Accuracy Assessment of Open-Source DEM: A Case for Nepal

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ABSTRACT

Digital representation of the earth topography is called Digital Elevation Model (DEM). DEMs are very useful for disaster assessment, 3D modelling, infrastructure planning and other development activities. There are various satellite systems providing the DEMs with different spatial resolution freely. This study assesses the reliability of the freely available DEMs while using those data for decision making. Reference elevation point data are taken from the topographical base map of the respective area. Statistical calculation was carried out for the testing reliability of the data. Root Mean Square Error (RMSE), Standard Deviation and Mean deviation are calculated to conduct the accuracy assessment. From the study, it is seen that, ALOS PRISM DEM of 30m resolution gave the precise result based on RMSE with the value of 5.9m in comparison to other five DEMs used in this study.

1. INTRODUCTION

"A map is a symbolized representation of geographic reality, representing selected features or characteristics, resulting from the creative effort of its author's execution of choices, and is designed for use when spatial relationships are of primary relevance." (ICA, 2003). With the views that the map should include traditional and modern maps, real and virtual maps like web maps, 3D maps, animated maps and globe etc., new definition of map was given by Lapaine *et al.* (2021) as "A map is a medium designed for communication of generalized spatial information and relationships".

Maps can serve as data brain for different applications (Li *et al.*, 2024). Map represents the ground features in pictorial format through symbols. Map can have 2-dimensional or 3-dimensional or both information. Planimetric maps only have 2D information whereas topographical maps holds both 2D and 3D features. 2D maps only gives the information of "x" and "y" position of the objects and the 3D gives the "z" value as well. In 2D maps, the details are represented with symbols. On the other hands, 3D information is shown with different forms like contour, hachure, hill shade, spot height, TIN, DEM. 3D maps gives the perspective of 3 dimensions even the landscape is shown in 2-dimensional media (Christian, 2002).

The topography of earth surface can be

represented digitally in the form of Digital Elevation Model (DEM), Triangulated Irregular Network (TIN) and contour based model (Jalal *et al.*, 2020). DEM comprises of two main categories: one is Digital Terrain Model (DTM) which represent earth surface without any natural or manmade structure and another is Digital Surface Model (DSM) which represent ground surface as well as all natural and manmade structured on the ground (Abili, 2021).

The paper is the study on accuracy assessment of different open-source DEM.

2. SOURCE OF DEM

DEM is the representation of squared cells called as pixel where each pixel has elevation value (Manuel, 2004). It is the symbolization of height information of the earth surface (Hasan, 2019) or the digital representation of the ground topography which can be created with different technology and methods with varying accuracies depending on the method adopted (Farah *et al.*, 2008; Mukherjee *et al.*, 2013) and every methods has its own advantages and disadvantages (Elsonbaty *et al.*, 2023).

2.1. Generation of DEM

Traditional methods like levelling, topographical mapping with total station, stereo photographs were used to generate DEM (Abili, 2021; Hasan, 2019). However, these kinds of traditional methods are expensive whereas DEM generation from GNSS technology gives cost effective solution among other advanced technologies like laser scanning, radar interferometry etc. (Farah et al., 2008). Emerging UAV technology together with photogrammetry can also generate cost effective and accurate DTM (Jiménez-Jiménez et al., 2021). DEM can also be generated automatically from aerial and satellite images by image processing methodologies (Krupnik, 2000).

Height information can be derived from the contour lines of topographic maps, spot heights, photogrammetry and also field surveys and generate the DEM from this information (Jalal *et al.*, 2020). Contours have the properties of consecutive equivalence in height information along its line and also the topological property, they are considered as suitable feature lines to generate DEMs (Li *et al.*, 2017). Basically, DEMs can be generated from contour lines of topographic maps, field surveys, stereo photographs/photogrammetry, radar interferometry and laser altimetry (Manuel, 2004).

2.2. Open-source DEM

Besides generation of DEM from secondary data or field observation, there are also freely available DEM available which were generated from different methods. The Shuttle Radar Topographic Mission (SRTM) of 30m x 30m resolution is the most popular Global DEM freely available from the National Aeronautics and Space Administration (NASA) and TerraSAR-X with approximate resolution of 90m x 90 m) is another freely available DEM which represents the bare Earth surface. (Jalal *et al.*, 2020). Advanced Land Observation Satellite Phased Array L-band Synthetic Aperture Radar (ALOS PALSAR 12.5 m) is the most precise GDEM which is freely available (Halim *et al.*, 2019). ASTER and SRTM DEM are most widely used DEMs and ALOS AW3D30 and TanDEM-X are gaining popularity in different field (Han *et al.*, 2021; Liu *et al.*, 2022).

3. ACCURACY ASSESSMENT REVIEW

Quantitative analysis like statistics and accuracy metrics, and qualitative analysis like visual inspection are often used for DEM accuracy evaluation (Wise, 2007). However, the quality of DEM is defined by different factors like terrain type, algorithm, grid spacing & characteristics as well as sensor types (Hebeler & Purves, 2009) and also the result of quality assessment depends on source of data, resolution of DEM, distribution of GCP used as reference and topography (Toz & Erdogan, 2008). Further, large number of reference check points with high accuracy are required to compute the DEM RMSE with some reliability (Aguilar *et al.*, 2007). Elsonbaty *et al.* (2023) accessed five freely available DEMs, ASTER GDEM2, SRTM 90 m, SRTM 30 m, Sentinel 1, and TanDEM-X 90 m with the reference of GNSS observation. Statistical evaluation of the five DEMs shows the Root Mean Square (RMSE) of ± 20.25 m, ±3.56 m, ±57.68 m, ±10.21 m, and ± 5.89 m for Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER), SRTM 30, SENTINEL 1, TanDEM-X, and SRTM3 respectively showing the highest accuracy of SRTM 90 among the five (Elsonbaty *et al.*, 2023). Study by Jalal *et al.* (2020) shows the RMSE of ±7.3 m, ±7.6 m and ±6.5 m checked with the reference of 12 fixed Ground Control Points (GCPs) for the ALOS PALSAR (12.5 m), the SRTM (30 m) and the TerraSAR-X respectively.

Similarly, comparison of freely created DEM from Google Earth, SRTM 30 and ASTER GDEM shows the RMSE of ±6.9m, ±5.5m and ±4.8 m respectively for the case of Iraq (Hasan, 2019). Accuracy assessment of open source DEMs, SRTM 30, ALOS and ASTER GDEM showed the RMSE of ± 4.63 m, ± 5.25 and ± 11.18 m in the study area of Adama City, Ethiopia showing the higher accuracy of SRTM in comparison to ALOS DEM and ASTER GDEM (Abili, 2021). Similar type of study between ASTER and SRTM DEM shows the RMSE of 12.62 m and 17.76 m respectively for both (Mukherjee *et al.*, 2013). Accuracy assessment of ALOS W3D30, ASTER GDEM and SRTM 30 done for the case of Nigeria shows the high accuracy of ALOS W3D30 with the RMSE value of 5.4 m against 7.47m and 20.03 m RMSE of SRTM and ASTER respectively (Apeh *et al.*, 2019). Accuracy assessment of open source global DEM against GNSS levelling shows that TanDEM-X shows the smallest RMSE of 2.574 m compared to SRTM30, SRTM90, ASTER, GMTED10, and ALOSW3D with RMSE of 2.968 m, 3.006 m, 3.217 m, 2.975 m, and 2.876 m respectively (Abd Rahman *et al.*, 2022) Similarly, accuracy assessment of ALOS AW3D30 and ALOS PRISM against contour data shows that AW3D30 DSM presents two or three times lower Root Mean Square Error (RMSE) than the respective DSMs from ALOS PRISM images (Konstantinos, 2020).

Though there are many research on examination of vertical accuracy of DEM, there is always enough scope of research since the accuracy vary for different landscape (Mukherjee *et al.*, 2013). Also, majority of the research on assessment of accuracy of DEM are based on point type reference data rather than linear and surface data expanding the scope of more research with standardized assessment methods (Mesa-Mingorance & Ariza-López, 2020)

4. METHODOLOGY

Kavrepalanchok district of Nepal was selected for the study (Figure 1). Openly accessible global DEM for the study area were downloaded from different source. Contour and spot height from existing base map of 1:25000 scale was used as reference data for validation.

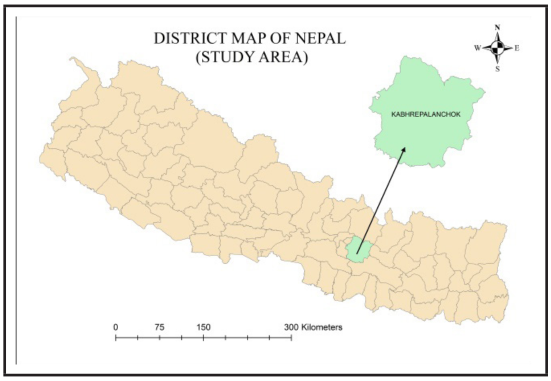


Figure 1: Study Area Map

4.1. Open-Source DEM Used for Analysis

Six open-source DEM were used for this study. The DEM used were ALOS PALSAR (12.5 m), CartoDEM V3 R1 (30 m), ASTER GDEM V2 (30 m), SRTM (30m), ALOS PRISM (30m), TanDEM-X (90 m). The major characteristics are shown in Table 1

Table 1: Specifications of DEM use for study

S. No.	DEM	Method of DEM	Vertical Datum	Spatial Resolution
1	PALSAR	RADAR	EGM96	12.5 m
2	Carto DEM	Optical Sterio	WGS84	1 arc second
3	PRISM	Optical Sterio	EGM96	1 arc second
4	SRTM	RADAR	EGM96	1 arc second
5	ASTER	Optical Sterio	EGM96	1 arc second
6	TanDEM-X	RADAR	WGS84	3 arc second

4.2. Methodology

DEM of the study area were downloaded. For the validation of the height value, reference points were collected from the topographical base map. The validation points were selected on the basis of contour value and the spot height shown in the topographical maps. The height generated for validation points were converted to global datum as per the datum of the DEM to be validated. For every point selected for validation, height value from DEM was extracted. Then after, statistical analysis was done to find the RMSE and deviations. The flow diagram of methodology is shown in Figure 2.

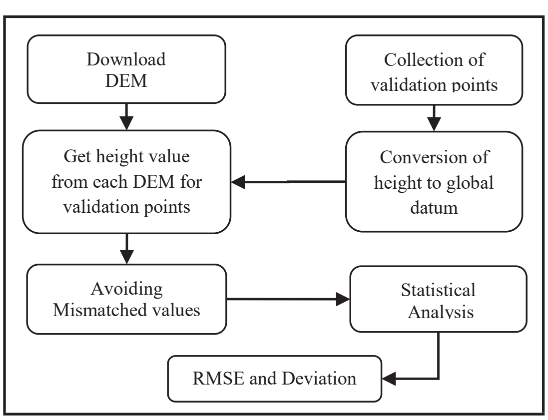


Figure 2 : Study Methodology

4.3. Data Analysis

Total 44 reference points for validation were extracted from 1:25000 scale topographical base map. Data analysis was carried out in GIS environment using reference points as vector data and DEMs as raster data. The extraction of height from DEMs to reference data was carried out using Extract Multi Values to Points tool available in ArcGIS 10x. Since vertical datum of openly accessible DEMs were not same, 'GeoidEval utility' was used for online calculation of Geoid undulation for conversion from orthometric height to Ellipsoid height (WGS84). Minimum elevation is 367 m and maximum elevation is 2682 m.

The statistical calculation for the mean deviation and RSME was done using MS-Excel. The scatter plot and charts were also produced by using Excel. During the calculation of RMSE, the difference value of map height to the DEMs height greater than 20 meters are assumed to be gross errors and hence, those points are removed during calculation assuming that height of the building and vegetation should not be more than 20m for those sample areas.

5. RESULT AND DISCUSSION

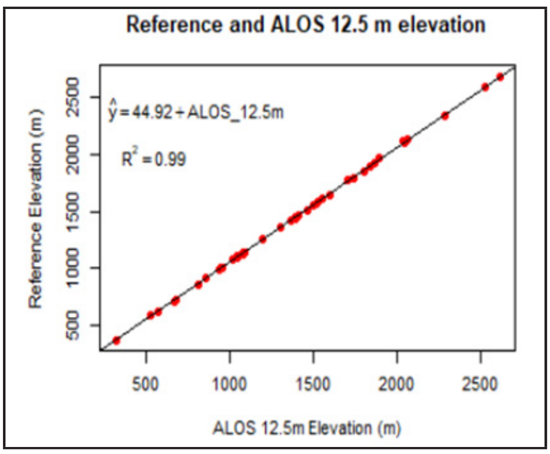
RMSE for each DEM, mean deviation of height derived from DEM and reference as well as standard deviation for the same values were calculated. Table 2 shows the results of statistical analysis.

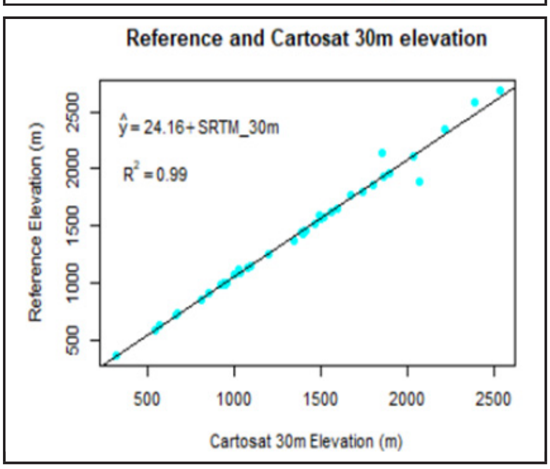
Table 2: Statistical analysis result.

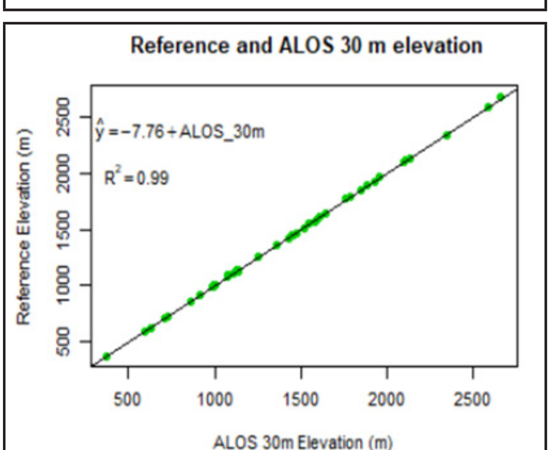
S.N.	DEM	RMSE	Mean Deviation	Standard Deviation
1	PALSAR	6.4	5.64	5.81
2	Cartosat	11.4	5.79	7.59
3	SRTM	6.6	5.26	6.13
4	ASTER	12.5	10.22	7.85
5	PRISM	5.9	5.28	6.58
6	TanDEM	11.3	8.03	8.22

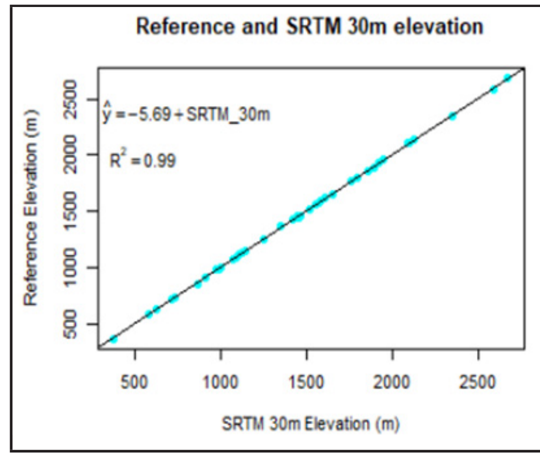
The analysis shows that, among six DEMs the least RMSE value is 5.9m for ALOS PRISM 30m spatial resolution. Similarly, least mean deviation is 5.26 m for SRTM and least standard deviation is 5.81m for ALOS PALSAR.

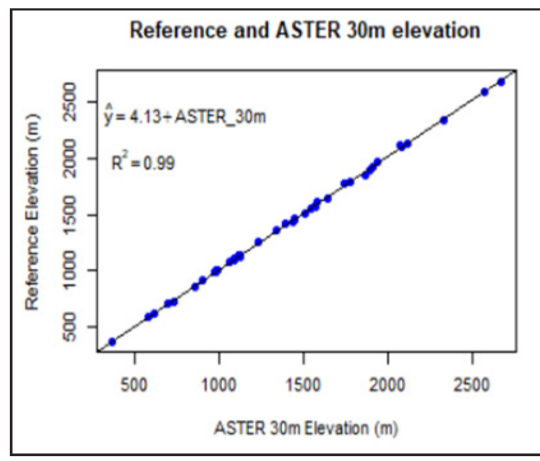
The scatter plot for all reference data and height from DEMs shown that there is a good linear relationship between them. The Figure 3 showed the linear relationship between the reference elevation data and each DEM in Nepal.











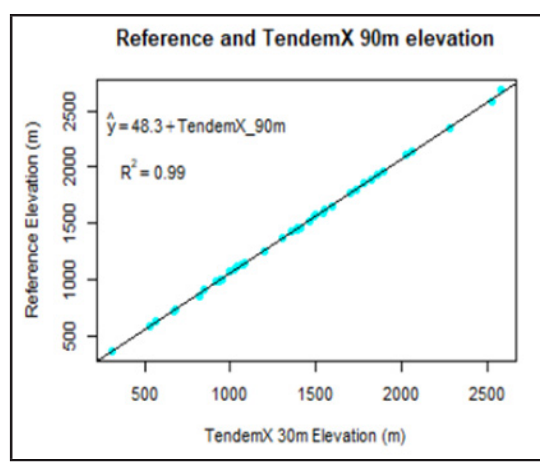


Figure 3: Scatter plot of reference data used.

It showed that there is only small variation between testing elevation data and SRTM data, while the others showed a nearly perfect linear relationship. It is also noted that there is a bigger variation in flat areas (less than 500m in elevation) compared to higher height. This can be the effect of topography and some errors in the DEM. 99% of variations in the model can be explained by DEMs ($R^{\wedge 2}$ = 0.99), which showed that there is a very small difference between openly accessible DEMs and assumed true values.

6. CONCLUSION & RECOMMENDATIONS

There are various satellite systems which provide openly accessible global DEMs generated by various technologies. The validation samples are taken from the topographical base map of scale 1:25000. The height provided in different DEMs are in different vertical datum those heights are converted to ellipsoidal height using Online geoid calculations using the GeoidEval utility with geoid undulation for each reference sample points based on latitude and longitude.

The RMSE calculation shows that the ALOS PRISM DEM 30m spatial resolution having RMSE value 5.9m is the best DEM among the six DEMs for study area. RMSE value of the ALOS PALSAR having 6.4 seems to be less accurate than the ALOS PRISM DEM having 12.5m spatial resolution. This study is expected to provide the public users as a reference so that they can choose the "best" openly accessible DEMs as per requirement. Further, secondary data extracted from the topographical base maps were used for validation of DEMs. However, it is recommended to use primary field data for validation of the DEMs which is better compared to the use of validation points from topographical map of scale 1:25000.

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