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# Evaluation of digital elevation model in hilly region of Uttarakhand: A case study of experimental farm Hawalbagh

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**ABSTRACT**

Digital Elevation Model (DEM) is used to display terrestrial information on map. Moreover, DEMs are often used in geographic information systems (GIS), and serve as a basis for generation of relief map. The present study was conducted to evaluate the google earth (GE) derived DEM with three established open source DEMs such as, shuttle radar topographic mission (SRTM) DEM, advanced space borne thermal emission and reflection radiometer (ASTER) DEM and advanced land observing satellite phased array type l–band synthetic aperture radar (ALOS PALSAR) DEM. The study area of present research is experimental farm, Hawalbagh of the ICAR–Vivekananda Parvatiya Krishi Anusandhan Sansthan (VPKAS), Almora, India which lies in middle Himalayas using online tool (GPS visualizer). The accuracy statistics were evaluated using 100 points in the study area having varying topography with three DEMs such as, SRTM DEM, ASTER DEM and ALOS PALSAR DEM. The result showed that google earth data was positively correlated with all established DEM with $r^2$ value of 0.88 for SRTM, 0.92 for ALOS PALSAR Dem and 0.83 for ASTER DEM. The result showed that the accuracies for the google earth derived DEM is suitable for hydrological and other water resources modelling.

## 1. INTRODUCTION

Digital Elevation Model (DEM) is an important primary input used for terrain modeling analysis such as, digital topography analysis, including slope, curvature, roughness and local relief. DEMs are employed as primary source input in various remote sensing investigations and application such as terrain modelling, geomorphology, land cover research, natural disaster assessment, urban flood mapping, and flood or drainage modelling and glacier observation (Pope *et al.,* 2007; Rayburg *et al.,* 2009; Erasmi *et al.,* 2014). DEM is the depiction of the earth surface and various utilization in hydrological modelling (Raybus *et al.,* 2002; Stock *et al.,* 2002; Rexer and Hirt, 2014; Kumar *et al.,* 2020; Kumar *et al.,* 2021). It plays an indispensible role in delineation of watershed, mapping of drainage line and geomorphological study of the watershed (Abbot *et al.,* 1986; Kumar *et al.,* 2021). Several sources of DEM are accessible nowadays such as SRTM 90 DEM has been disseminated freely by United States Geological Survey (USGS) since 2008. It is supplied by National Aeronautics and Space Administration (NASA) and declared to provide over 80% of DEM data across the globe. Among several techniques of deriving DEMs using contour maps, topographic maps, field surveying using auto level, total station survey and global positioning system (GPS), photogrammetry method, radar interferometry, and laser altimetry (Manuel, 2004; Kumar *et al.,* 2021). Although these approaches are the most accurate, they are long–established, cumbersome and expensive particularly for larger region.

The SRTM imparts the most up–to–date, finer scale DEM at one's disposal for entire earth. The fundamental principle behind this is interferometric SAR or In SAR, which utilize phase–difference estimation computed from two radar imagery obtained with a minuscule base to height ratio (typically 0.0002) to quantify landscape. SRTM data validation was evaluated using several well established open source DEM (Helm *et al.,* 2002; Sun *et al.,* 2003; Muller, 2005; Jarvis *et al.,* 2004; Smith and Sandwell, 2003). The product of ASTER DEM is produced with bands 3N (nadir–viewing) and 3B (backward–viewing) of an ASTER level–I A image obtained by the visible near infrared (VNIR) sensor.

Japan Aerospace and Exploration Agency (JAXA) started to distribute ALOS PALSAR on 2006. In hilly region for hydrological modelling, better efficacy of DEM is required at finer scale. With the development of more robust google earth data base, generation of DEM by utilizing the google earth elevation data has gained attention. The process of converting google earth derived data into DEM can be done by various open source software and tools. We have used QGIS for this purpose. The principal advantage of this method is that finer resolution DEM can be obtained for small area. Nevertheless, the precision provided by different open source DEMs (SRTM, ASTER and ALOS PALSAR) might not be suitable for application in site identification for water harvesting and drainage network extraction. Keeping this point in mind the present research was taken for developing high resolution DEM for hilly region. Therefore, this case study intends to examine the accuracy of google earth derived DEM (GE DEM) with the SRTM DEM, ASTER DEM and ALOS PALSAR DEM.

## 2. MATERIALS AND METHODS

### Study Area

This investigation was conducted at experimental farm of the ICAR−VPKAS, Almora, Uttarakhand, India. The surface elevation ranges from 1147 m to 1252 m above mean sea level. The extent of study area from 79.62717°N, 29.63795°E in upper left corner and 79.63728°N, 29.62949°E in lower right corner (Fig. 1). The climatology of the study area is sub−temperate, characterized by mild summer (May−June), a spell of extreme winter (December−January).

### Elevation Extraction and DEM Generation

First of all, the location of the study area is identified. After selecting the study area around 1000 marks are done to extract the elevation data. The attribute of every point has latitude and longitude in WGS84 (World Geodetic System) projection. Later, these points were exported to extract elevation data in an online tool named "GPS visualizer". This tool is user friendly and easy as it requires only some fundamental description such as the location (latitude, longitude) and numbers of check points. It naturally fixes the check points which depend on the desired requirement of the detail for the data. To obtain detailed elevation data for particular region reduce the extent area but increase the number of sampling points. The outcome of the extraction method is the coordinates having longitude and latitude with elevation in meters. The coordinates of outcome are further copied into a text file for later steps in Arc−GIS 9.3.1. Fig. 2 shows the step by step method of extracting the elevation data in google earth.

### Accuracy Assessment

For testing the efficacy of the google earth derived DEM with the well−established SRTM DEM, three performance indicators, *viz.,* coefficient of determination ($r^2$), root mean square error (RMSE) and Nash−Sutcliffe efficiency (NSE) were used in this study. For this, the 100 number of check points in the study area having different topography is selected. The summary statistics are calculated using following formula:

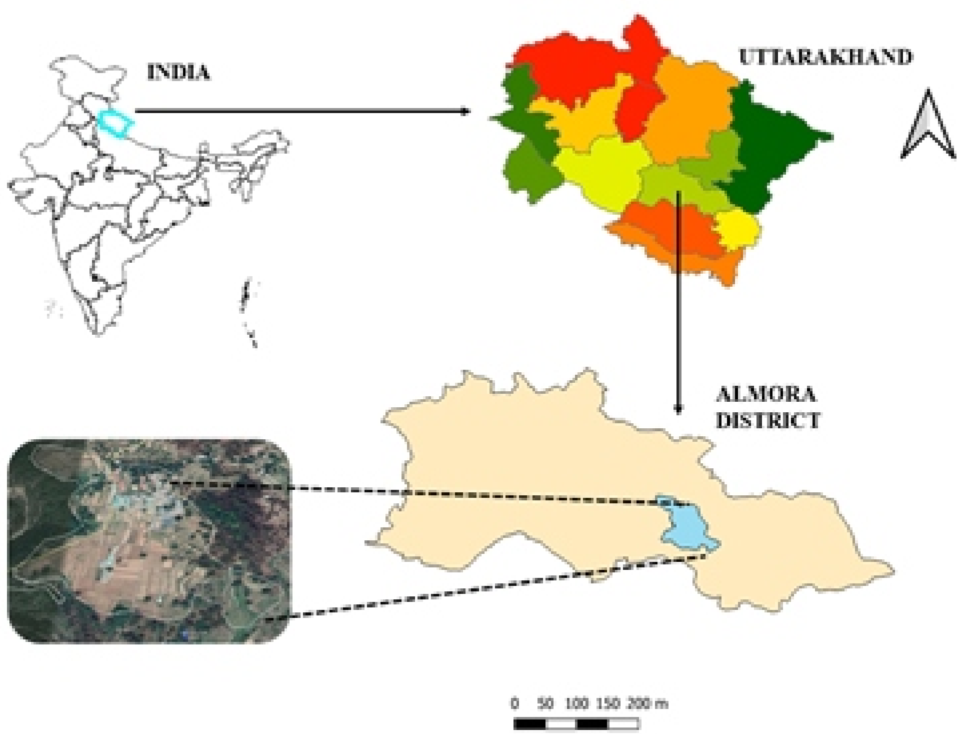


**Fig. 1. Location of study area experimental farm, Hawalbagh**

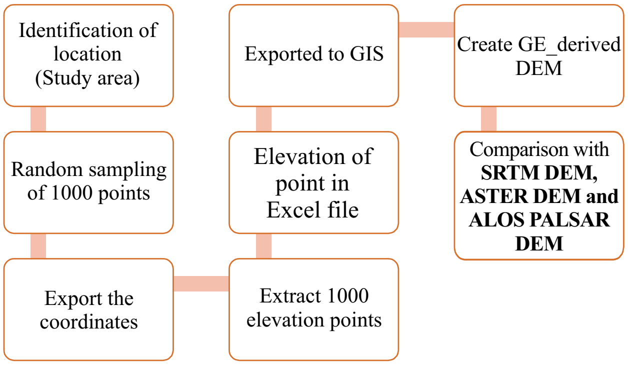


**Fig. 2. The brief step by step process of DEM generation**

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(X_{obs,i} - X_{Simulated,i})^2}{n}} \quad ...(1)$$

$$r = \frac{\sum_{i=1}^{n}(x_i - \bar{x})\cdot(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2 \cdot \sum_{i=1}^{n}(y_i - \bar{y})^2}} \quad ...(2)$$

$$E = 1 - \frac{\sum_{i=1}^{n}(X_{obs,i} - X_{Simulated})^2}{\sum_{i=1}^{n}(X_{obs,i} - \overline{X_{obs}})^2} \quad ...(3)$$

Where, $X_{obs}$ is observed values and $X_{Simulated}$ is simulated values at time/place $i$.

## 3. RESULTS AND DISCUSSION

### Correlation Analysis

We have done further analysis to validate google earth elevation derived DEM in a typical middle Himalaya micro-watershed having natural spring. The scatter plots between google earth DEM and different open source DEMs (Fig. 3) obtained for the study area; scatter plot is based on a surveyed 100 number of points. It was found that all (100 check points) google earth DEM showed strong correlation coefficient value with other three open sources DEM. Summary statistics for vertical accuracy for the four DEMs are presented in Table 1. Maximum NSE was observed for ALOS PALSAR followed by SRTM and ASTER DEM, respectively. A total of 100 random points from DEM derived using surveyed data were correlated with google earth elevation data. NSE (E) was computed to measure the association of google earth DEM derived data with the ALOS PALSAR, SRTM and ASTER DEM. The coefficient of determination value which is $r^2$, between both data shows the magnitude of strength. Conclusion can be drawn that google earth data was positively correlated with all established DEM with $r^2$ value of 0.88 for SRTM, 0.92 for ALOS PALSAR Dem and 0.83 for ASTER DEM (Fig. 3). The distribution and number of selected points have affected by this situation. Similar results also reported by Pulighe and Fava (2013) and Pakoksung and Takagi (2015).

**Table: 1**
**Summary of comparison for the GE derived DEM using the SRTM DEM**

| Parameter | SRTM DEM | ALOS PALSAR DEM | ASTER DEM |
|---|---|---|---|
| NSE | 0.89 | 0.90 | 0.84 |
| RMSE | 3.45 | 3.28 | 4.31 |
| MAE | 2.65 | 2.52 | 3.26 |

### Comparison of Vertical Elevation Between Different Open Source DEMs

The accuracy of the google earth DEM produced by utilizing the elevation data from google earth was assessed by comparing the elevation data of 100 check points. The distribution of check points versus elevation over the study area is shown in Fig. 4. The vertical accuracy between google earth DEM with SRTM DEM, ASTER DEM and ALOS PALSAR DEM will be summarized using coefficient of determination ($r^2$), RMSE, mean absolute error (MAE) and NSE. The obtained values of performance indicator are presented in the Table 1.

In the present study, the NSE criterion has been used to test the performance of google earth derived DEM. The value of NSE varies from −1 to 1. NSE value of 1 (E = 1) indicates a perfect relation between simulated and observed value. Incorporating the elevation value from google earth

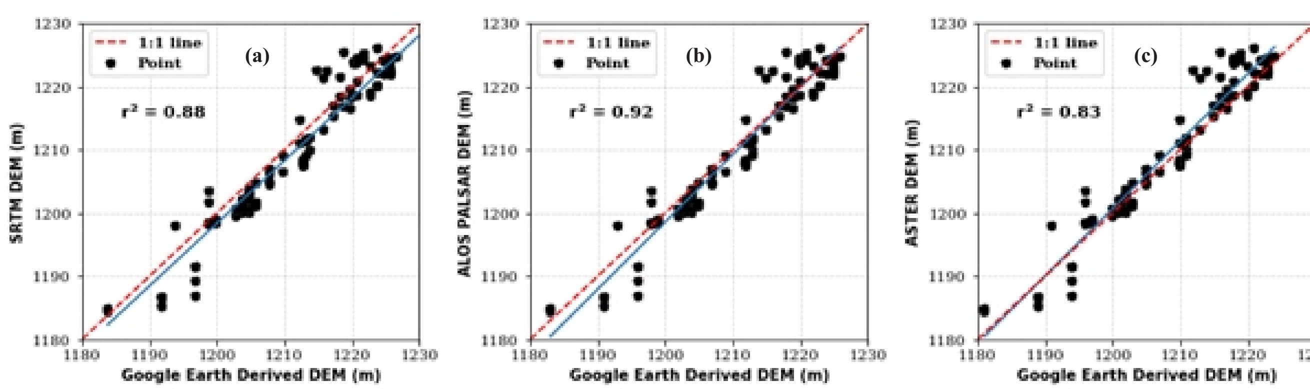


**Fig. 3. Scatter plot showing the relationship between a) Google earth derived DEM and SRTM DEM b) Google earth derived DEM and ALOS PALSAR DEM c) Google earth derived DEM and ASTER DEM**

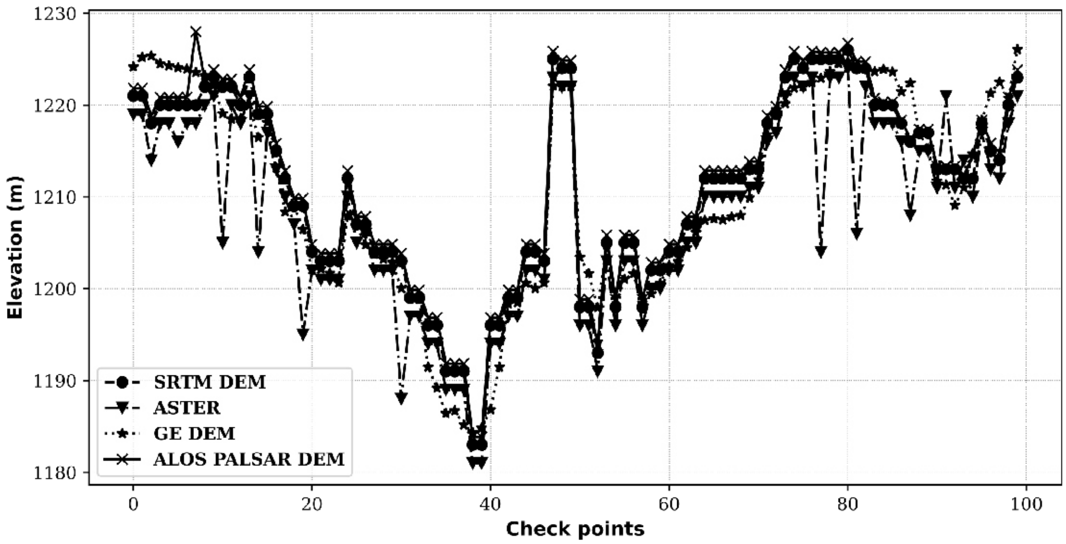


**Fig. 4. Distribution of check points for study area (total number of check points 100)**

DEM and three other DEMs in eq. 3, the efficiency NSE is found highest for ALOS PALSAR DEM (0.90) followed by SRTM DEM (0.89) and ASTER DEM (0.84). This study presents a statically analysis showing additional evidence that DEM derived from google earth is commendable and has a good correlation with ALOS PALSAR DEM elevation data (Fig. 3). Results of present investigation exposes that the value of NSE (E) 0.89 for SRTM are in accordance with previous study by Mukherjee *et al.* (2013). The RMSE value of about 3.28 m was found ALOS PALSAR DEM in line with previous Athmania and Achour (2014).

## 4. CONCLUSIONS

We have evaluated three of the up−to−date and open−sources DEMs against google earth derived DEM in the experimental Farm of ICAR−VPKAS, Almora. The conversion of DEMs into the same datum is a critical step prior to assess their accuracy. DEM with the highest resolution (ALOS PALSAR 12.5 m) gave the best performances with lower uncertainty and their horizontal and vertical accuracies are excellent compared to other DEMs. As regards the DEMs with the same 30 m resolution, results show that SRTM 1−arcsec carry out better than ASTER GDEM 1−arcsec. The ASTER DEM gave the worst accuracy compared with the three other DEMs. The results obtained improve the effect of DEM accuracy and resolution on topographic indices. This case study is an attempt to demonstrate and analyze the errors introduced by freely DEMs in the accuracy assessment of water erosion risk to acquaint the researchers with the use of up−to−date open−source DEMs. We hope that this paper provides a reference to choose open source DEMs with higher accuracy for natural hazards assessment. Authors are thankful to all the field and laboratory staff for their help in this study. We are very much thankful to the Director, ICAR-VPKAS, Almora as well as ICAR, New Delhi for providing financial support during the course of investigation.

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