

Proceeding Paper

# Accuracy Assessment of Openly Accessible CartoDEM V3 R1 and TanDEM-X 90 Using a Smartphone with Assisted GPS for Ratlam City and Surroundings <sup>†</sup>

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<sup>†</sup> Presented at the 8th International Electronic Conference on Sensors and Applications, 1–15 November 2021; Available online: <https://ecsa-8.sciforum.net>.

**Abstract:** The Digital Elevation Model (DEM) is mostly used to extract the terrain parameters for surface and elevation analysis to represent the topography of the earth's surface in the best possible way. Nowadays, smart devices such as smartphones and tablets employed with GPS chipsets are easily available in the market. These smart devices can measure elevation data and are cost effective. The relatively plain areas of Ratlam City (Madhya Pradesh) were the study area. A Vivo 1606 smartphone incorporated with Assisted-GPS (A-GPS) was used with a GPS utility App called Mobile Topographer to collect the ground coordinates and elevation data. The ground control points (GCPs) were collected in parts of urban areas, such as open grounds, streets, parks, and other uniformly distributed GCP locations with few GCPs in outer regions of the city. Using smartphone-derived GCPs as a reference, the two openly accessible DEMs—namely CartoDEM V3 R1 and TanDEM-X—were evaluated statistically. Statistical parameters such as Mean Error (ME), Mean Absolute Error (MAE), and Root Mean Square Error (RMSE) were computed for comparative quality analysis between CartoDEM V3 R1 and TanDEM-X 90, using the observed GPS elevation data. The ME (4.60 m), MAE (6.12 m), and RMSE (7.15 m) for TanDEM-X 90 were higher than that of CartoDEM V3 R1, ME (3.09 m), MAE (5.05 m), and RMSE (6.17 m), respectively. The results from the A-GPS Smartphone revealed that the accuracy of CartoDEM V3 R1 is higher and it statistically performs better than TanDEM-X in plain areas of Ratlam using the Smartphone A-GPS.

**Keywords:** smartphone; A-GPS; CartoDEM V3 R1; TanDEM-X 90



**Citation:** Yadav, U.; Bhardwaj, A. Accuracy Assessment of Openly Accessible CartoDEM V3 R1 and TanDEM-X 90 Using a Smartphone with Assisted GPS for Ratlam City and Surroundings. *Eng. Proc.* **2021**, *10*, 64. <https://doi.org/10.3390/ecsa-8-11328>

Academic Editor: Stefano Mariani

Published: 1 November 2021

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## 1. Introduction

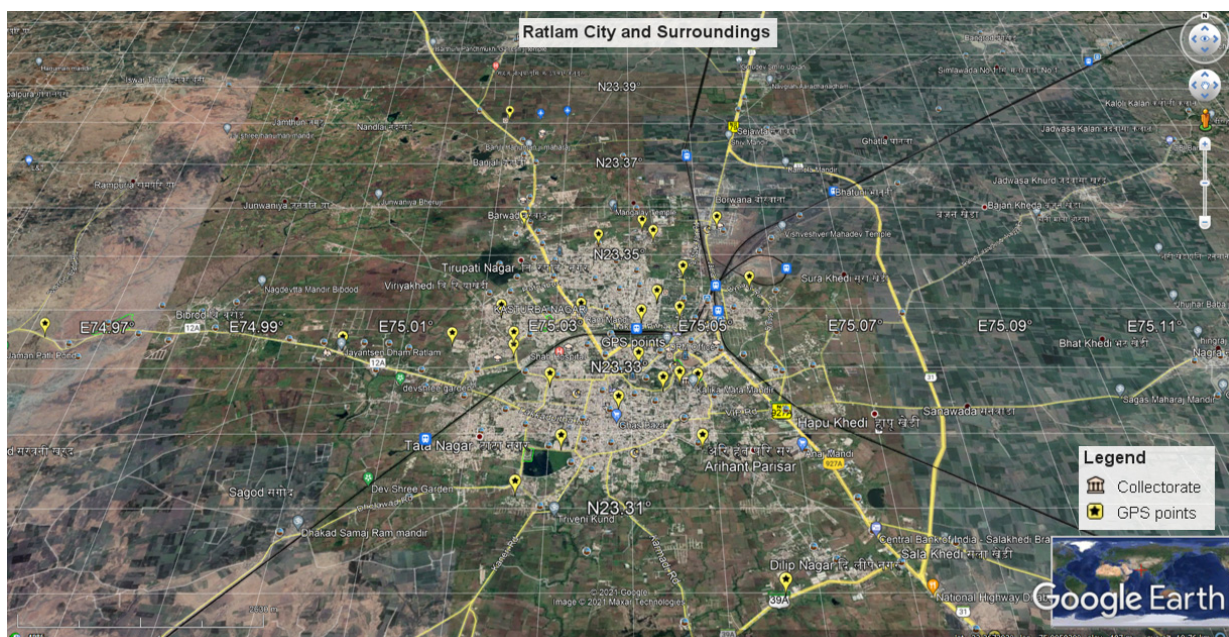
The digital elevation model (DEM) represents the earth's topographic surface digitally, either as a raster or vector representation incorporating the elevation data. A set of quality ground control points (GCPs) are required to create DEM, in the form of a two-dimensional array with elevation at every latitude, and longitude location [1,2]. Openly accessible DEMs are available on various web portals such as BHUVAN for CartoDEM V3 R1 data with 1 arc, 30 m resolution, and GeoServices DLR for TanDEM-X 90 with 90m resolution. The TanDEM-X had challenges in vertical accuracy due to different imaging configurations as well as data processing methods, and contained various errors. CartoDEM products are used to establish the accurate geographic location of features and make measurements with its improved version three, release one; i.e., CartoDEM V3 R1 [2–5]. CartoDEM V3 R1 works best with the plain regions when evaluated with the GCPs collected using the differential Global Positioning System (D-GPS) method, which is relatively expensive and provides inputs for erosion mapping, and terrain modeling [4,6]. Different DEM generation techniques present different accuracies for different applications, making the need for evaluation of DEM accuracy compulsory [7–10]. Ionospheric delay is the most

potential and unpredictable positioning error. It is frequency dependent and is directly proportional to the total electron content (TEC) [11,12]. A high-accuracy geodetic GPS receiver gives submeters- to centimeters-level accuracy, depending on its ability to track, identify, and minimize the error in satellite signals during processing. The positioning systems of smartphone-based A-GPS receivers or as Location-Based Services (LBS) are not as accurate as of the geodetic DGPS instruments, but the data accuracy is enough for many regional- to local-level applications for the management of various services in cities, including civil works for water and sewerage pipelines. Qualcomm's gpsOne technology-based smartphone supporting multiple modes of A-GPS was used as a GPS receiver for highly reliable positioning capabilities in areas where cellular networks are not accessible [13]. Vivo 1606 is capable of tracking single frequency multi-constellation measurements using GPS (L5), GLONASS (L1), and Beidou (B1) frequencies. Smartphones manufactured before 2017 were mostly single-frequency receivers [14]. As Smartphone technology has become the predominant tool, millions of people are now using small GPS-capable smartphones not only for navigation but also for many applications such as reality-based gaming apps, bicycle rentals, and so on [13,15]. Mobile Topographer is one of the android apps available on the Google play store, which also has paid as well as free services ideal for surveyors and other users for navigation or collecting the GCPs with preferable DOP (<1.3) values. Its updated features include an increase in GPS accuracy, and the ability to display and coordinate conversion [16]. New LBS have emerged that require more accurate positioning results, such as in A smartphone-based photogrammetric aerial vehicle system [17]. This study quantitatively examines the openly accessible DEMs using GCPs from a smartphone with A-GPS.

## 2. Material and Method

### 2.1. Study Area

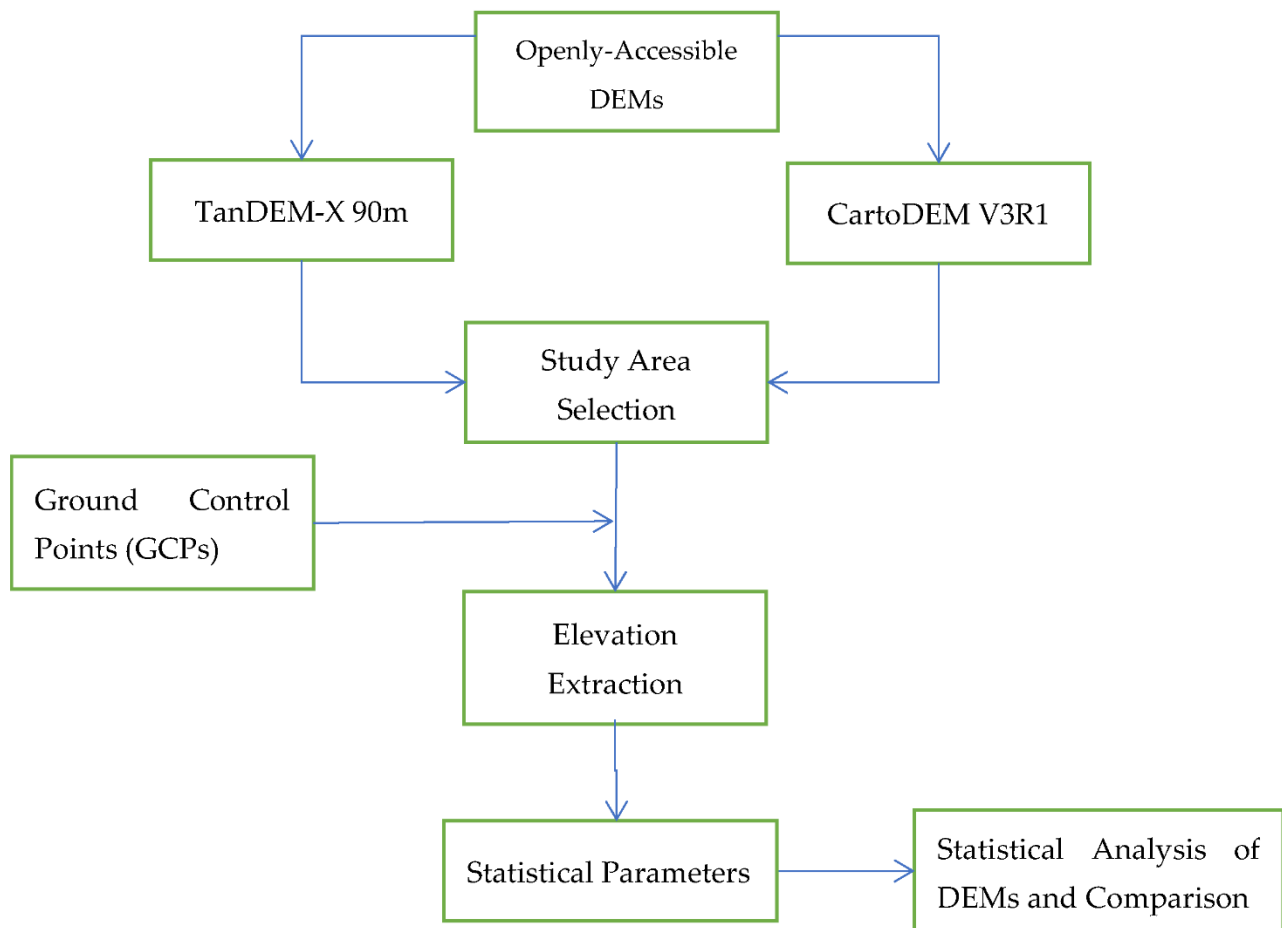
The Ratlam District has an area of about 4861 km<sup>2</sup>, primarily characterized as relatively plain terrain. It is located around 23°20'3.0084" N and 75°2'15.4896" E and is a major part of the Malwa Plateau. Ratlam city is well known for gold jewelry. The study was performed in Ratlam city and its surroundings (Figure 1).



**Figure 1.** Ratlam city and surroundings overlaid with GCPs (smartphone A-GPS) on the Google Earth platform.

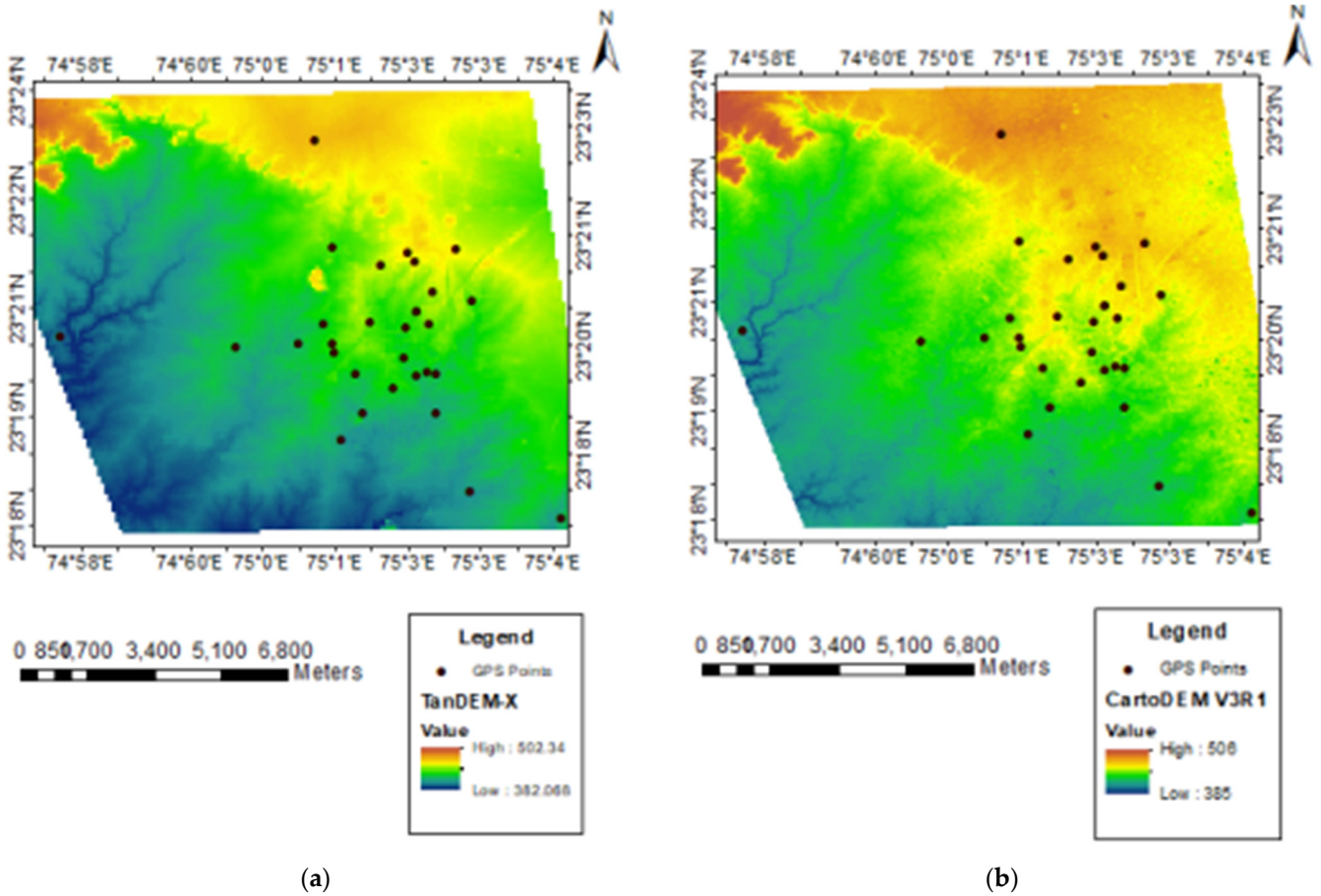
## 2.2. Ground Control Point (GCP) Collection

The study area was surveyed using a Vivo 1606 phone with the Mobile Topographer app, for the evaluation of DEMs. A survey was carried out for collecting GCPs at appropriate locations such as parks, streets, urban areas, open grounds, and rural outer areas of Ratlam city for utilization as the checkpoints for the DEMs. The points were collected in the World Geodetic System (WGS-84) datum. The flowchart in Figure 2 describes the methodology.



**Figure 2.** Flow chart of the methodology for DEM evaluation using GCPs collected from A-GPS enabled Smartphone.

According to the researchers, coordinate accuracy can be achieved in the order of 1 m or better after 30 min of data collection using smartphone GPS [18]. In this study, the A-GPS smartphone data were collected as reference data for statistical analysis of DEMs and a minimum PDOP value of about 0.2 was attained in approximately 35 min of operations at desired GCP locations. Elevation data of TanDEM-X 90 and CartoDEM V3 R1 were extracted after superimposing the GCPs (Checkpoints) using ArcGIS as a standard method used in various studies for evaluation of DEMs [19,20]. Figure 3 displays a set of 30 GCPs obtained from a smartphone superimposed on DEMs.



**Figure 3.** Displays smartphone A-GPS points superimposed on (a) TanDEM-X 90 m; (b) CartoDEM V3 R1 DEMs.

2.3. Statistical Analysis

The elevation or height values extracted from both the DEMs were used to calculate the differences with DEMs. The accuracy estimation with smartphone A-GPS observation datasets is performed by calculating ME (Equation (1)), MAE (Equation (2)), and RMSE (Equation (3)) [21,22].  $H_{i(DEM)}$  ( $=H_{i(CartoDEM)}$  or  $H_{i(TanDEM-X)}$ ) is the extracted elevation from the DEMs dataset and  $H_{i(A-GPS)}$  is the A-GPS observed reference datasets at different GCP locations ( $i = 1$  to  $n$ ).

$$ME = \frac{\sum_{i=0}^n H_{i(DEM)} - H_{i(A-GPS)}}{n} \tag{1}$$

$$MAE = \frac{\sum_{i=0}^n | H_{i(DEM)} - H_{i(A-GPS)} |}{n} \times 100 \tag{2}$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^n (H_{i(DEM)} - H_{i(A-GPS)})^2}{n}} \tag{3}$$

3. Results and Discussion

The difference between A-GPS reference elevation values and the openly accessible DEMs (TanDEM-X 90, and CartoDEM V3 R1) were evaluated as shown in Table 1 for analysis. The range of minimum and maximum values of TanDEM-X 90 using 30 GCPs in the study area is 11.09 and 17.83 m. Similarly, the values for CartoDEM V3R1 are 10.71

and 14.20 m, respectively. Table 2 indicates the results of statistical analysis between the two DEMs in the form of ME, MAE, and RMSE.

**Table 1.** Statistical analysis of TanDEM 90 and CartoDEM V3R1 using Smartphone A-GPS (Sample set).

S No.	$H_{(\text{TanDEM-X})} - H_{(\text{A-GPS})}$	$(H_{(\text{TanDEM-X})} - H_{(\text{A-GPS})})^2$	$H_{(\text{CartoDEM})} - H_{(\text{A-GPS})}$	$(H_{(\text{CartoDEM})} - H_{(\text{A-GPS})})^2$
1	4.32	18.69	3.08	9.47
2	6.28	39.45	5.33	28.37
...	...	...	...	...
30	3.38	11.44	-0.30	0.09

**Table 2.** Statistical results of TanDEM-X 90m and CartoDEM V3R1.

DEM	ME (m)	MAE (m)	RMSE (m)
TanDEM-X 90 m	4.60	6.12	7.15
CartoDEM V3R1	3.09	5.05	6.17

The results revealed that the accuracy of CartoDEM V3 R1 is higher compared with TanDEM-X 90 in plain terrain regions of Ratlam city and surroundings. The elevation accuracy of DEM depends on the slope and land cover of the terrain, which allows the user to predict the DEM quality according to the terrain regions utilized as per the user's requirements [8,23]. The difference between TanDEM-X 90, and CartoDEM V3 R1 elevation values is reasonable based on their methods of generation and thus may require more accurate methods for reference data generation such as DGPS or LiDAR datasets.

#### 4. Conclusions

The GCPs were obtained with Vivo 1606 Smartphone A-GPS using Mobile Topographer app for successful experimentation, with an assessment of openly accessible DEMs. The DEM accuracy of the openly accessible DEMs using low-cost smartphones incorporated with A-GPS was computed reasonably, which serves applications meeting the accuracy requirement criterion. The methodology developed for the assessment of individual accuracies (35 min observation, PDOP~0.2) was well within the margins of the accuracy of an A-GPS Smartphone reference GCPs. The statistical result revealed that the accuracy of CartoDEM V3 R1 was higher compared to TanDEM-X 90, as found in similar studies [23]. However, the uncertainty in the analysis was governed by the accuracy of A-GPS and local site characteristics.

**Author Contributions:** Conceptualization, A.B.; methodology, A.B. and U.Y.; resources, U.Y.; data curation, U.Y. and A.B.; writing—original draft preparation, U.Y.; writing—review and editing, A.B. and U.Y. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research received no external funding.

**Institutional Review Board Statement:** Not applicable.

**Informed Consent Statement:** Not applicable.

**Data Availability Statement:** Publicly available datasets were analyzed in this study. These data can be found here: <https://bhuvan.nrsc.gov.in/home/index.php> and <https://download.geoservice.dlr.de/TDM90/> (accessed on 30 July 2021).

**Acknowledgments:** The authors would like to thank the Indian Space Research Organisation (ISRO), National Aeronautics and Space Administration (NASA), German Aerospace Center (DLR), and Google LLC for their immense support. The authors are highly indebted to the Director, IIRS, for his constant support and encouragement in conducting the research activities.

**Conflicts of Interest:** The authors declare no conflict of interest.

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