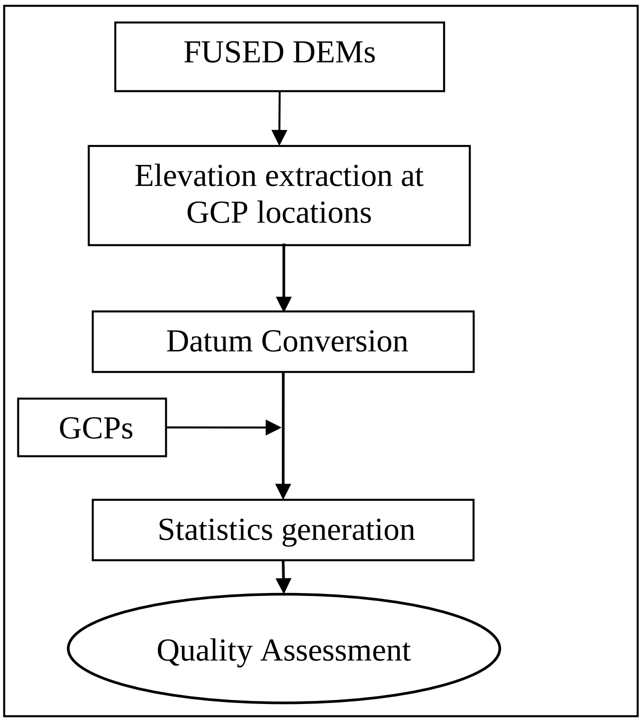
MOL2NET, International Conference Series on Multidisciplinary Sciences
USINEWS-04: US-IN-EU Worldwide Science Workshop Series, UMN, Duluth, USA, 2020

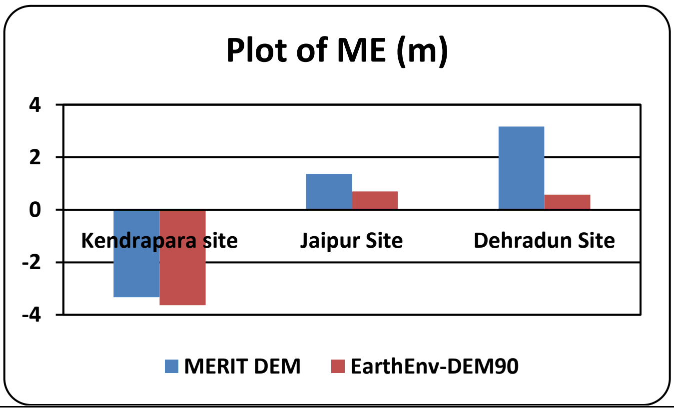
Quality Assessment of Openly Accessible Fused EarthEnv-DEM90 DEM and its comparison with MERIT DEM using Ground Control Points for Diverse Topographic Regions

Ashutosh Bhardwaj
ashutosh@iirs.gov.in

Indian Institute of Remote Sensing, Dehradun, India-248001

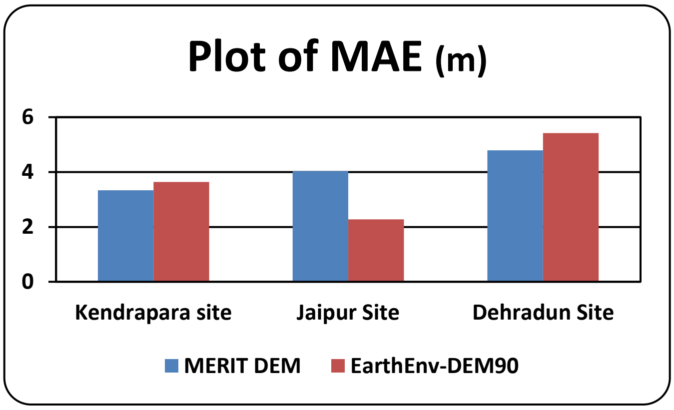
Graphical Abstract

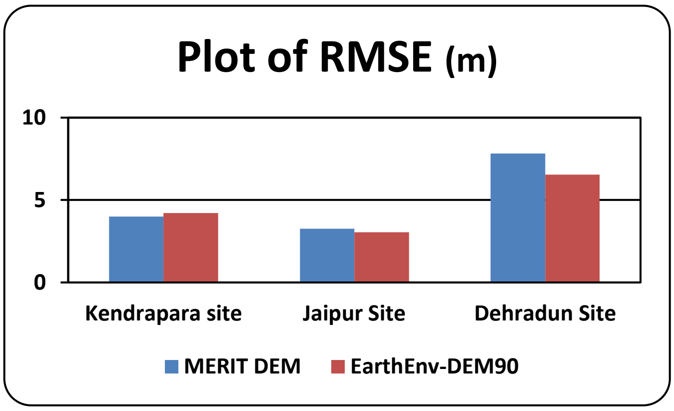




Abstract.

Currently, many of the practical engineering and environmental applications require a digital elevation model (DEM) as an important scientific input causing variations in the quality of the results in an application depending on the accuracy of the DEM. The availability of fused or assimilated DEMs at a global scale is a recent development strengthening the topographic studies and modeling of the related phenomenon. Openly accessible EarthEnv-DEM90 is generated by the fusion of ASTER GDEM2 and CGIAR-CSI v4.1 (SRTM 90m) products using rigorous techniques for enhanced quality under a collaborative project of NASA known as EarthEnv project. Whereas the other publicly available Multi-Error-Removed Improved-Terrain (MERIT) DEM is the product generated by Dai Yamazaki (University of Tokyo) using SRTM3 v2.1 and AW3D-30m v1 along with supplementary datasets available in different regions of the globe and primarily focusing it for global hydrodynamic modeling. In this study, EarthEnv-DEM90 and MERIT DEM are evaluated using ground control points (GCPs) acquired through the differential global positioning system (DGPS) surveys at the three





experimental sites with varied landforms and consequent topography. The resulting DEM statistics can assist an application scientist in the selection of a suitable fused DEM product with improved accuracy for specific applications in comparison to individual DEM products. Mean error (ME), Mean absolute error (MAE) and root mean square errors (RMSE) were computed and revealed that MERIT DEM performs better in plains of Kendrapara site with RMSE as 4 m. However, the EarthEnv-DEM90 achieves better accuracy in moderate topography at Jaipur site and rugged topography at Dehradun site with RMSE of 3.05m and 6.55m respectively.

Keywords: *Topography, Landforms, Digital Elevation Model (DEM), Hydrodynamic modeling, EarthEnv-DEM90, MERIT DEM*

Introduction

The recent developments in the field of DEM fusion or DEM assimilation have resulted in additional availability of improved DEM to the user community. However, these fused DEMs need evaluation for their accuracy before utilization in an application, since the results of these will vary with different complexities in the terrain. Openly accessible fused DEMs namely, EarthEnv-DEM90 DEM and MERIT DEM are currently available for the users for incorporation in their modeling applications specifically. EarthEnv-DEM90 datasets can be downloaded free of charge from the website: http://www.earthenv.org/DEM.html [1]. Similarly, MERIT DEM datasets are accessible and can be downloaded free of charge from the website: http://hydro.iis.u-tokyo.ac.jp/~yamadai/MERIT_DEM [2]. The performance of these fused DEMs will depend on the type of landforms constituting the topography of a specific experimental site.

The current popular practice is to generate DEM mostly using photogrammetry [3]–[9] and Synthetic Aperture Radar Interferometry (InSAR) followed by DEM derivative [10]–[14] and morphometric analysis [15]–[19]. It is also important to observe the nature of the error in the DEMs, such as the presence of floating and digging mass points, which affect the DEM derivatives such as slope and as an effect of smoothening of DEMs [20]. The Earth geoid models represent the equipotential gravitational surface, which is required for the transformation of coordinates between various datums and is a prerequisite for applications in cartography, photogrammetry, geophysics, and oceanography [21]–[23].

Tan et al. studied the effect of DEM on the Soil & Water Assessment Tool (SWAT) model and evaluated RMSE of EarthEnv-DEM 90, which is found to be higher than that of SRTM v4.1 and ASTER GDEM2 [24]. DEM fusion or assimilation techniques are also used by researchers for improved accuracy of DEM and its products [1], [2], [25]–[30]. The latest techniques of convolutional neural networks and transfer learning are being implemented for increasing the information content in a DEM [31]. Separation of shadows from water bodies is also done using DEM for the development of Global 3 arc-second Water Body Map (G3WBM) [32].

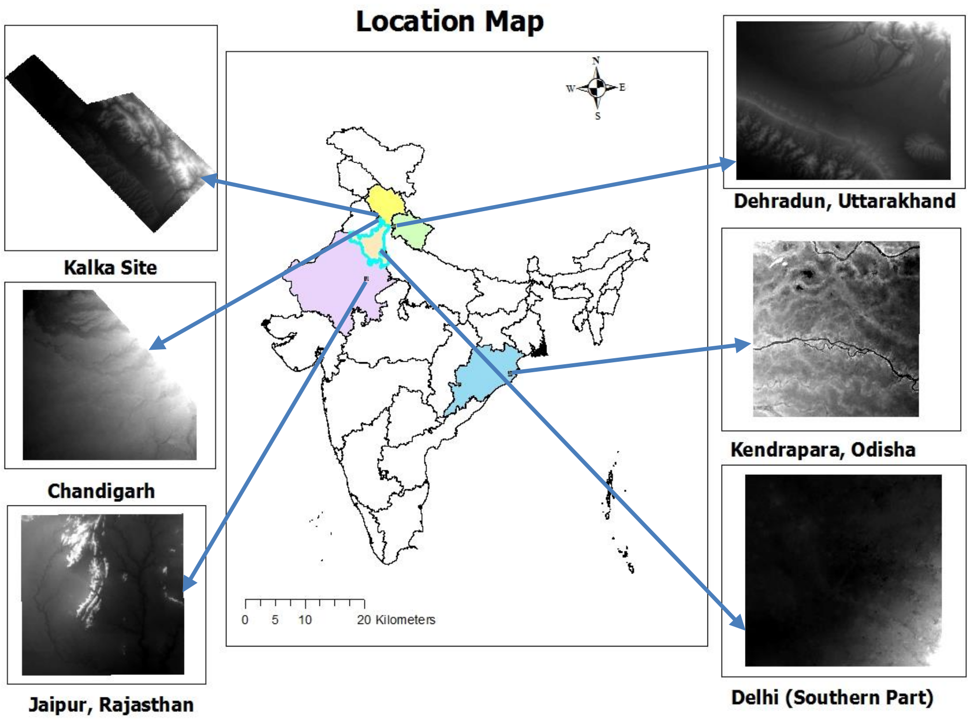


Figure 1: Location map of the MERIT experimental sites with DEMs

MERIT DEM has been assessed for six experimental sites (Figure 1) at Dehradun, Kendrapara, Jaipur, Delhi, Chandigarh, and Shivalik hills near Kalka with detailed analysis using Statistical parameters like RMSE, ME, MAE, the linear error at 90% confidence level (LE90=STD*1.65) and standard deviation [33]. Openly accessible DEMs are assessed for Dehradun, Kendrapara, Jaipur, Ahmedabad, Bhubaneshwar, and Rishikesh depicting the variations in the accuracy among the various DEMs in topographic regions with varying complexity [30], [34], [35]. Similarly, Yamazaki et al have analyzed global sites for MERIT DEM datasets [36]. The current study presents the results of three sites at Dehradun, Kendrapara, and Jaipur for evaluation of EarthEnv-DEM90 datasets and further comparison with MERIT DEM.

Materials and Methods

MERIT DEM and EarthEnv-DEM90 datasets were downloaded from the respective websites for the three experimental sites at Dehradun, Kendrapara, and Jaipur. GCPs collected using DGPS mode, were utilized for evaluation of the EarthEnv-DEM90 and compared to MERIT DEMs at the three experimental sites. The statistical parameters for quality assessment of DEM such as ME, MAE, and RMSE were calculated as described in Figure 2 to assess the performance of the method or the model applied in DEM fusion. The inference on the nature of the terrain undulations or the topographic ruggedness is based on the analysis of the difference between the ME and the MAE representing the accuracy of the fused DEM products (MERIT DEM and EarthEnv-DEM90). MAE is mathematically linear whereas the RMSE is quadratic and thus implies equal weightages to errors in case of calculating MAE. However, RMSE has a relatively high weight to large errors because the errors are squared before averaging.

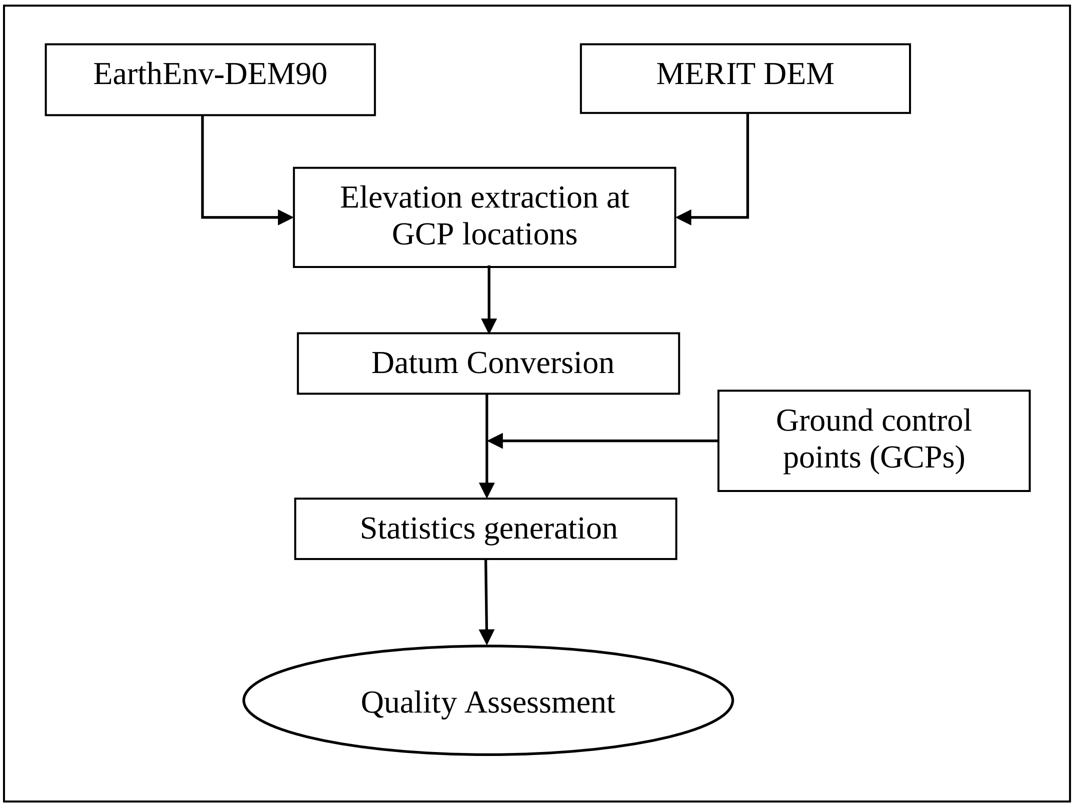


Figure 2: Flowchart for Quality Assessment of openly accessible fused DEMs

The elevation values extracted from the DEMs were calculated to the same datum using equation 1. Here, N is the Geoid Height, h_{GPS} is the GPS elevation at the GCP location in WGS84 (World Geodetic System 1984) datum and H_{EGM} is the orthometric height with respect to the EGM96 Earth gravitational model. The ME (equation 2), MAE (equation 3) and RMSE (equation 4) were calculated using respective equations.

$$H_{EGM} = h_{GPS} - N \tag{1}$$

$$\mathrm{ME} = \frac{\sum_{i=0}^{n} z_{i(DEM)} - z_{i(REF)}}{n} \tag{2}$$

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

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n} \left(z_{i(DEM)} - z_{i(REF)}\right)^2}{n}} \quad (4)$$

where $z_{i\ (DEM)}$ is the extracted elevation from the fused DEM dataset and $z_{i\ (REF)}$ is the observed reference elevation at the GCP locations with i=1 to n.

Results and Discussion

Table 1 describes the statistical evaluation of EarthEnv-DEM90 and compares it with MERIT DEM at the experimental sites at Dehradun, Kendrapara, and Jaipur. ME, MAE and RMSE reveals that the MERIT DEM performs better in plains of Kendrapara site with RMSE as 4 m in comparison to EarthEnv-DEM90 having RMSE of 4.22m. However, the EarthEnv-DEM90 has better accuracy in moderate topography regions at Jaipur site and highly undulating topography at Dehradun site with RMSE of 3.05m and 6.55m; as compared to RMSE of MERIT DEMs as 3.27m and 7.82m respectively. RMSE is not a good indicator of average model performance in specific situations and may be a deceptive indicator of average error, and thus the MAE can represent a better statistics for that purpose [37], [38].

Table 1: Vertical accuracy measures computed for the three experimental sites

Experimetnal Sites	**ME (m)**		**MAE (m)**		**RMSE (m)**	
DEMs-90m	**MERIT**	**EarthEnv**	**MERIT**	**EarthEnv**	**MERIT**	**EarthEnv**
Jaipur Site	1.37	0.70	4.03	2.28	3.27	3.05
Kendrapara site	-3.33	-3.64	3.33	3.64	4.00	4.22
Dehradun Site	3.17	0.57	4.79	5.42	7.82	6.55

The results of ME and RMSE also depict that the ME values can be very low and still has a higher RMSE as shown in Table 1 for the study sites at Jaipur and Dehradun. This especially occurs when the DEM has mass points in both floating (hanging) and digging, i.e. above and below the surface of the earth, which implies the overestimation and underestimation of the elevation values respectively. LE90 can be calculated directly from RMSE (LE90=1.65 X RMSE) [39], [40], and thus has not been shown separately in table 1. The negative ME at Kendrapara site which is equal to MAE except for the sign, indicates that all the elevation points in the MERIT, as well as EarthEnv DEMs, are above the earth’s surface at GCP locations representing the overestimation of elevation values. It is also observed that for the plain experimental site at Kendrapara the performance of CartoDEM R3 V1 (RMSE= 2m) dataset available on the ISRO platform is superior to both EarthEnv-DEM90 and MERIT DEM products [30].

Conclusion

The results depict that different available fused DEMs perform differently in varying terrain conditions prevailing at the experimental sites. The study concludes that the fused DEM shall be selected through a quality assessment before further use in any application. Additionally, the fused DEM shall also be assessed with regard to the DEMs, which are available freely and not used in the DEM fusion or assimilation process. In the study presented here, it can be observed that the CartoDEM V3 R1, has better quality, especially in the plain experimental site of Kendrapara. This improvement can be attributed to reasons such as the better spatial resolution of Cartosat-1 stereopairs, adequate base-height (b/h) ratio, and use of GCPs in the photogrammetric procedures for the development of CartoDEM V3 R1 including the DEM editing in the generation of consequent versions of DEM.

Acknowledgment

The author would like to thank the space agencies: NASA, ESA, JAXA, ISRO, Yale University, University of Tokyo and their collaborators for their insights on benefits of DEM fusion and support the user community free of cost through data sharing platforms, which are highly valuable as well as critical in the presented study at various stages. Author thanks Dr. N. Robinson and Dr. Dai Yamazaki in particular for generating and making the fused DEM data available for research. The author is highly indebted to Director, IIRS for support and encouragement for conducting the research activities.

References

[1] N. Robinson, J. Regetz, and R. P. Guralnick, “EarthEnv-DEM90: A nearly-global, void-free, multi-scale smoothed, 90m digital elevation model from fused ASTER and SRTM data,” *ISPRS J. Photogramm. Remote Sens.*, vol. 87, pp. 57–67, Jan. 2014.

[2] D. Yamazaki, D. Ikeshima, J. Sosa, P. D. Bates, G. H. Allen, and T. M. Pavelsky, “MERIT Hydro: A High-Resolution Global Hydrography Map Based on Latest Topography Dataset,” *Water Resour. Res.*, vol. 55, no. 6, pp. 5053–5073, 2019.

[3] K. Jacobsen, “Comparison of High resolution mapping from space,” *Indian Cartogr.*, vol. 24, pp. 106–119, 2002.

[4] P. Capaldo, M. Crespi, F. Fratarcangeli, A. Nascetti, and F. Pieralice, “Dsm Generation From High Resolution Cosmo-Skymed Imagery With Radargrammetric Model,” *ISPRS - Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci.*, vol. XXXVIII-4/, no. June, pp. 239–244, 2011.

[5] M. Crespi, F. Fratarcangeli, F. Giannone, G. Colosimo, F. Pieralice, and K. Jacobsen, “Geometric Potential of Cartosat-1 Stereo Imagery,” in *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences. Vol. XXXVII. Part B1.*, 2008, pp. 1323–1329.

[6] A. Bhardwaj, “Evaluation of DEM, orthoimage generated from Cartosat-1 with its potential for feature extraction and visualization,” *Am. J. Remote Sens.*, vol. 1, no. 1, pp. 1–6, 2013.

[7] G. Dial, “IKONOS satellite mapping accuracy,” in *Proceedings of ASPRS Annual Convention 2000*, 2000.

[8] J. Grodecki and G. Dial, “Block adjustment of high-resolution satellite images described by Rational Polynomials,” *Photogramm. Eng. Remote Sensing*, vol. 69, no. 1, pp. 59–68, 2003.

[9] C. S. Fraser, G. Dial, and J. Grodecki, “Sensor orientation via RPCs,” *ISPRS J. Photogramm. Remote Sens.*, vol. 60, no. 3, pp. 182–194, 2006.

[10] Y. Dong, G. Tang, and T. Zhang, “A systematic classification research of topographic descriptive attribute in digital terrain analysis,” *Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci.*, vol. 37

B2, pp. 357–362, 2008.
[11] J. P. Wilson and J. C. Gallant, *Terrain analysis□: principles and applications*. Wiley, 2000.
[12] J. Barlow, S. Franklin, and Y. Martin, "High spatial resolution satellite imagery, DEM derivatives, and image segmentation for the detection of mass wasting processes," *Photogramm. Eng. Remote Sens.*, vol. 72, no. 6, pp. 687–692, Jun. 2006.
[13] S. Kienzle, "The effect of DEM raster resolution on first order, second order and compound terrain derivatives," *Trans. GIS*, vol. 8, no. 1, pp. 83–111, 2004.
[14] G. Szabó, S. K. Singh, and S. Szabó, "Slope angle and aspect as influencing factors on the accuracy of the SRTM and the ASTER GDEM databases," *Phys. Chem. Earth*, vol. 83–84, pp. 137–145, 2015.
[15] J. Minár and I. S. Evans, "Elementary forms for land surface segmentation: The theoretical basis of terrain analysis and geomorphological mapping," *Geomorphology*, vol. 95, no. 3–4, pp. 236–259, 2008.
[16] R. J. Pike, "A Bibliography of Geomorphometry, the Quantitative Representation of Topography Supplement 2.0," 1996.
[17] M. Fiorentino, P. Claps, and V. P. Singh, "An entropy-based morphological analysis of river basin networks," *Water Resour. Res.*, vol. 29, no. 4, pp. 1215–1224, Apr. 1993.
[18] M. Gilichinsky, D. Melnikov, I. Melekestsev, N. Zaretskaya, and M. Inbar, "Morphometric measurements of cinder cones from digital elevation models of Tolbachik volcanic field , central Kamchatka," vol. 36, no. 4, pp. 287–300, 2010.
[19] S. Nitheshnirmal, A. Bhardwaj, C. Dineshkumar, and S. A. Rahaman, "Prioritization of Erosion Prone Micro-Watersheds Using Morphometric Analysis coupled with Multi-Criteria Decision Making," *Proceedings*, Jun. 2019.
[20] P. K. Parida, M. K. Sanabada, and A. K. Mohapatra, "Slope generation using ArcGIS Model Builder a tool to check the accuracy of Digital Elevation Model (DEM) generated through photogrammetric block," in *Esri India User Conference Proceedings*, 2013, pp. 1–8.
[21] H. Heiskanen, W.A.; Moritz, *Physical Geodesy;* W.H. Freeman: San Francisco, CA, USA, 1967.
[22] B. Sadasiva Rao, G. Anil Kumar, P. V. S. S. N. Gopala krishna, P. Srinivasulu, and V. Raghu Venkataraman, "Evaluation of EGM 2008 with EGM96 and its Utilization in Topographical Mapping Projects," *J. Indian Soc. Remote Sens.*, vol. 40, no. 2, pp. 335–340, Jun. 2012.
[23] A. Bhardwaj, "Evaluating terrain type using geoid heights obtained from different geoids in varied topographic regions with different complexity," in *MOL2NET, International Conference Series on Multidisciplinary Sciences, USEDAT-08: USA-Europe Data Analysis Training Program Workshop, UPV/EHU, Bilbao-MDC*, 2020, pp. 1–7.
[24] M. L. Tan, D. L. Ficklin, B. Dixon, A. L. Ibrahim, Z. Yusop, and V. Chaplot, "Impacts of DEM resolution, source, and resampling technique on SWAT-simulated streamflow," *Appl. Geogr.*, vol. 63, pp. 357–368, 2015.
[25] R. Deo, C. Rossi, M. Eineder, T. Fritz, and Y. S. Rao, "Framework for Fusion of Ascending and Descending Pass TanDEM-X Raw DEMs," *IEEE J. Sel. Top. Appl. Earth Obs. Remote Sens.*, vol. 8, no. 7, pp. 3347–3355, 2015.
[26] K. C. Slatton, M. M. Crawford, and B. L. Evans, "Fusing interferometric radar and laser altimeter data to estimate surface topography and vegetation heights," *IEEE Trans. Geosci. Remote Sens.*, vol. 39, no. 11, pp. 2470–2482, 2001.
[27] L. Yue, H. Shen, L. Zhang, X. Zheng, F. Zhang, and Q. Yuan, "High-quality seamless DEM generation blending SRTM-1, ASTER GDEM v2 and ICESat/GLAS observations," *ISPRS J. Photogramm. Remote Sens.*, vol. 123, pp. 20–34, 2017.
[28] H. Papasaika, E. Kokiopoulou, E. Baltsavias, K. Schindler, and D. Kressner, "Fusion of digital elevation models using sparse representations," *Photogramm. Image Anal.*, pp. 171–184, 2011.
[29] A. Bhardwaj, R. S. Chatterjee, and K. Jain, "Assimilation of DEMs generated from optical stereo and InSAR pair through data fusion," *Sci. Res.*, vol. 1, no. 3, pp. 39–44, 2013.
[30] A. Bhardwaj, K. Jain, and R. S. Chatterjee, "Generation of high-quality digital elevation models by assimilation of remote sensing-based DEMs," *J. Appl. Remote Sens.*, vol. 13, no. 04, p. 1, Oct.

2019.

[31] Z. Xu, Z. Chen, W. Yi, Q. Gui, W. Hou, and M. Ding, "Deep gradient prior network for DEM super-resolution: Transfer learning from image to DEM," *ISPRS J. Photogramm. Remote Sens.*, vol. 150, pp. 80–90, Apr. 2019.

[32] D. Yamazaki, M. A. Trigg, and D. Ikeshima, "Development of a global ~90m water body map using multi-temporal Landsat images," *Remote Sens. Environ.*, vol. 171, pp. 337–351, 2015.

[33] A. Bhardwaj, "Evaluation of openly Accessible MERIT DEM for vertical accuracy in different topographic regions of India," in *39th INCA International Congress on New Age Cartography And Geospatial Technology in Digital India*, 2019, pp. 1–9.

[34] E. Metilda, S. Khatriker, A. Bhardwaj, and K. Gupta, "Accuracy Assessment of Open Accessible Digital Elevation Models in Urban Areas," in *National Seminar on Recent Advances in Geospatial Technology & Applications*, 2020, pp. 1–7.

[35] R. Agarwal, K. Sur, and A. S. Rajawat, "Accuracy assessment of the CARTOSAT DEM using robust statistical measures," *Model. Earth Syst. Environ.*, vol. 6, no. 1, pp. 471–478, Mar. 2020.

[36] D. Yamazaki *et al.*, "A high-accuracy map of global terrain elevations," *Geophys. Res. Lett.*, vol. 44, no. 11, pp. 5844–5853, 2017.

[37] T. Chai and R. R. Draxler, "Root mean square error (RMSE) or mean absolute error (MAE)?- Arguments against avoiding RMSE in the literature," *Geosci. Model Dev*, vol. 7, pp. 1247–1250, 2014.

[38] C. J. Willmott and K. Matsuura, "Advantages of the mean absolute error (MAE) over the root mean square error (RMSE) in assessing average model performance," *Clim. Res.*, vol. 30, no. 1, pp. 79–82, 2005.

[39] J. Dolloff and J. Carr, "Computation of scalar accuracy metrics LE, CE, and SE as both predictive and sample-based statistics," in *Proceeding of the ASPRS/IGTF Annual Conference*, 2016, pp. 1–15.

[40] B. Eilmus, G. Heidelmeyer, and U. Klingauf, "Analysis of terrain data based on satellite imagery for aviation purposes," *Sensors, Syst. Next-Generation Satell. XI*, vol. 6744, no. October 2007, p. 67442G, 2007.