MOL2NET, **2020**, 6, ISSN: 2624-5078
http://sciforum.net/conference/mol2net-06

MOL2NET, International Conference Series on Multidisciplinary Sciences
USEDAT-08: USA-Europe Data Analysis Training Program Workshop,
UPV/EHU, Bilbao-MDC, Miami, USA, 2020

Quality Assessment of merged NASADEM products for varied Topographies in India using Ground Control Points from GNSS

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Graphical Abstract

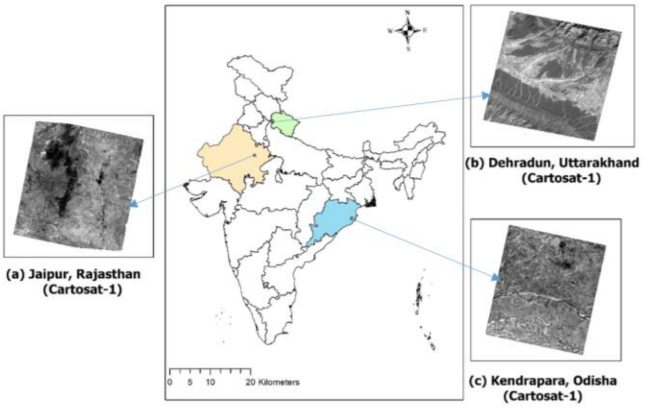

Figure 1: Location Map of the three Experimental sites with Orthoimages (Cartosat-1)

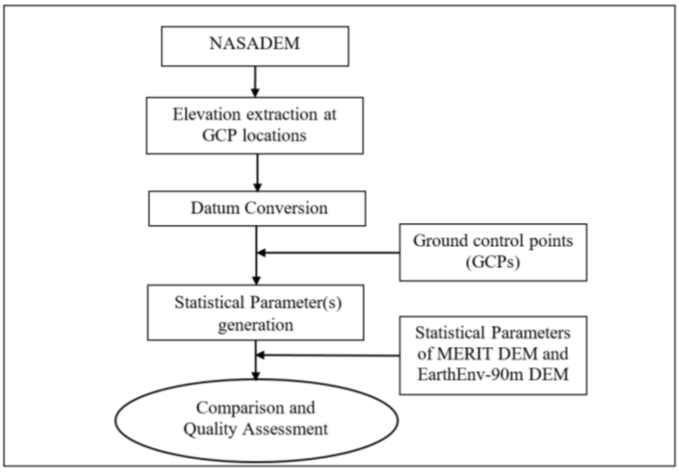

Figure 2: Flowchart for Quality Assessment of openly accessible NASADEM products

Abstract.
NASADEM (NASA Digital Elevation Model) is a merged digital elevation product prepared by the National Aeronautics and Space Administration (NASA) from SRTM (Shuttle Radar Topography Mission) DEM as primary data along with other secondary datasets generated from remote sensing-based techniques like satellite photogrammetry and spaceborne LiDAR. These DEM products of NASADEM are reanalysis datasets produced from SRTM and datasets such as ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) DEM; Ice, Cloud, and land Elevation Satellite (ICESat) - Geoscience Laser Altimeter System (GLAS) elevation datasets; and Advanced Land Observing Satellite (ALOS) - Panchromatic Remote-sensing Instrument for Stereo Mapping (PRISM) DEM datasets, available at various locations globally. Three sites were chosen, namely Kendrapara (Odisha), Jaipur (Rajasthan), and Dehradun (Uttarakhand) with plain, moderate, and highly undulating terrain conditions for the assessment of NASADEM. The RMSE results were compared with other merged DEM products namely EarthEnv-DEM90 and MERIT (Multi-Error-Removed Improved Terrain) DEM. The ground control points (GCPs) collected through differential GNSS (DGNSS) surveys were used for the assessment of

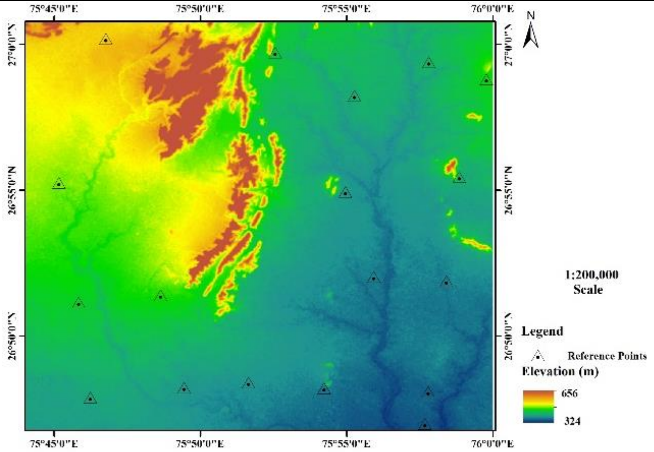

Figure 3: NASADEM (Jaipur site)

vertical accuracy and the statistical parameters, such as mean error (ME), mean absolute error (MAE), and root mean square error (RMSE). The RMSE of 4.71m at the Dehradun site depicts that in undulating regions NASADEM is performing better than both EarthEnv-DEM90 and MERIT DEM. However, in the case of urban and plain regions, the performance of MERIT DEM and EarthEnv DEM is superior to that of NASADEM.

Introduction

The digital elevation models (DEM) expresses the topographic information with digital representation, providing a convenient means for terrain analysis and terrain visualization. The increase in the knowledge of the remote sensing datasets, data processing, and quality product generation has resulted in the improved products commonly referred to as reanalysis data. The ICESat-1 spaceborne LiDAR-based elevation products set forth a successful model for such reanalysis data products through its large number of versions representing the reanalysis of the data over a decade long series of analysis. Among the DEMs, SRTM has been the most popular data used widely for global applications. Similarly, CartoDEM developed using Cartosat-1 stereo datasets by National Remote Sensing Centre (NRSC) has been extensively experimented by researchers and utilized for various applications in India.

NASADEM products are reanalysis datasets produced primarily from SRTM and datasets such as ASTER DEM, ICESat-GLAS elevation datasets, National Elevation Data for US and Mexico, Canadian Digital Elevation Data, Global Multi-resolution Terrain Elevation Data 2010 (GMTED2010), and ALOS-PRISM DEM datasets, available at various locations globally [1]. AW3D30 was found to be most promising in the investigation of seven public freely-accessed DEM datasets (ASTER GDEM V2, SRTM-3 V4.1 DEM, SRTM-1 DEM, AW3D30 DEM, VFP-DEM, MERIT DEM, Seamless SRTM-1 DEM) over the HMA region (Hengduan Mountains and Himalayas) which includes different versions of SRTM beside other DEMs [2]. Vaka et al. (2019) have compared openly accessible DEMs such as NASADEM, TanDEM-X, SRTM, and DEMs available from airborne LiDAR, over Indian sites having flat terrain, flat terrain with forest cover and hilly terrain conditions using reference data (GPS and ICESat elevation point data). In the study, the provisional version of NASADEM depicted better vertical accuracy than the existing SRTM DEMs [3]. Uuema et al. (2020) examined the accuracy of six freely available global DEMs (ASTER, AW3D30, MERIT, TanDEM-X, SRTM, and NASADEM) using LiDAR and Pleiades-1A based reference DEMs in four geographic regions from Norway, China, New Zealand, and Estonia with different terrain conditions. This study found that the best results are from AW3D30, whereas NASADEM, showed a slight improvement over SRTM as its successor of SRTM [4].

The objective of this study was to examine the quality and suitability of NASADEM in a different type of terrain conditions. Three locations with plain, moderate, and rugged topographic conditions were selected for experimentation and comparison with similar DEM products of EarthEnv-DEM90 and MERIT DEM on these locations

Study Area

The three experimental sites selected for the study were chosen in three different terrains types at Jaipur site, Kendrapara site, and Dehradun site. The characteristics of these three experimental sites can be seen in Figure 1 and are detailed in [5], [6].

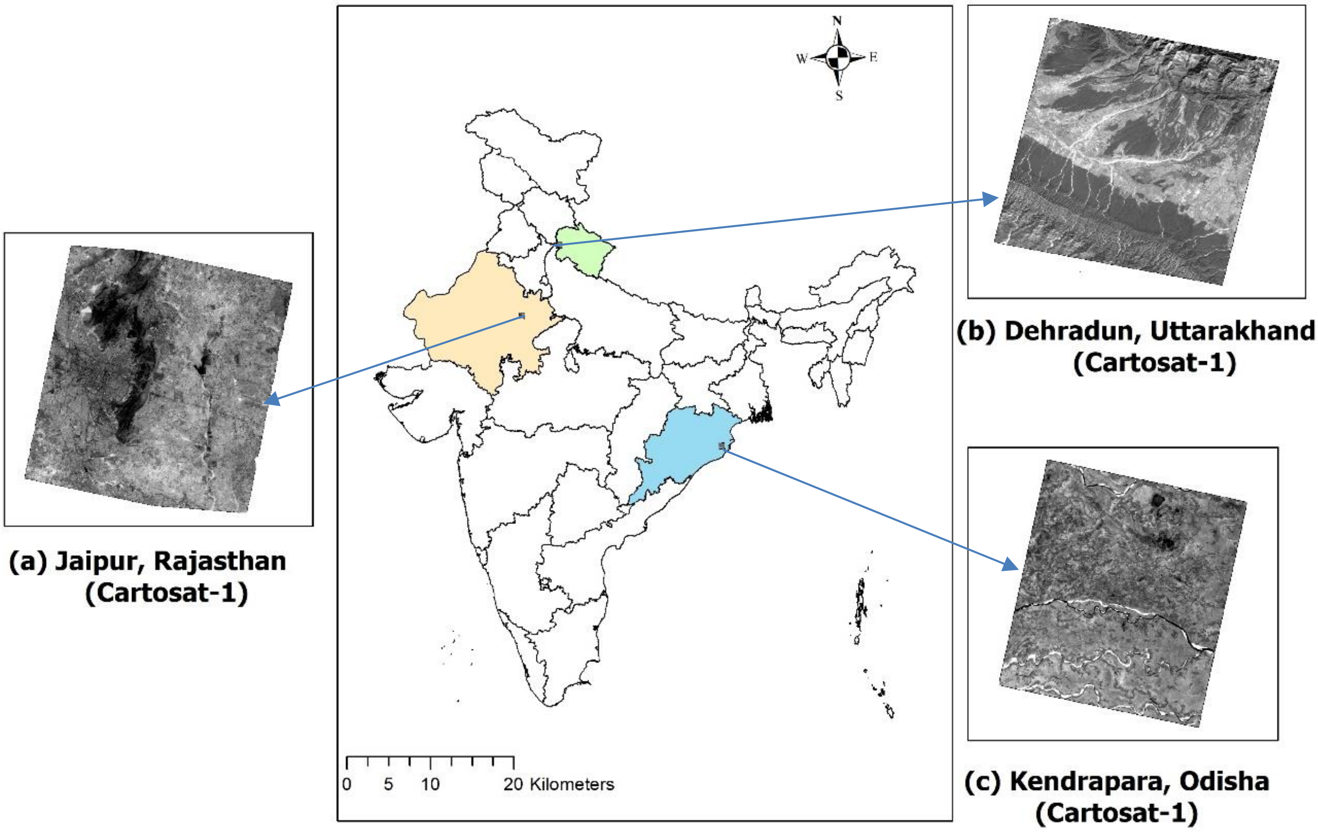

Figure 1: Location Map of the three Experimental sites with Orthoimages (Cartosat-1)

Material and Methods

The NASADEM datasets for the three experimental sites at Jaipur, Kendrapara, and Dehradun were downloaded from the website platform provided by NASA [7]. The detailed description of openly accessible NASADEM products can be seen in [1]. The orthoimages generated from Cartosat-1 data were utilized for the terrain visualization (Figure 1). Table 1, gives the details of the toposheets (Scale 1:50,000) used for carrying out the fieldwork during DGNSS surveys at the experimental sites.

Table 1: SOI Toposheets used at the three Experimental sites

S. No.	Study area	SOI Toposheet nos.
1	Jaipur Site	45N/9, 45N/13
2	Kendrapara site	73L/6, 73L/7
3	Dehradun Site	53J/3, 53J/4, 53F/15, 53F/16

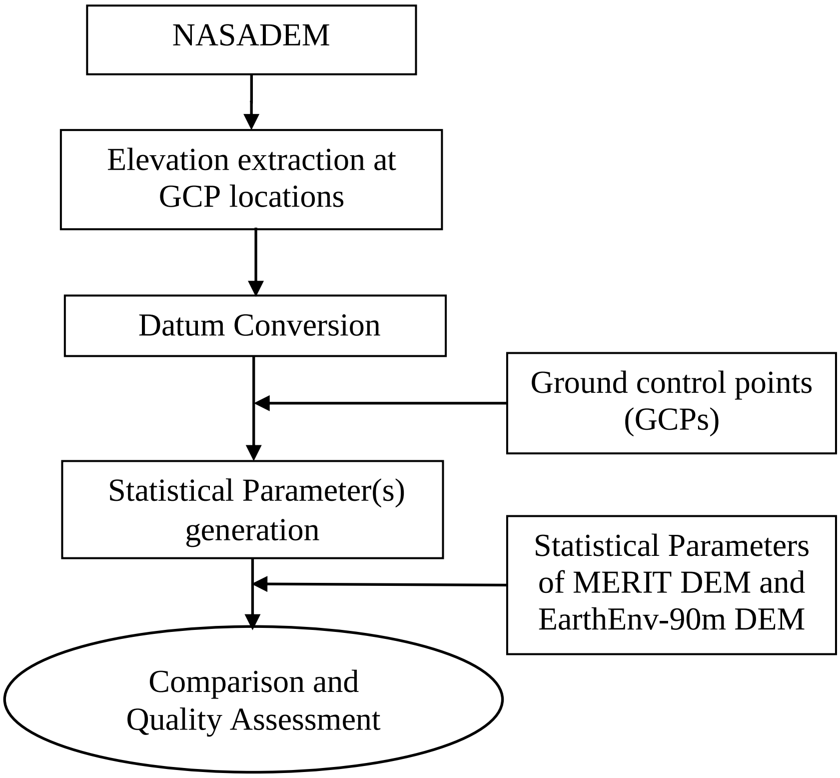

Figure 2: Flowchart for Quality Assessment of openly accessible NASADEM products with GCPs and its comparison with MERIT DEM and EarthEnv 90m DEM [8], [9]

The statistical parameters for quality assessment of DEM such as mean error (ME), mean absolute error (MAE), and root mean square error (RMSE) were calculated as described in Figure 2 to assess the performance of the merging method or the model applied in producing the NASADEM. MAE is mathematically linear and thus implies equal weightages to errors. However, the RMSE is quadratic, where it mathematically squares the errors before averaging and thereby provides a relatively high weight to large errors. The error at the GCP location is defined as the difference between the value of the respective height from the NASADEM ($Z_{(NASADEM)}$), and the observed i.e. reference height ($Z_{(DGNSS)}$), measured in the field through the DGNSS survey. 41, 18, and 20 numbers of GCPs were used for the analysis at the experimental sites of Dehradun, Jaipur, and Kendrapara respectively. The elevation values extracted from the DEMs were calculated to the same datum using equation 1. Here, N is the Geoid Height, Z_{DGNSS} is the GNSS elevation at the GCP location in WGS84 (World Geodetic System 1984) datum and Z_{EGM} is the orthometric height with respect to the EGM96 Earth gravitational model. The statistical parameters ME (equation 2), MAE (equation 3), and RMSE (equation 4) were calculated using respective equations, for the assessment of vertical accuracy. Additionally, the method of vertical accuracy assessment for DEM have been detailed in terms of linear error at 90 percentile (LE90, 90% confidence) and is used extensively for accuracy assessments of DEMs (equation 5) [10]–[12].

$$Z_{EGM} = Z_{DGNSS} - N \quad (1)$$

$$ME = \frac{\sum_{i=0}^{n} z_{i(NASADEM)} - z_{i(DGNSS)}}{n} \quad (2)$$

$$\text{MAE} = \frac{\sum_{i=0}^{n} | z_{i(NASADEM)} - z_{i(DGNSS)} |}{n} * 100 \quad (3)$$

$$\text{RMSE} = \sqrt{\frac{\sum_{i=1}^{n} (Z_{i(DGNSS)} - Z_{i(NASADEM)})^2}{n}} \quad (4)$$

where $Z_{i\ (NASADEM)}$ is the extracted elevation from the NASADEM products and $Z_{i\ (DGNSS)}$ is the observed reference elevation at the GCP locations with i=1 to n; where n indicates the number of observations available for the validation.

$$\text{LE90} = 1.6449 * \text{RMSE} \quad (5)$$

Results and Discussion

Ground control points (GCPs) collected through differential GNSS (DGNSS) surveys and used for the evaluation of DEMs at the experimental sites are shown in figure 3 (Jaipur site), figure 4 (Kendrapara site), and figure 5 (Dehradun site). Table 2, provides the vertical accuracy measures computed for the three experimental sites. The RMSE of 4.71m at the Dehradun site depicts that in undulating regions NASADEM is performing better than both EarthEnv-DEM90 and MERIT DEM. MERIT DEM performs better in plains of Kendrapara site with RMSE as 4 m, as compared to NASADEM and EarthEnv-DEM90. However, in the case of urban regions (Jaipur site), the performance of EarthEnv DEM (RMSE=3.05m) is superior to that of NASADEM and MERIT DEM [8], [9].

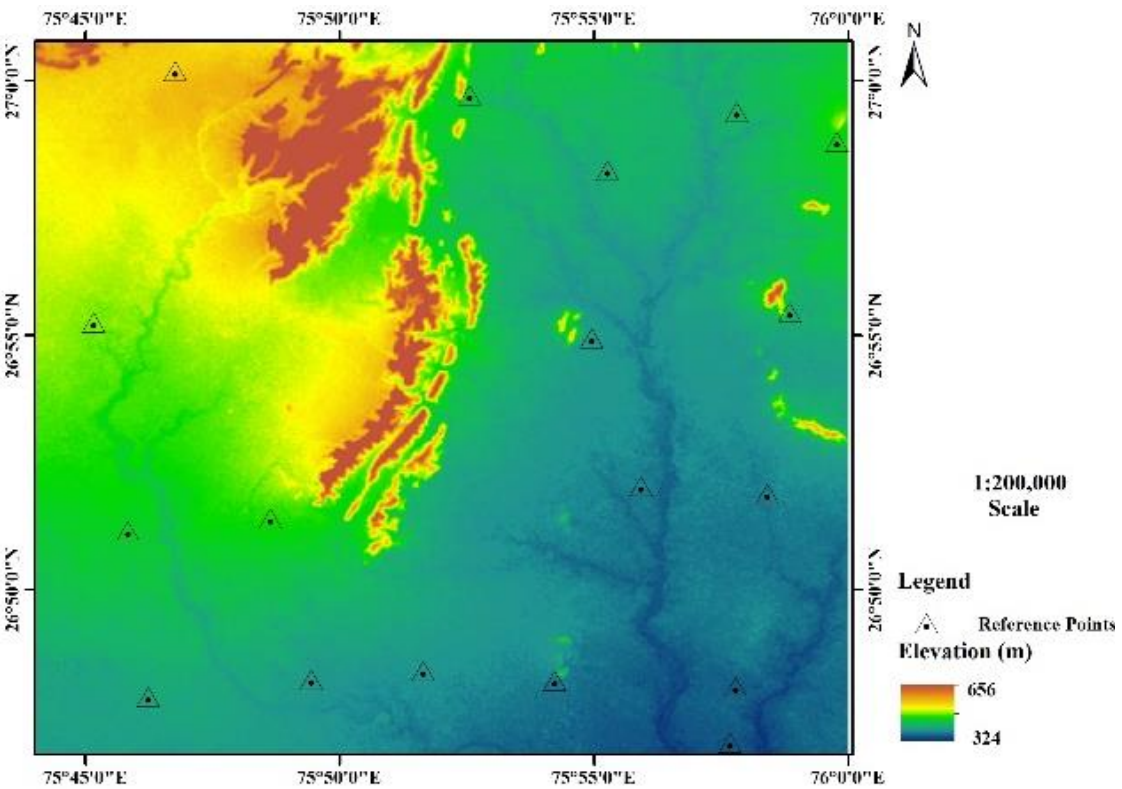

Figure 3: NASADEM (Jaipur site)

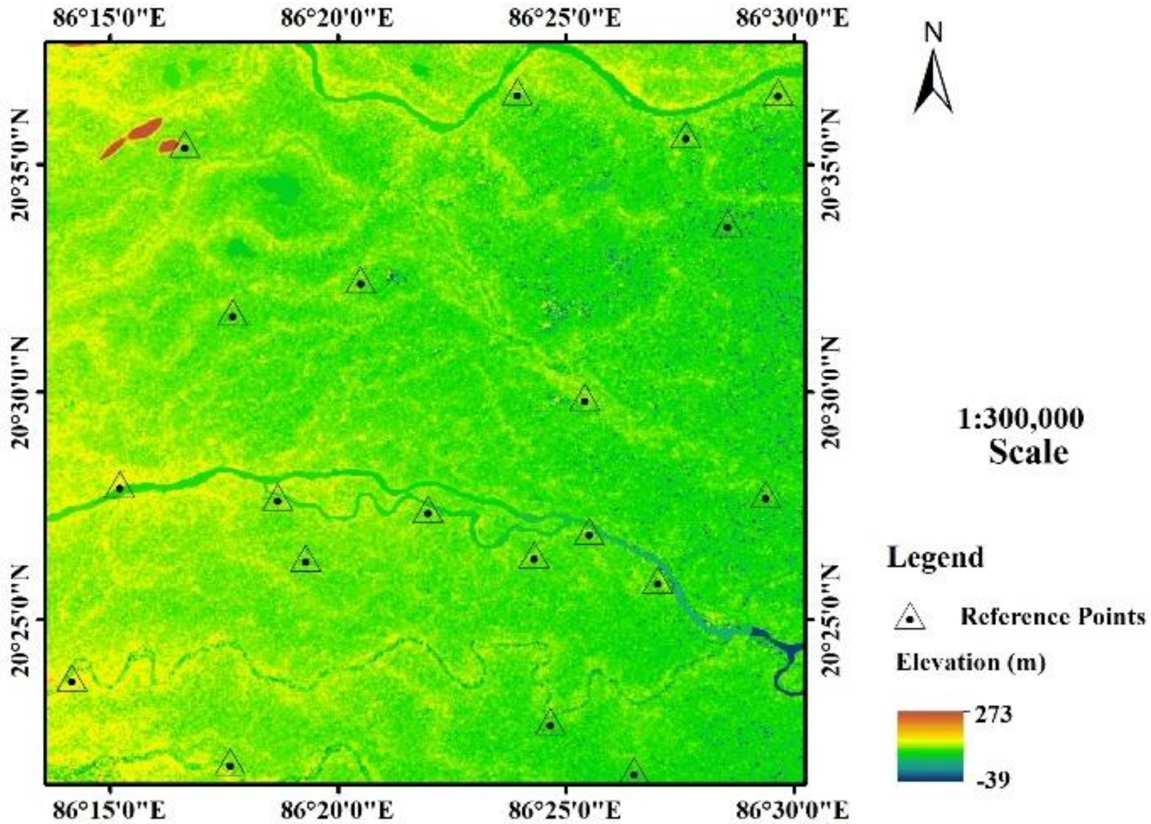

Figure 4: NASADEM (Kendrapara site)

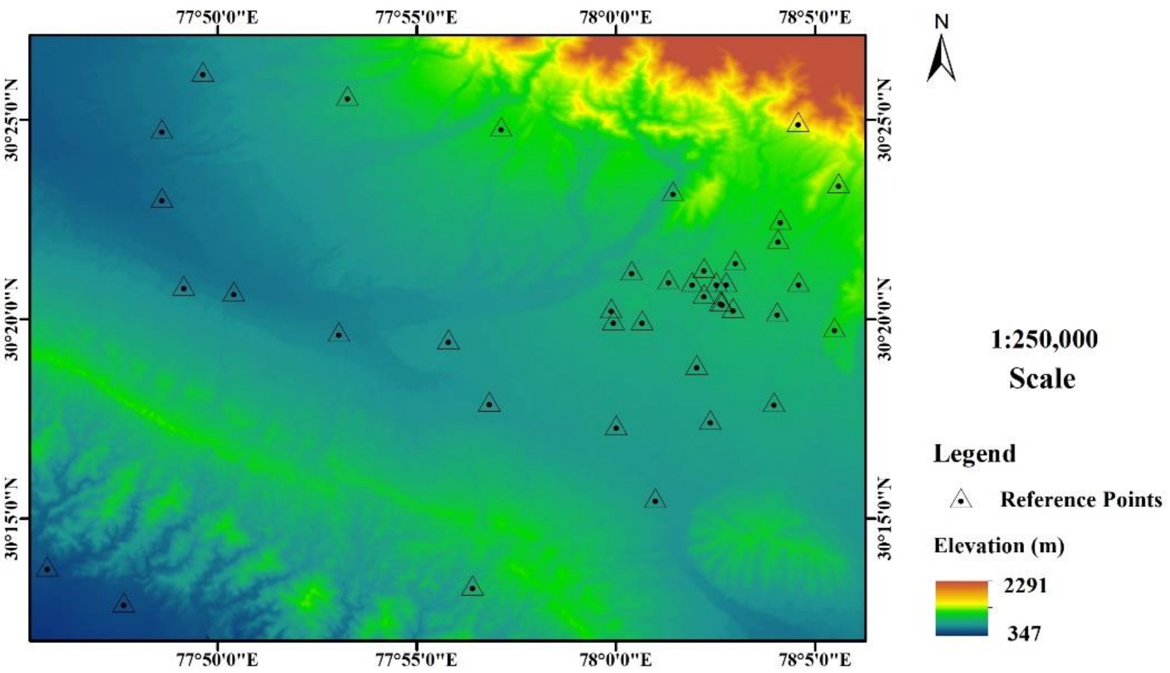

Figure 5: NASADEM (Dehradun site)

Table 2: Vertical accuracy measures computed for the three experimental sites

Experimental Sites	ME (m)	MAE (m)	RMSE (m)	LE90 (m)
Jaipur Site	-1.31	3.09	3.67	6.03
Kendrapara site	-4.64	4.72	5.37	8.83
Dehradun Site	-0.96	3.87	4.71	7.75

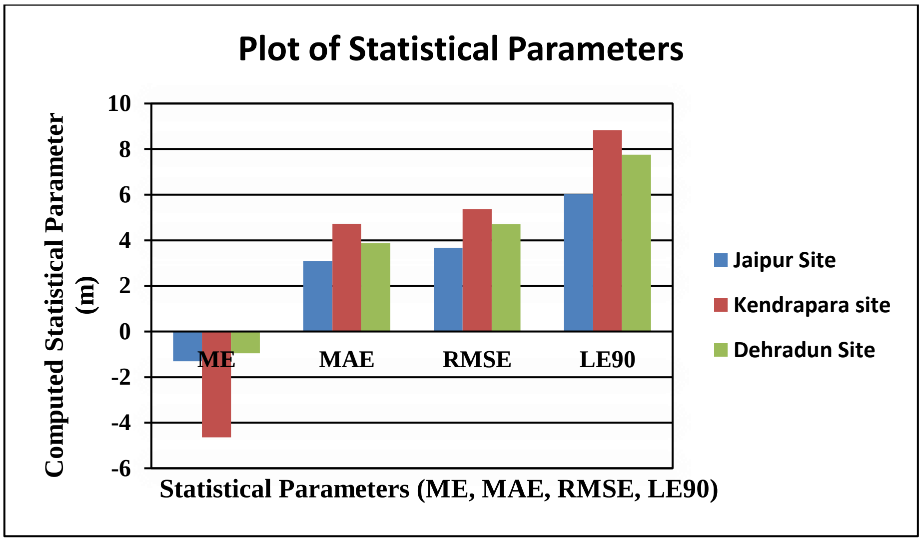

Figure 6: Plot of ME, MAE, RMSE and LE90 for NASADEM datasets at three experimental sites

Mean Absolute Error (MAE) for the experimental sites at Dehradun, Jaipur and Kendrapara are 3.87m 3.09m, and 4.72m. MAE. RMSE and MAE both describe average model-performance errors in the generation of NASADEM products, wherein, RMSE gives comparatively higher weight to larger errors, making MAE a more natural measure of average error [13]. Figure 6, depicts that the mean error (ME) at all the experimental sites are negative, depicting more of digging effect in the mass points. The model bias for the undulating Dehradun site is the least as the negative and positive biases largely cancel each other.

Discussion

The variability in the quality of openly accessible DEMs suggests that the studied openly accessible DEMs performs variedly in the different type of topographic regions and thus shall be utilized cautiously after their evaluations to meet the application requirements. The studies also reveals in the analysis, that a correct selection of input DEMs, along with terrain specific fusion or merging algorithm is required while creating improved DEMs [14]–[16]. The earlier study has revealed that in plain regions the CartoDEM V3 R1 has high accuracy than most of these openly accessible as well as reanalysis and assimilated openly accessible DEMs [6], [14]. In the plain terrain, the RMSE of TanDEM-X is 2.56 m (LE90 = 4.21 m) is better than NASADEM [17]. Newer techniques utilizing the machine learning methods may further improve the results in times to come.

Conclusions

The study concluded that the NASADEM is having high accuracy in the undulating region at the Dehradun site when evaluated with GCPs collected using DGNSS survey. However, the accuracies of NASADEM in moderate and plain terrain of Jaipur and Kendrapara respectively, are less than the accuracies of EarthEnv-DEM90 and MERIT DEM. Moreover, it is observed in the series of experimentations that for the plain regions, the CartoDEM (Version 3, Release 1) data has better performance than any of the currently available openly accessible DEMs such as TanDEM-X, SRTM, ASTER or merged (assimilated) such as NASADEM, EarthEnv-DEM90, and MERIT DEM [6], [8], [9], [17].

Acknowledgements

The author would like thank and send words of appreciation to the Indian Space Research Organisation (ISRO), Japan Aerospace Exploration Agency (JAXA), National Aeronautics and Space Administration (NASA), European Space Agency (ESA), Deutschen Zentrum für Luft- und Raumfahrt (DLR), Yale University, and the University of Tokyo along with their collaborators for their insights and support for research through their data sharing platforms, which are highly valuable in the presented study. The author is highly indebted to Director, IIRS for support and encouragement for conducting the research activities.

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