engineering proceedings

MDPI

Proceedings Paper

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

Unnati Yadav and Ashutosh Bhardwaj *

Photogrammetry and Remote Sensing Department, Indian Institute of Remote Sensing, Dehradun 248001, Uttarakhand, India; unnatiyadav06@gmail.com
* Correspondence: ashutosh@iirs.gov.in
† Presented at 8th International Electronic Conference on Sensors and Applications, 1–15 November 2021; Available online: https://ecsa-8.sciforum.net.

Abstract The spaceborne lidar dataset from 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 1.49 m, 1.62 m, and 0.21 m respectively. The computed ME, MAE, and RMSE for CartoDEM V3R1 are 3.23 m, 3.28 m, and 0.36 m respectively. The statistical results reveal that TanDEM-X 90 performs best 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 for the terrain for infrastructural developments, which otherwise need time-consuming traditional surveys using a theodolite or a total station.

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

Citation: Yadav, U.; Bhardwaj, A. Accuracy Assessment of TanDEM-X 90 and CartoDEM Using ICESat-2 Datasets for Plain Regions of Ratlam City and Surroundings. *Eng. Proc.* **2021**, 3, x. https://doi.org/10.3390/xxxxx

Academic Editor:

Published: 1 November 2021

1. Introduction

Ice, Cloud, and Land Elevation Satellite-2 (ICESat-2) is a space-borne Lidar system with an instrument called 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 off-nadir pointing operation system to collect the data across mid and low- latitudes for land and ocean areas, along with the optimized measurement data collection for canopy heights. ATLAS works under six beam of three paired acquisitions as strong and weak beams containing global geolocated photon and height data. The data is freely available with global coverage for various applications utilizing vegetation height, global sea-level anomaly 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, 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 to space or airborne platform based technologies. Spaceborne SAR (Synthetic Aperture radar), and LiDAR has enabled data to be collected at any time of day or night, even in overcast dense forest environment, along with other applications including UAV platforms [1–4]. The accuracy of ICESat-2 data is high and has large number of footprints over Earth. As a result, it is frequently used as a reference for estimating DEM accuracy. 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

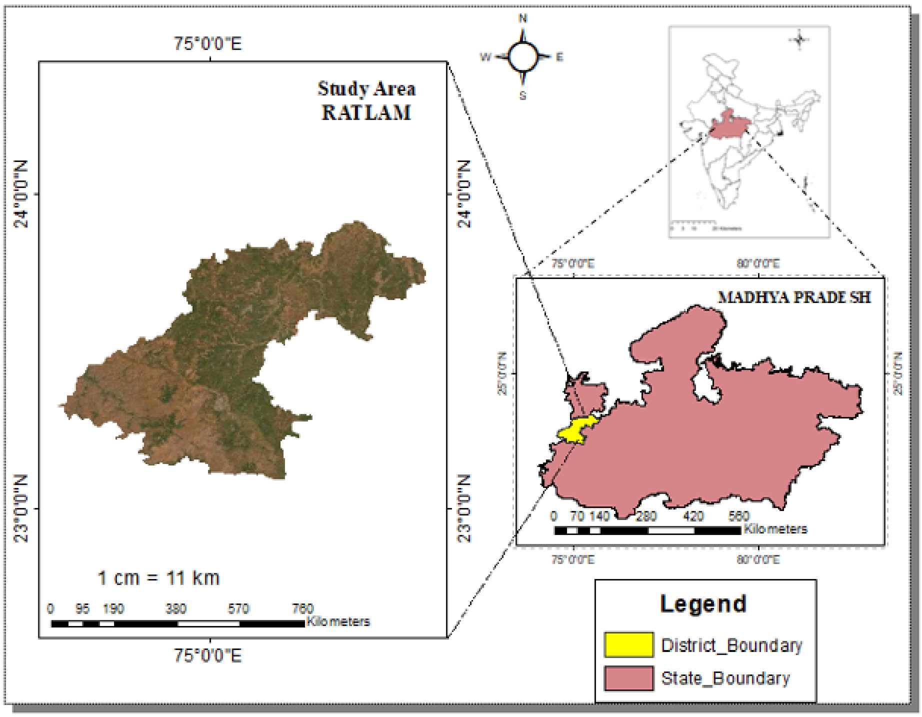


Figure 1. ICESat-2 datasets for parts of Ratlam city in Ratlam district.

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

2.3. 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), 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) product 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.

2.4. 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/). 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]. TanDEM-X 90 specification has spatial resolution of 90 m with 32bits per pixel information. It is available in WGS84 datum.

2.5. 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 the spatial resolution of 1 arc-second (30 m) with 16 bits per pixel and WGS84 datum.

2.6. Methodology

The 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 is 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 later use as a reference elevation value. The accuracy of ICSat-2 datasets and openly accessible DEMs is 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.

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

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

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

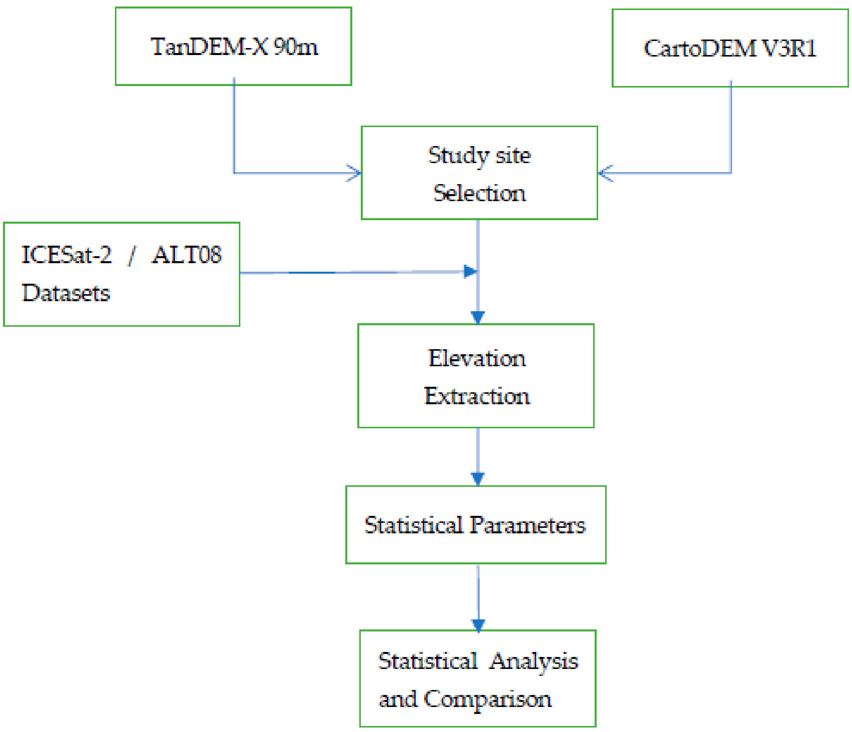
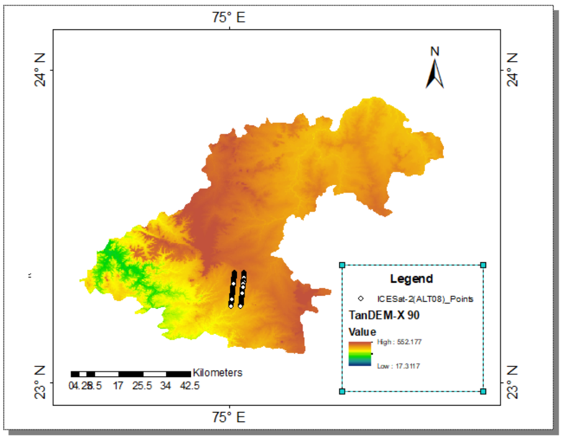
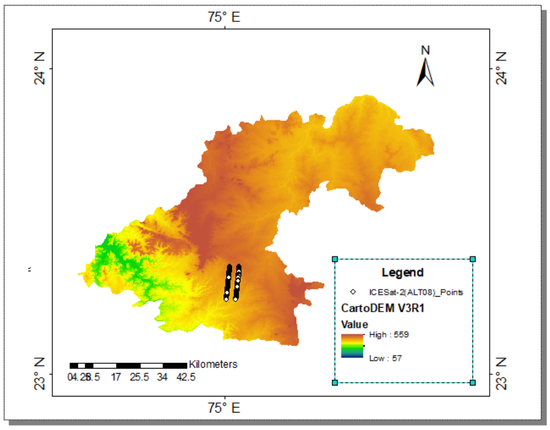


Figure 2. Flow chart of the methodology for DEM evaluation using ICSat-2 datasets



(**a**)



(**b**)

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). The strong beam data is collected for the analysis in order to ensure the accuracy of the ICESat-2 elevation data. TanDEM-X 90 and CartoDEM V3 R1 elevation data is extracted using ICESat-2 reference elevation datasets and analysed for statistical comparison to determine the vertical accuracy of both the openly accessible DEMs. According to the findings in Figure 4, it has been observed that the performance of TanDEM-X 90 is better than CartoDEM V3R1. The accuracy of TanDEM-X 90 m is comparatively higher, indicating that TanDEM-X90 is more correlated to ICESat-2 space-borne Lidar datasets in plain terrain.

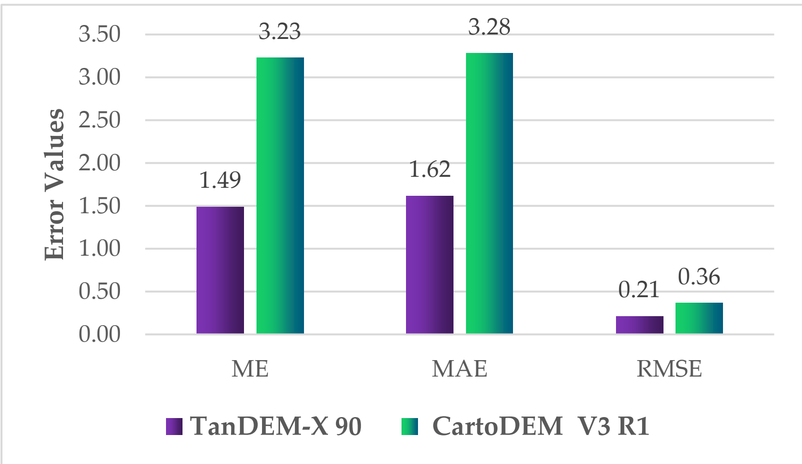


Figure 4. Plot of ME, MAE, and RMSE for TanDEM-X 90 and CartoDEM V3 R1.

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

5. Conclusions

The comparison of freely available DEMs over plain regions of Ratlam using ICESat-2 data reveals better performance of TanDEM-X 90 over CartoDEM 90. The results of the study lead to the following conclusion that, the accurate DEMs such as TanDEM-X 90 can help planners make quick evaluation of topography for infrastructure development projects that would otherwise need time-consuming traditional surveys with a theodolite or a total station.

Author Contributions Conceptualization, A.B.; methodology, A.B. and U.Y.; formal analysis, U.Y., and A.B.; resources, U.Y.; writing—original draft preparation, U.Y.; writing—review and editing, A.B. and U.Y. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Publicly available datasets were analyzed in this study. This 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/. Further, the Google Earth platform is used in the study for data visualization.

Acknowledgments: The authors would like to thank ISRO, NASA, DLR, and Google Earth platform for their support to the researchers through openly accessible data-sharing platforms. The authors are highly indebted to Director, IIRS for his constant support and encouragement in conducting the research activities.

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

References

1. Markus, T.; Neumann, T.; Martino, A.; Abdalati, W.; Brunt, K.M.; Csatho, B.; Farrell, S.; Fricker, H.; Gardner, A.; Harding, D.;et al. The Ice, Cloud, and land Elevation Satellite-2 (ICESat-2): Science requirements, concept, and implementation. *Remote Sens. Environ.* **2017**, *190*, 260–273, doi:10.1016/j.rse.2016.12.029.
2. Nandy, S.; Srinet, R.; Padalia, H. Mapping Forest Height and Aboveground Biomass by Integrating ICESat-2, Sentinel-1 and Sentinel-2 Data Using Random Forest Algorithm in Northwest Himalayan Foothills of India. *Geophys. Res. Lett.* **2021**, *48*, 1–10, doi:10.1029/2021GL093799.
3. Polidori, L.; el Hage, M. Digital elevation model quality assessment methods: A critical review. *Remote Sens.* **2020**, *12*, 1–36, doi:10.3390/rs12213522.
4. Zhang, Y.; Pang, Y.; Cui, D.; Ma, Y.; Chen, L. Accuracy Assessment of the ICESat-2/ATL06 Product in the Qilian Mountains Based on CORS and UAV Data. *IEEE J. Sel. Top. Appl. Earth Obs. Remote Sens.* **2021**, *14*, 1558–1571, doi:10.1109/JSTARS.2020.3044463.
5. Neuenschwander, A.; Pitts, K. The ATL08 land and vegetation product for the ICESat-2 Mission. *Remote Sens. Environ.* **2019**, *221*, 247–259, doi:10.1016/j.rse.2018.11.005.
6. Brunt, K.M.; Neumann, T.A.; Larsen, C.F. Assessment of altimetry using ground-based GPS data from the 88S Traverse, Antarctica, in support of ICESat-2. *Cryosphere* **2019**, *13*, 579–590, doi:10.5194/TC-13-579-2019.
7. Neumann, T.A.; Martino, A.J.; Markus, T.; Bae, S.; Bock, M.R.; Brenner, A.C.; Brunt, K.M.; Cavanaugh, J.; Fernandes, S.T.; Hancock, D.W.; et al. The Ice, Cloud, and Land Elevation Satellite—2 mission: A global geolocated photon product derived from the Aadvanced Ttopographic Llaser Aaltimeter Ssystem. *Remote Sens. Environ.* **2019**, *233*, doi:10.1016/J.RSE.2019.111325.
8. Amitabh, B.; Krishna, G.; Srinivasan, T.P.; Srivastava, P.K. An integrated approach for topographical mapping from space using Cartosat-1 and Cartosat-2 imagery. In *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Vol. XXXVII, Part B4*; 2008; pp. 1355–1358.
9. Jacobsen, K. ISPRS-ISRO Cartosat-1 Scientific Assessment Ptogramme (C-SAP) Technical report—Test areas Mausanne and Warsaw. In *ISPRS COM IV, GOA 2006, IAPRS, Vol. 36, Part 4*; 2006; pp. 1052–1056. Available online: http://citeseerx.ist.psu.edu/viewdoc/summary?doi=10.1.1.584.5348 (accessed on 7 April 2017).
10. Bhardwaj, A.; Jain, K.; Chatterjee, R.S., Generation of high-quality digital elevation models by assimilation of remote sensing-based DEMs. *J. Appl. Remote Sens.* **2019**, *13*, 1, doi:10.1117/1.JRS.13.4.044502.
11. Yadav, U.; Bhardwaj, A. Accuracy Assessment of Openly Accessible CartoDEM V3R1 and TanDEM-X 90 Using Smartphone Having Assisted GPS for Ratlam City and Surroundings. 2021. Available online: https://ecsa-8.sciforum.net/ (accessed on).