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Proceeding Paper

Accuracy Assessment of TanDEM-X 90 and CartoDEM Using ICESat-2 Datasets for Plain Regions of Ratlam City and Surroundings †

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Abstract: The spaceborne LiDAR dataset from the Ice, Cloud, and Land Elevation Satellite (ICESat-2) provides highly accurate measurements of heights for the Earth's surface, which helps in terrain analysis, visualization, and decision making for many applications. TanDEM-X 90 (90 m) and CartoDEM V3R1 (30 m) elevation are among the high-quality openly accessible DEM datasets for the plain regions in India. These two DEMs are validated against the ICESat-2 elevation datasets for the relatively plain areas of Ratlam City and its surroundings. The mean error (ME), mean absolute error (MAE), and root mean square error (RMSE) of TanDEM-X 90 DEM are 1.35 m, 1.48 m, and 2.19 m, respectively. The computed ME, MAE, and RMSE for CartoDEM V3R1 are 3.05 m, 3.18 m, and 3.82 m, respectively. The statistical results reveal that TanDEM-X 90 performs better in plain areas than CartoDEMV3R1. The study further indicates that these DEMs and spaceborne LiDAR datasets can be useful for planning various works requiring height as an important parameter, such as the layout of pipelines or cut and fill calculations for various construction activities. The TanDEM-X 90 can assist planners in quick assessments of the terrain for infrastructural developments, which otherwise need time-consuming traditional surveys using theodolite or a total station.

Keywords: spaceborne LiDAR; ICESat-2; CartoDEM V3R1; TanDEM-X 90 m

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1. Introduction

The Ice, Cloud, and Land Elevation Satellite-2 (ICESat-2) is a space-borne LiDAR system with an instrument called the Advanced Topographic Laser Altimetry System (ATLAS). The National Aeronautics and Space Administration (NASA) launched this mission in September 2018, to obtain global laser altimetry data over the Earth's surface. ICESat-2 uses an off-nadir pointing operation system to collect the data across mid and low latitudes for land and ocean areas, along with optimized measurement data collection for canopy heights. ATLAS works under six beams of three paired acquisitions, as strong and weak beams containing global geolocated photon and height data. The data are freely available with global coverage for various applications utilizing vegetation height and global sea-level anomalies, among others. Airborne LiDAR, total stations, level gauges, and theodolites provide high accuracy and reliability. However, they can collect data for detailed studies for specific local terrain, but their use is limited due to their higher cost, and requirements of work force, material resources, and more accurate ground control points (GCPs). These methods make field measurements and data processing relatively cumbersome and time consuming as compared with space or airborne platform-based technologies. Spaceborne SAR (synthetic aperture radar), and LiDAR enable data to be collected at any time of day or night, even in overcast dense forest environments, along with other applications, including UAV platforms [1–4]. The accuracy of ICESat-2 photon data is high and has a large number of footprints over Earth, which provides it with an edge over traditional surveying techniques, including satellite-based positioning techniques. As a result, it is currently being used frequently and globally by various researchers as a reference for estimating DEM accuracy, tree heights and terrain ruggedness. This study quantitatively evaluates the openly accessible DEMs using ICESat-2/ATL08 along-track heights above the WGS84 ellipsoid (ITRF2014 reference frame).

2. Material and Method

2.1. Study Area

Ratlam City, traditionally known as Ratnapuri, is located in the northwestern Malwa region of Madhya Pradesh, India (Figure 1). It is located 480 m above mean sea level (MSL).

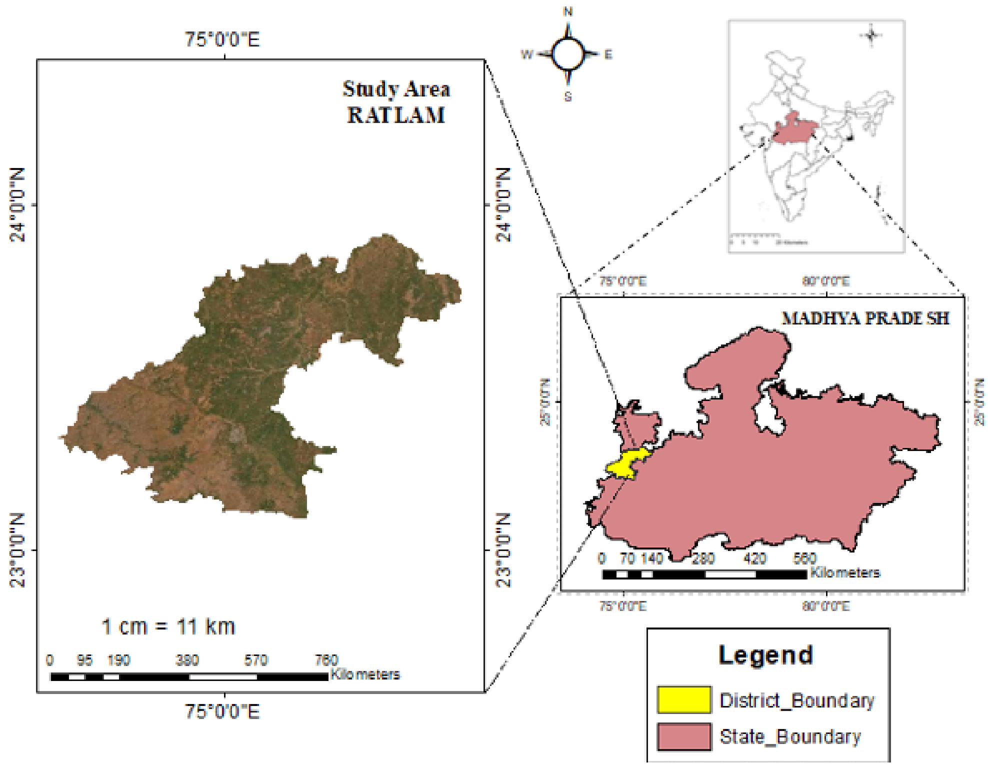

Figure 1. ICESat-2 datasets for parts of Ratlam City, in the Ratlam district.

2.2. ATLAS (ALT08)

ICESat-2 carries an ATLAS laser altimetry instrument capable of delivering pulses at a repetition rate of 10 kHz (10,000 per second), with single-photon detection, and samples at about 0.7 m. It calculates the distance between the satellite and the Earth's surface by measuring the travel durations of laser pulses. For each photon, it includes information such as time, latitude, longitude, and height in the World Geodetic System 1984 (WGS84) datum. The ICESat-2 (ALT08) measures terrain height and canopy heights at precise spatial scales along the track with a predetermined segment size of 100 m to maintain data parameter continuity [5–7]. The recent footprints (122 numbers) acquired by ICESat-2 on 30 May 2021 were retrieved for the study site.

2.3. TanDEM-X 90 DEM

TanDEM-X 90 is the latest DEM released by the German Aerospace Center (DLR) and is downloaded from (https://download.geoservice.dlr.de/TDM90/, 15 July 2020). The twin satellite constellation used in its generation reduces the effect of temporal decorrelation and atmospheric disturbances of conventional repeat pass due to bi-static interferometry [8].

The TanDEM-X 90 specification has a spatial resolution of 90 m with 32 bits per pixel information. It is available in WGS84 datum.

2.4. CartoDEM V3 R1

CartoDEM is a national DEM established by the Indian Space Research Organization (ISRO). CartoDEM version 3 release 1 is the latest version derived from the Cartosat-1 satellite sensor and is the first Indian remote sensing (IRS) satellite capable of acquiring high-resolution stereo imagery with 2.5 m pixel size. It was primarily designed for topographic mapping and the creation of digital terrain models [8–10]. CartoDEM V3 R1 comes with a spatial resolution of 1 arc-second (30 m) with 16 bits per pixel and WGS84 datum.

2.5. Methodology

Figure 2 depicts the methodology in the form of a flow chart. The two DEMs, namely CartoDEM V3 R1 and TanDEM-X 90, were pre-processed according to the study site, and elevation was extracted using ArcGIS software at the ICESat-2/ATL08 footprint locations. ICESat-2 footprints are shown as superimposed on both of the DEMs (Figure 3) in the process of elevation extraction and were later used as a reference elevation value. The accuracy of ICSat-2 datasets and openly accessible DEMs was estimated by calculating mean error (*ME*, Equation (1)), mean absolute error (*MAE*, Equation (2)), and root mean square error (*RMSE*) (*RMSE*, Equation (3)). The vertical accuracy is determined by the differential values. $H_{(i(ICESat-2))}$ is the reference height, whereas $H_{(i(DEM))}$ denotes the height of openly accessible DEMs (TanDEM-X 90 and CartoDEM V3 R1) for i = 1 to n, as below:

$$ME = \frac{\sum_{i=0}^{n} H_{i(DEM)} - H_{i(ICESat-2)}}{n} \quad (1)$$

$$MAE = \frac{\sum_{i=0}^{n} \mid H_{i(DEM)} - H_{i(ICESat-2)} \mid}{n} * 100 \quad (2)$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n} \left(H_{i(DEM)} - H_{i(ICESat-2)}\right)^2}{n}} \quad (3)$$

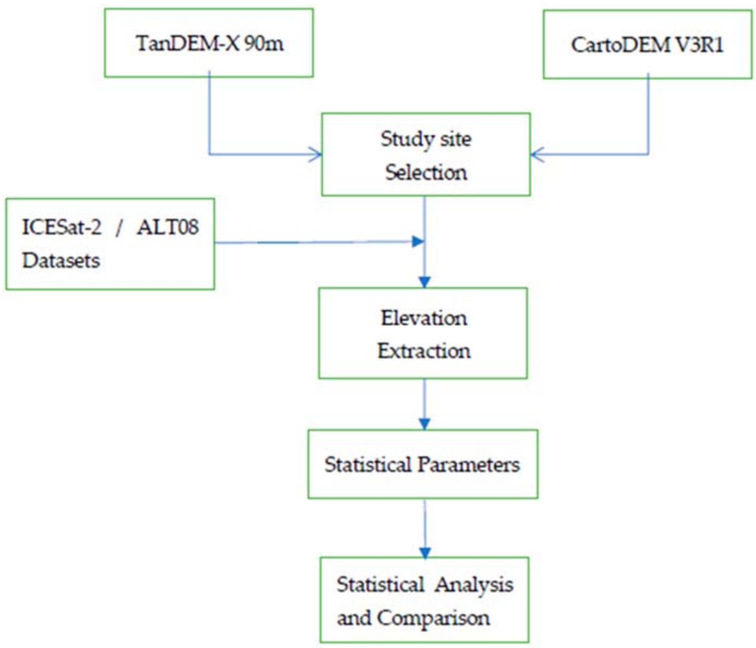

Figure 2. Flow chart of the methodology for DEM evaluation using ICESat-2 datasets.

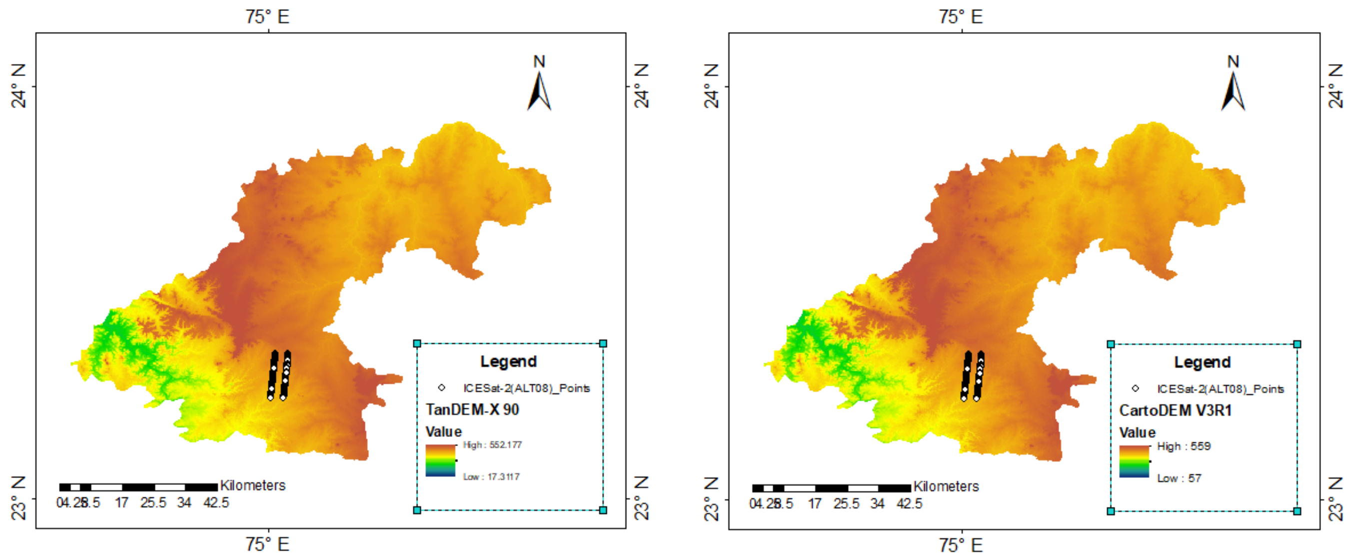

Figure 3. (**a**) ICESat-2 (ALT08) points superimposed on TanDEM-X 90; (**b**) ICESat-2 (ALT08) points superimposed on CartoDEMV3 R1.

3. Results and Discussion

ICESat-2 elevation datasets are used as a reference for measuring vertical error for the DEMs (TanDEM-X 90 and CartoDEM V3 R1), as an alternative approach to the usual method of conducting DGPS (Differential Global Positioning System)/DGNSS (Differential Global Navigation Satellite System) surveys. The DGPS/DGNSS surveys can provide more accurate results, but are time consuming, costly and challenging to conduct in inaccessible or busy areas. The strong beam data were collected among the 6 splited beams (3 stong and 3 week) for the analysis in order to ensure the higher accuracy of the ICESat-2 elevation data. TanDEM-X 90 and CartoDEM V3 R1 elevation data were extracted using ICESat-2 reference elevation datasets and analyzed for statistical comparison to determine the vertical accuracy of both of the openly accessible DEMs. According to the findings, as shown in Figure 4, it is observed that the performance of TanDEM-X 90 (RMSE = 2.19 m) is better than CartoDEM V3R1 (RMSE = 3.82 m) with similar results for the ME and MAE. The accuracy of TanDEM-X 90 m is comparatively higher, indicating that TanDEM-X90 is more strongly correlated with ICESat-2 space-borne LiDAR datasets in plain terrain.

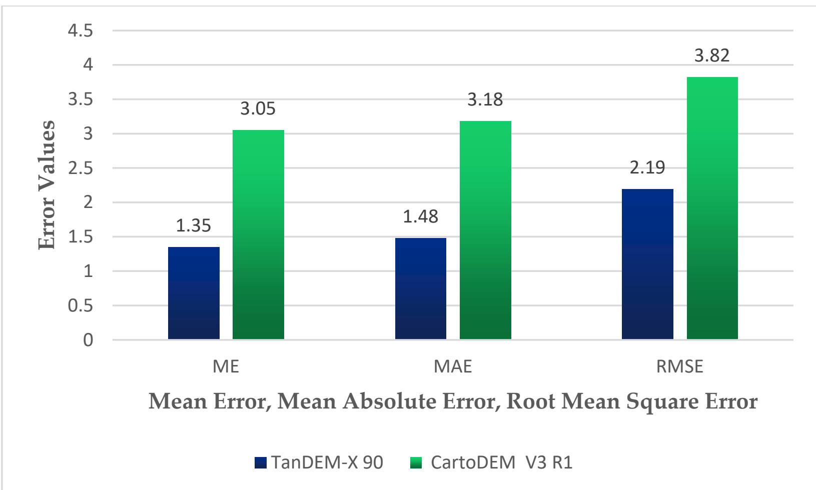

Figure 4. Plot of ME, MAE, and RMSE for TanDEM-X 90 and CartoDEM V3 R1 with ICESat-2 elevation data as a reference.

The comparative study found the better performance of CartoDEM V3 R1 using smartphone GPS datasets for flat urban terrain regions [11]. ICESat-2 data were found to be the optimal choice for DEM accuracy assessment, due to the higher accuracy and wider coverage range over terrain than accuracy assessment using an A-GPS smartphone.

4. Conclusions

The comparison of freely available DEMs over plain regions of Ratlam using ICESat-2 data reveals a better performance of TanDEM-X 90 over CartoDEM 90. ICEsat-2 provides a new technology and is an alternative to GNSS-based studies, which can be highly useful for difficult terrain, congested or busy urban regions and inaccessible areas. The results of the study lead to the following conclusion, that accurate DEMs such as TanDEM-X 90 can help planners to make a quick evaluation of topography for infrastructure development projects that would otherwise need time-consuming traditional surveys with theodolite or a total station.

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Data Availability Statement: Publicly available datasets were analyzed in this study. The data can be found here: https://bhuvan.nrsc.gov.in/home/index.php and https://download.geoservice.dlr.de/TDM90/, and NASA's https://openaltimetry.org/data/icesat2/ (accessed on 15 July 2021). Furthermore, the Google Earth platform was used in the study for data visualization.

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Conflicts of Interest: The authors declare no conflict of interest.

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