosat DEM and ASTER-GDEM are same and SRTM-DEM is derived from SAR image data pair. Further the spatial resolutions of the three DEMs are same but still there is a variation observed (Figure 6). The study infers that the mean and standard deviation of SRTM-DEM is almost close to the values derived from topographical map. In comparison to SRTM-DEM, Cartosat and ASTER GDEM show significant deviation for all the three locations. But earlier in case of SRTM-DEM (90m) the deviation was significant for highly rugged terrains like Kanchenjunga, (Sharma et al.,2010). Further the ASTER-GDEM values of Kanchenjunga area (highly rugged terrain) almost close to point heights extracted from topographical map (Figure:3) whereas, for other areas i.e. Roorkee and Lalitpur the spots heights values derived from Cartosat-DEM shows a significant drop in comparison to the topographical map. The Figures 3, 4 and 5 supports our study where surface profiles are been created using the extracted spot height values from the corresponding DEM. In case of Kanchenjunga the spot height graph almost overlapped for toposheet, ASTER and Cartosat DEM, but large fluctuations were observed in case of Cartosat-DEM for other areas i.e. Roorkee and Lalitpur.

5. Conclusions

The spot height accuracy of SRTM-DEM 1arc second seems to be good for all kind of terrain. For Cartosat DEM point height accuracy for highly rugged terrain is acceptable in comparison to ASTER-GDEM. Though the two DEMs are generated in same technique, Cartosat-DEM shows more
mismatches for near flat and moderately rugged terrain in comparison to ASTER-GDEM but holds good for highly rugged terrain.

**Acknowledgement**

ASTER-GDEM, Cartosat-DEM and SRTM-DEM data used in this study were downloaded from USGS. Authors would like to acknowledge the availability of above DEMs for such scientific studies.

**References**


