# Reliability of Data obtained by ASTER Satellite for Digital Elevation Models

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## ABSTRACT

**The Digital Elevation Model (DEM) is a typical type of topographic data. Data on elevation are often used as a major information source for analysis and modeling by geographic information systems. Modern continuous changes across space are represented by DEM. Particularly, the European Union Digital Elevation Model (EU-DEM), a new dataset derived from the EU's Copernicus Land Monitoring Service, which features contours developed for all DEMs which are compared with the contours of a topographic map. One of the most important sources of topographical information is the Advanced Spaceborne Thermal Emission and Reflection Radiometer Global Digital Elevation Model (ASTER GDEM). Compared to data from the Ground Control Points (GCPs), the vertical differences in ASTER products are utilized to calculate the Root Mean Squared Error (RMSE). The vertical accuracy of this DEM is assessed to be 13.13 m, which is the RMSE that was determined based on the data collected in the field by GNSS. In addition, the Standard Deviation (SDT) error came in at 2.60 m. After considering the effect of correcting bias, the error findings may range from a minimum of -6.47 m to a maximum of 1.998 m. Variations in RMSE and SDT are less than 0.991 m and 0.960 m, respectively.**

***Keywords- DEM; remote sensing; ASTER satellite; digital elevation model***

## I. INTRODUCTION

The DEM is one of the simplest techniques deployed for displaying topographic surfaces. Many geospatial applications make use of DEMs. A DEM is either a digitally stored quantitative model of a topographic surface or a digital photograph of such a model [1]. This type of digital topography is the most common and fundamental. Among the most well-known examples of DEMs that provide topographic data are the Shuttle Radar Topography Mission (SRTM) model developed from the Shuttle Radar Topography Mission and the ASTER GDEM [2]. The beneficial impact of the almost globally accessible DEM data obtained from space-based measurements, such as the DEM data collected by the SRTM, are examples of these positive effects [3]. Researching the precision of the DEM is necessary because of its significant influence on many areas of engineering and other sciences.

Although the DEM plays an essential part in hydrological modeling and the water cycle understanding, many issues remain unsolved, mainly regarding how DEM affects the accuracy of the models' hydrological predictions [4]. The DEM's production is related to important geomatics engineering applications that are based on remote sensing science principles [5]. In survey engineering applications, the DEM is an important factor to consider. NASA and NIMA have collaborated on the SRTM V3 [6]. The development of the cadastral map relied heavily on vertical aerial photos as a key component of the imaging product set [7-9]. After extensive reprocessing of the SRTM, the NASA DEM, a near-global scope project, was made publicly available for evaluation and usage in February 2020 [10]. The DEM which is obtained from remote sensing data is a practical, reliable data source that may be used for mapping, terrain visualization, communications, navigation, emergency management, and the design of civil engineering infrastructures, as well as the orthorectification of aerial and satellite images [11]. Because of their all-encompassing perspective of the activities that take place on the Earth's surface, satellite photos have become useful instruments for various scientific and practical investigations [12]. Considering the information presented above, this study aims to assess the vertical accuracy of the local scale ASTER DEM compared to high-reliability primary elevation data collected in the observation field by a GPS device.

## II. STUDY AREA

The latitude of 33.34 and longitude of 44.40 places the research area in the northern Iraq. The area has a flat topography and is 41 m above the sea level (Figure 1). The study area is around 204.2 km$^2$.

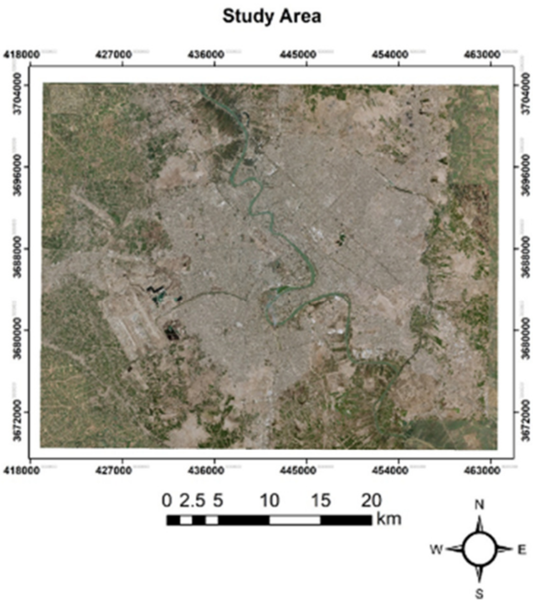


Fig. 1. Location of the research: Baghdad Governorate.

## III. THEORETICAL BACKROUND

Satellites and other forms of remote sensing instruments provide an enormous amount of data for studying the geographical and temporal variability of the environmental parameters [7]. The ASTER is an imaging sensor with 15 separate channels that operates aboard NASA's Terra spacecraft [14]. It is also possible to generate DEM by utilizing lasers, photoclinometry, synthetic aperture radar, stereoscopy, and radar altimetry [15, 16]. DEM errors can be either of a technological nature, or may emerge from a malfunction of the equipment acting as inherent limits of the sensors. They may be also generated from natural causes, such as unfavorable weather conditions or owing to the low contrast of the relief, possibly produced by low or extremely high relief, and attributed to different causes. [17, 18]. According to the sensor's design, image data may be obtained from the ASTER sensor in 14 visible, near-infrared, short-wavelength, and thermal infrared spectral bands. Regardless of the way DEM data were collected and produced in the past, the vertical accuracy of DEM is affected by factors, involving the slope, land cover, geolocation, horizontal inaccuracy, and other systematic biases. If the bias meter is near to zero, it can be concluded that this data are homogenous. The term "bias" refers to the amount to which two data sets differ regarding gap and variation [19]. The measure of bias is:

$$\text{Range Elevation} = \text{Max Elevation} - \text{Min Elevation} \quad (1)$$

The only two values considered in (1) are the highest and the lowest, which might lead to issues when uncommon values are considered [20]. To calculate them, the formulas for the mean error, the standard error, and the RMSE are used:

$$\text{ME} = \frac{\sum_{i=1}^{n} \text{Zdff(i)}}{n} \quad (2)$$

$$\text{STD error} = \sqrt{\frac{\sum_{i=1}^{n}(\text{Zdff}-\text{ME})^2}{n-1}} \quad (3)$$

$$\text{RMSE} = \sqrt{\frac{\sum_{i=1}^{n}(\text{Zdff(i)})^2}{n-1}} \quad (4)$$

where:

$$\text{Zddf} = \text{Z DEM} - \text{Z GCP} \quad (5)$$

and n is the number point.

## IV. METHODOLOGY

This research employed the RTK/GNSS method, complying with the required criteria. In addition, devices equipped with the Differential Ground Positioning System (DGPS) of record E and N control points located on the ground, underwent processing by the OPUS website [21-23]. By integrating RS and GIS techniques, it is possible to analyze and classify the changing patterns of the land cover over a long time period, and as a result, a better understanding of the changes in the target range is provided [24]. The three basic steps of this procedure are included and summarized below.

### *1) Collection of DEM Data*

The conducted research was designed using the chart presented in Figure 2 to accurately analyze the ASTER DEM data. Figure 2 depicts the acquisition of three fundamental elements, namely DEM data, ground data, and assessment accuracy. The ASTER DEM V2 was downloaded from the USGS (US Geological Survey). Similarly to the coordinate System – UTM, the Datum - World Geodetic System (WGS84), namely the data type to which the Geo TIFF belongs, the stereo ASTER stellate image is used to create a DEM despite the fact that this model only incorporates the near-infrared wavelength range from 0.78 µu to 0.86 µu.

### *2) Ground Data Collection.*

The ASTER DEM (V2) is made available without any cost in a Geo TIFF format. The user has access to the former, which has an exact spatial resolution of 30 m, a Quick Bird satellite picture with a resolution of 0.6 m, and coordinate systems (UTM, WGS84). Thirty Control Points (30 GCP) must be collected for the research regions to achieve a confidence level of 95%. The data set deployed to validate the DEM consists of 60 geodetic points collected during different regional campaigns. Measurements of the networks were performed using the GPS which is the only system subsequently considered. The CORS observation in the Baghdad

Governorate was used to keep tabs on the basis point (Network approach) for around 10 h. Figure 3 depicts the planned GCP distribution related to the research region, Baghdad Governorate, where the resulting image will cover a total area of about 204.2 $km^2$. The next step entails entering the ASTER DEM (V2) layer of the DEM, and simultaneously generating a Shapefile (Shp) that has information for thirty GCP (this step is part of the Enter and data management stage). A GCP is useful for accuracy evaluation, since the vertical value is extracted using spatial analyst tools for the matching, DEM, and feature point layers, displayed in Table I.

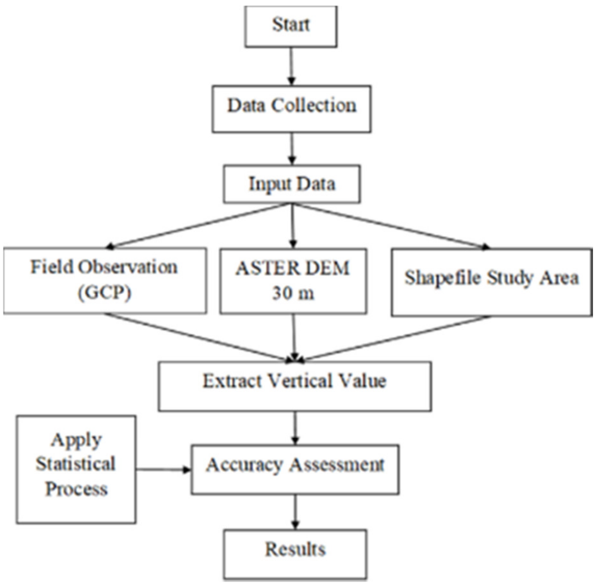


Fig. 2. The work methodology.

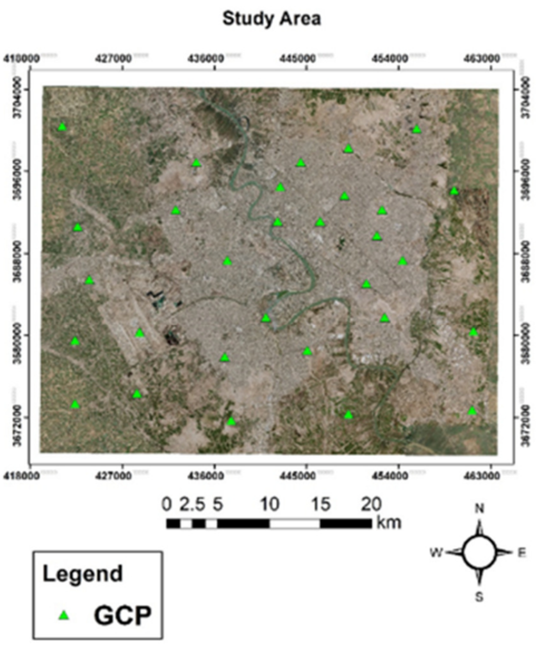


Fig. 3. Distribution of Ground Control Points (GCP).

TABLE I. ELEVATION INFORMATION: ACTUAL AND ELEVATION ASTER.

| No. | Easting (m) | Northing (m) | Actual elevation actual (m) | ASTER elevation (m) |
|---|---|---|---|---|
| 1 | 432231 | 3692256 | 43.672 | 45 |
| 2 | 442433 | 3694523 | 49.945 | 48 |
| 3 | 449109 | 3698302 | 45.854 | 43 |
| 4 | 451880 | 3689737 | 55.805 | 60 |
| 5 | 452636 | 3681801 | 52.092 | 53 |
| 6 | 445079 | 3678526 | 45.89 | 44 |
| 7 | 437017 | 3677897 | 54.65 | 57 |
| 8 | 428704 | 3680290 | 45.956 | 45 |
| 9 | 422658 | 3690618 | 40.403 | 41 |
| 10 | 421146 | 3700443 | 43.592 | 40 |
| 11 | 455785 | 3700191 | 66.43 | 65 |
| 12 | 459438 | 3694145 | 64.322 | 64 |
| 13 | 461327 | 3680416 | 67.893 | 68 |
| 14 | 461201 | 3672732 | 45.309 | 47 |
| 15 | 449109 | 3672354 | 55.408 | 54 |
| 16 | 437647 | 3671725 | 54.229 | 56 |
| 17 | 428452 | 3674370 | 56.474 | 50 |
| 18 | 422406 | 3673362 | 56.009 | 54 |
| 19 | 422406 | 3679534 | 54.327 | 53 |
| 20 | 423792 | 3685454 | 57.457 | 58 |
| 21 | 437269 | 3687343 | 45.375 | 49 |
| 22 | 441048 | 3681801 | 47.453 | 48 |
| 23 | 446338 | 3691122 | 45.118 | 40 |
| 24 | 442181 | 3691122 | 45.306 | 44 |
| 25 | 434246 | 3696916 | 42.497 | 39 |
| 26 | 444449 | 3696916 | 65.496 | 63 |
| 27 | 448731 | 3693641 | 65.336 | 67 |
| 28 | 452384 | 3692256 | 55.603 | 54 |
| 29 | 454399 | 3687343 | 40.563 | 36 |
| 30 | 450873 | 3685076 | 62.048 | 66 |

## V. RESULTS AND DISCUSION

After the preprocessing step, i.e. after local geoid modeling was completed, the ellipsoidal height values for each DEM were derived. In general, due to the rising need for an accurate description of the global landscape, in the way it has been evolved, the construction of contemporary democratic models has nearly become a regional or even a global phenomenon. The requirement for accurately describing the global terrain is a developing concern, which is considered repetitive, in terms of the main or secondary products. Equivalently to these new elevation data sets, which are becoming more accurate, the verification procedure comes with more demanding conditions related to the availability, amount, and sampling of accurate reference topography information. By using GNSS signals, a sophisticated dual band with a huge number of channels, and GNSS towers, this information retrieval is quite straightforward. The currently operational systems are GPS, GLONASS, GALILEO, and Beidou.

The absolute vertical accuracy of every available DEM concerning the GNSS locations was estimated. The calculated inconsistencies were identified using the ASTER and a "DEM-GNSS" subtraction approach histogram. The findings, portrayed in Figure 4, demonstrate that the elevation values of the EU-DEM resemble more to the "real" values determined by the GNSS. A numerical value within the accompanying descriptive statistics was obtained. The statistics of the elevation range, mean value, and standard deviation for

ASTER, such as the reference GPS ellipsoidal heights are presented in Table II. The differences between the DEM ellipsoidal height and the GPS (residuals) result in an error value for each point and can be used for a more detailed assessment of the models' performance. The EU-DEM elevation error measurements are much more precise than the ASTER readings when comparing the mean, standard deviation, and the minimum and maximum values. The error (or disparity) reported by ASTER DEM (V2) might range from -6.47 m to a high of 4.20 m. The lowest value observed was 4.20 m. The standard deviation error was 2.60 m, and the RMSE was 13.13 m. After accounting for bias, the range of possible error values was from 1.998 m (max) to -6.47 m (min). The RMSE and the standard deviation from the mean were under 0.990 m. The resulting homogeneous surface obtained by the Natural Neighbor method for (GPS-ASTER) residuals is illustrated in Figure 5. The difference in values ranged from 31 m to 110 m. It should be also noted that the residuals for all stations were within 3σ (or RMSE).

TABLE II. SUMMARY STATISTICS OF DEMS FOR THE STUDY AREA

| DEM | RMSE | Mean Error | Max Error | Min Error | SDT Error |
|---|---|---|---|---|---|
| ASTER elevation (m) | 13.13 | -0.65 | 4.20 | -6.47 | 2.60 |

As a result, future research should focus on the need to validate DEM and to further evaluate its accuracy, when the latter is made available to the scientific community. In addition, future studies must concentrate on providing adequate reference data sets to evaluate the reliability and limits of the new data and popular topographic products.

This study dealt with the use of soil control points observed in the field and the application of commonly employed statistical procedures. The latter can be easily understood, without the need for further complexity, which may make the subject difficult and tedious for the next potential researchers, who will attempt to conduct research on the discussed subject, developing some of the scientific aspects of the current research. The exploitation of faster drone-derived DEM generation methods as well as the inclusion of various case studies and types of large-scale accessible DEMs related to the overall measurement of simulation performance could promote a more elaborate study on this field.

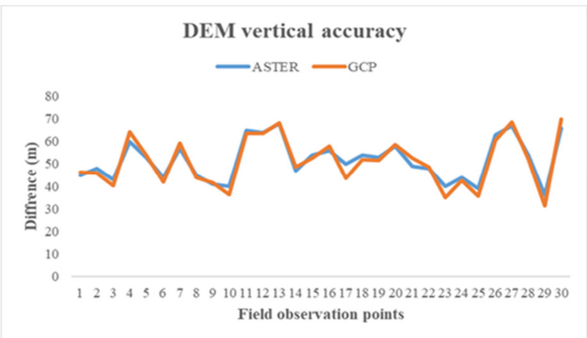


Fig. 4. Accuracy histograms for each DEM regarding absolute height: ASTER and GCP.

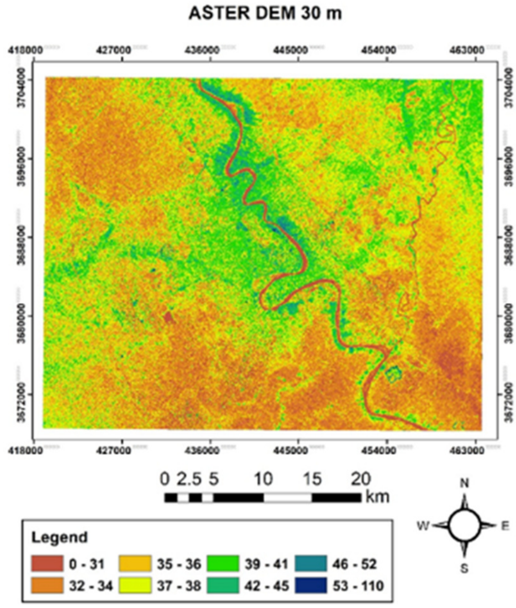


Fig. 5. Comparison of elevation achieved by subtracting matching pixel values from the first version of ASTER GDEM in the region of interest.

## VI. CONCLUSIONS

The present study was carried out to evaluate the vertical accuracy of DEMs in ASTER and GPS for the area of interest, Baghdad. The GPS network of TGP was used as reference data. In general, the results showed that open-source DEMs were very suitable for performing geodetic and hydrological studies in the study area. On the other hand, DEM elevations were increased, and the ASTER data revealed the average and standard deviation of the elevation variances. Compared to other free models, the digital elevation models generated by the Pleiades satellite were the most accurate ones. The ASTER model's accuracy was much lower than that of the other models. The fact that the acquired findings were consistent with those of earlier research offered reliability to the data collection and processing procedures. The following statistical information can be deduced from this paper:

1. RMSE: The value is relatively high (13.13 m), indicating a large difference between the expected and the actual values.
2. Mean Error: The mean error is close to zero (-0.65 m), indicating that the model does not tend to significantly increase or decrease the overall values.
3. Max Error and Min Error: The difference between the maximum and minimum values is large (-6.47 m to 4.20 m), which means that there is a large variation in the model accuracy in certain places.
4. SDT Error: The standard deviation of errors (2.60 m) indicates a scattering of errors, but not a very large one.

It can be considered that the ASTER elevation model provides reasonable elevation estimates of in the study area, but it simultaneously demonstrates some errors and variations in accuracy in some other areas. These statistics can be deployed to evaluate model performance and determine the need for corrections or improvements.

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