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Comparison of TopoDEM and CartoDEM for Height accuracy assessment over different terrains of Bhutan.

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Abstract - Digital Elevation Models (DEMs) are essential geospatial datasets representing Earth's surface elevation, widely used in applications such as flood modeling, urban planning, and disaster response. However, DEMs derived from sources like satellite imagery, LiDAR, or photogrammetry can contain errors due to sensor limitations, processing issues, and surface conditions. Accurate validation against high-quality reference data, such as ground-based surveys or GPS measurements, is crucial, employing statistical metrics like Root Mean Square Error (RMSE), Mean Absolute Error (MAE), and Standard Deviation of Errors (STD) to quantify discrepancies. This study assesses the vertical accuracy of a local 10 m DEM (TopoDEM) generated from contour lines and spot heights derived from 1:25,000 digital topographic maps via digital photogrammetry, compared to the Cartosat-1 DEM (CartoDEM) by ISRO, which claims 8 m accuracy at LE90. Validation utilized ground control points (GCPs) across test areas in Bhutan (Gelephu, Paro, and Trashiyangtse), computing elevation differences and statistical measures. Results indicate TopoDEM generally outperforms CartoDEM, with RMSE values ranging from 4.56 m to 6.62 m across terrains, versus CartoDEM's 4.26 m to 9.04 m. TopoDEM showed lower errors in Paro and Trashiyangtse, while Gelephu exhibited higher residuals due to recent topographic changes. Over flat terrains like Gelephu, RMSE was 4.26–6.62 m, and in high-altitude areas like Trashiyangtse, it ranged from 6.42–9.04 m. In conclusion, TopoDEM demonstrates superior vertical accuracy, underscoring the value of high-resolution datasets from digital photogrammetry for reliable elevation modeling in diverse landscapes. This highlights the need for rigorous accuracy assessments to ensure DEM reliability in critical applications.

Keywords - Digital Elvation Model (DEM), TopoDEM, CartoDEM.

I. INTRODUCTION

Digital Elevation Models (DEMs) are important geospatial datasets depicting the Earth's surface elevation topology in a grid format, which are used for flood modeling, urban planning, environmental monitoring and management, and disaster response, among other applications (Pakoksung & Takagi, 2015). DEMs from satellite imagery, LiDAR, or photogrammetry may incorporate errors depending on sensor limitations, processing errors, and the surface conditions.

As highlighted by (Ibrahim Yahaya & El Azzab, 2019), DEM's are subject to several types of errors due to data collection and processing methodology which must be evaluated it's accuracy before using them. The validation confirms and gauge the reliability and accuracy of the model based on higher quality reference data sets, such as ground-based surveys, GPS measurements, or higher accuracy elevation datasets. (Aponte Saravia, 2022) considered various computable assessment of DEM quality using standard statistical measures to express and quantify the difference between the DEM and reference elevations.

There are several key statistical decisions used in accuracy evaluation of DEMs that address different aspects of DEM quality with each of the statistics representing a different dimension of error (Aponte Saravia, 2022). For instance, Root Mean Square Error (RMSE) provides a measure of the average magnitude of an error, larger errors carry more weight than smaller errors. RMSE is computed by taking the square root of the mean squared differences of the DEM and reference heights. Thus, RMSE provides a useful generalization for the accuracy, with lower values of RMSE indicating better model performance. Mean Absolute Error (MAE), on the other hand, provides a calculation of the average of absolute differences, which organizes the measure of average error without introducing more influence from outliers.

MAE is particularly useful for evaluating any inherent biases possible with the estimated elevation. Bias (Mean Error) is the average difference between the DEM and reference values and indicates whether the model is over or under-estimated elevation. Close to zero bias indicates that there were no systematic errors. Standard Deviation of Errors (STD) provides a measure of the dispersion of errors to the mean which indicates the variance in the accuracy throughout the dataset. Importantly, STD provides an alternative complimentary perspective of accuracy than RMSE because RMSE captures the accuracy by a measure of dispersion (Aponte Saravia, 2022; Ibrahim Yahaya & El Azzab, 2019).

The objective of this study is to assess the vertical accuracy of the local DEM (10 m) generated from contour lines and spot heights created through the digital plotting of 1:25,000 digital topographic map using the ground control point with Cartosat-1 Digital Elevation Model (CartoDEM) developed by the Indian Space Research Organization (ISRO). Currently, we have nationwide coverage on CartoDEM claiming the vertical accuracy of 8m at LE90 –Linear Error at 90% confidence (S. Muralikrishnan, 2011). The TopoDEM created from the digital topographic datasets using the contour lines and spot heights derived from the stereo plotting in photogrammetry work environment cover approximately 75% of the total area with vertical accuracy of 10 meter RMSE as per the technical specification for creation of DEM in 1:25,000 digital topographic map.

Study Area

Bhutan is located between the two big neighboring countries, India to South and China to North. The topography of the country is dominated by high mountains with elevation ranges from as low as 96 m to 7500m above sea level. The majority of the land cover type in the country is forest (69%) followed by other land cover classes DoSAM (2023).

Test area

Three different terrains with varying elevation and vegetation cover are chosen for the present study. The first test site lies in the Gelephu, Sarpang District where the terrain is flat with agriculture land. The second test site is at Paro District with relatively flat with forest cover. The third test site is at Trashiyangtse with altitude ranging from 740 – 2800 m above sea level.

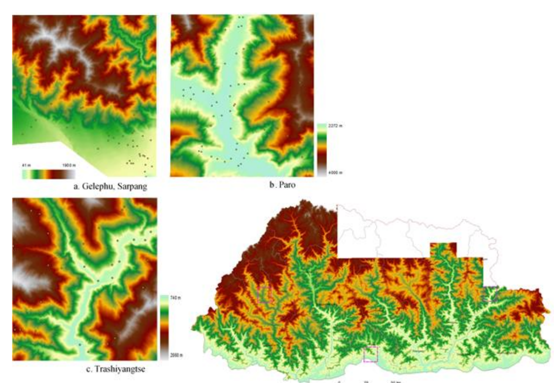

Fig.1 Part of TopoDEM showing the three test sites with varying elevations (a. Gelephu, Sarpang, b. Paro & c. Trashiyangtse)

II. METHODOLOGY

Data sets

CartoDEM

The datasets for the accuracy evaluation include the CartoDEM derived from satellite images by the NRSC, ISRO from the Cartosat-1 stereo payload launched in May 2005 (S. Muralikrishnan, 2011). The original output with a tile of 7.5′×7.5′ wide with DEM spacing of 1/3 arcsec is available on chargeable basis. However, the public data sets are available at 30m and 90m. The detailed description of the data used is given in Table 1 (R. Zade, 2022).

Table 1. CartoDEM details

CartoDEM -3.1	
Acquisition year	2005
Release year	2015
Agency	NRSC/ISRO
Mission GSD	2.5 m
Sensor	PAN Stereo
Method	Stereo-strip Triangulation
Absolute Vertical Accuracy	<8m (LE90)
Reference to Vertical Accuracy	Muralikrishnan, S. et.al., 2011
Vertical/Horizontal datum	WGS84
Absolute Horizontal Accuracy	15 m
Website	https://bhuvanapp3.nrsc.gov.in/data

TopoDEM

TopoDEM is generated from the digital topographic datasets of 1:25,000 scale using the contour lines and spot heights derived from the stereo plotting in photogrammetry work environment. The output Dem is at 10m wide grid spacing.

Table 2. TopoDEM details

TopoDEM	
Grid Spacing	10 m
Vertical Accuracy	10 m (RMSE)
File Format	Geo TIFF
Agency	NLCS
Datum	DrukRef03
Method	The contour lines and spot heights created through digital plotting were used to generate the DEM.

Reference elevation data

DEMs accuracy assessment involves a high accuracy reference points. For this study, the reference points were observed by using GPS survey techniques establish as the secondary control points (GCP) in the ground. The GCP has a vertical accuracy of less than 10 cm. Maximum of 50 numbers of control points was chosen in three different test areas for evaluation of the heights generated from the digital elevation model's.

Elevation accuracy analysis

The vertical accuracy of the DEMs was estimated by comparing the differences between the value of the DEM pixel and the GCP reference point elevation using the following equations (Zhang et al., 2019). The vertical accuracy analysis is based on the analysis of statistical parameters such as Mean Error (ME), Standard Deviation (STD) and Root Means Square Error (RMSE).

Elevation error $(Z_{diff}) = Z_{GCP} - Z_{DEM}$ ______ (1)

Mean error (ME) $= \frac{1}{n}\sum_{i=1}^{n} Z_{diff}$ ______ (2)

Standard deviation error (STD) $= \frac{1}{n-1}\sqrt{\sum_{i=1}^{n}(Z_{diff} - ME)^2}$ ______ (3)

Root mean square error (RMSE) $= \frac{1}{n}\sqrt{\sum_{i=1}^{n}(Z_{diff})2}$ ______ (4)

Here,
Z_GCP = elevation value of GCP points
Z_DEM = elevation values of DEM
n = Number of check points

The Z_diff tells us whether a set of measurements consistently underestimate or overestimate the true/reference value. RMSE indicate an average deviation of observed values from the true value. It is a single estimates characterizing error surface, and the mean error reflects the bias of the error surface (Pakoksung & Takagi, 2015).

Results and discussions

Table 3 summarizes the statistics of the elevation difference between the reference data and DEMs. Comparison of GCP measurement at three test areas (Sarpang, Paro & Trashiyangtse) indicated that the TopoDEM return the lowest RMSE value in Paro and Trashiyangtse except Sarpang. Sarpang test area has RMSE value of 6.62 compared to 4.26 m in CartoDEM. This variation of residual error is from the massive topography changes in the recent years in the test area and the digital topographic mapping also carried out lately. It is also evident from the return of the mean error values from 5.45 to 0.97 m in the area. For rest of the test areas, it was observed that TopoDEM has relatively less error compared to the CartoDEM.

Table 3. Height accuracy assessment of DEMs by computing differences to reference data.

Accuracy measures	TopoDEM			CartoDEM		
	Sarpang	Paro	Trashiyangtse	Sarpang	Paro	Trashiyangtse
Mean Error (ME)	5.45	2.32	4.28	0.97	4.90	5.34
Standard Deviation (SD)	3.81	4.04	4.84	4.37	4.23	7.57
Root Mean Square Error (RMSE)	6.62	4.56	6.42	4.26	6.49	9.04

III. CONCLUSION

The vertical accuracy of two DEMs has been assessed. From the vertical accuracy comparison analysis of the two DEMs, TopoDEM showed the greatest vertical accuracy whose RMSE values ranges from 4.56 to 6.62 respectively. The elevation data are used as the reference data and statistics of the

elevation differences between the reference data and DEMs are calculated.
Over the flat terrain of Gelephu test area, the RMSE is between 4.26 and 6.62 m. For Paro with relatively flat and forest cover it ranges from 4.56 to 6.49 m, and for high altitude (Trayangtse) test area, the RMSE ranges from 6.42 to 9.04 m.

Accordingly, it can be deduced that for the study area the TopoDEM model has a high vertical accuracy which revealed the importance of generating the DEM from the high accuracy datasets. The TopoDEM was generated from the topographic datasets derived from the digital photogrammetry method using the high resolution satellite imagery and recommended to use the TopoDEM for the analysis purposes.

REFERENCES

1. Aponte Saravia, J. (2022). Vertical Accuracy Assessment of Open Access Digital Elevation Models: Bucaramanga-Colombia Case Study. Geodesy and cartography, 48(1), 36-45. https://doi.org/10.3846/gac.2022.14266
2. DoSAM. (2023). Land use Land cover assessement of Bhutan 2020, Technical report.
3. Ibrahim Yahaya, S., & El Azzab, D. (2019). Vertical accuracy assessment of global digital elevation models and validation of gravity database heights in Niger. International Journal of Remote Sensing, 40(20), 7966-7985. https://doi.org/10.1080/01431161.2019.1607982
4. Pakoksung, K., & Takagi, M. (2015). Digital elevation models on accuracy validation and bias correction in vertical. Modeling Earth Systems and Environment, 2(1). https://doi.org/10.1007/s40808-015-0069-3
5. R. Zade, G. P. S., K.K. Gupta. (2022). Vertical accuracy assessment of CartoDEM, SRTM and ALOS DEM's using GTS and DGPS
6. measurement in Narmada Basin, Madhya Pradesh. Journal of Geomatics, 16, 15.
7. S. Muralikrishnan, B. N., Shashivardhan Reddy and Abhijit Pillai. (2011). Evaluation of Indian National DEM from Cartosat-1 Data.
8. Zhang, Daniel Gann, Michael Rosss, Quin Robertson, Juan Sarmiento, Sheyla Santana, Jamie Rhome, & Fritz, C. (2019). Accuracy Assessment of ASTER, SRTM, ALOS, and TDX DEMs for Hispaniola Island and Implications for Mapping Vulnerability to Coastal Flooding. https://doi.org/https://doi.org/10.1016/j.rse.2019.02.028