Accuracy Assessment of Digital Elevation Models Produced From Different Geomatics Data

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ABSTRACT
Digital Elevation Models (DEM) are now being used in several geospatial applications. DEMs play an important role in the preliminary surveys for constructing dams and reservoirs, highways, canals, and projects in which earth work is essential. In many remote sensing applications, DEMs have become a significant tool for InSAR (Interferometric Synthetic Aperture Radar) processing, ground cover classification and images orthorectification. In this study, the accuracy of DEMs obtained from ALOS V1.1, ASTER V2, SRTM V3 and other obtained from a pair of Pleiades high-resolution (PHR) 1B satellites in a study area were evaluated after comparing them with high accuracy GNSS/RTK checkpoints. The SRTM3, ALOS V1.1, ASTER V2 DEM revealed a Root Mean Square Error (RMSE) of 2.234m, 0.838m, and 15.116m respectively; while the DEM which is produced from a 0.5m resolution of Pleiades 0.5m shows an RMSE of 0.642m. The correct bias Linear transformation algorithm was used and the RMSE results were: SRTM V3 (1.319m), ALOS V1.1 (0.830m), ASTER V2 (3.815m), and PHR (0.433m). The results showed that the ALOS V1.1 model is the most accurate of the open source models followed by the SRTM V3 model and then followed by ASTER V2. The results obtained from a pair by Pleiades high-resolution (PHR) 1B satellites show a higher accuracy than the results obtained from the open source models.

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1. INTRODUCTION
Digital elevation models (DEMs) derived from remote sensing data provide a valuable and consistent data source for mapping, terrain visualization, telecommunication, navigation, disaster management, planning of civil engineering infrastructures, and orthorectification of airborne and
satellite imagery. The DEM could be obtained utilizing technologies such as aerial stereo photogrammetry, airborne light detection and range detection (LiDAR), interferometric synthetic aperture radar (InSAR), and land surveying. Because of the high cost of producing digital elevation models by conventional ground surveys and the inaccessibility of some places due to the roughness of the terrain and the seriousness of the areas (the presence of military waste), it has become necessary to research the evaluation of the results of the less expensive and safer digital elevation models. Four digital elevation models from different Geomatics sources were evaluated in this paper.

The Global Elevation Data Set Shuttle Radar Topography Mission (SRTM V3) was a joint mission by the National Imagery and Mapping Agency (NIMA) and the National Aeronautics and Space Administration (NASA) [1]. STRM V3 provides the Earth's highest open DEM resolution. It is based on the Interferometry Synthetic Aperture Radar (SAR) or Interferometric Synthetic Aperture Radar (InSAR) standard, which uses phase-difference estimates obtained from two radar images. The Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER V2) is an international collaboration venture between Japan's Ministry of Economy, Trade, and Industry (METI), and the National Aeronautics and Space Administration (NASA) of the United States. Near-infrared stereo imagery is obtained simultaneously with a long-track synchronization at both nadir and off nadir angles. Ninety Nine percent (99 %) of Earth's land mass is covered by theASTER DEM. The spatial resolution of stereo image is 15 m and the created DEM is 30 m. Advanced Land Observing Satellite (ALOS) has a 30 m resolution. DEM was created after using the archived information about the Panchromatic Remote Sensing Instrument for Stereo Mapping DEM. The spatial resolution of stereo image is 15 m and the created DEM is 30 m. Advanced Land Observing Satellite (ALOS) has a 30 m resolution, DEM was created after using the archived information about the Panchromatic Remote Sensing Instrument for Stereo Mapping PRISM), portable on satellite ALOS by Japan Aerospace Exploration Agency’s (JAXA) in year 2006. PRISM consisted of three panchromatic radiometers that provided stereo images along a track with spatial resolution of 2.5 m in the nadir-looking[1]. By searching, we will try to indicate the accuracy of each method and the possibility of increasing the accuracy depending on the mathematical methods and algorithms. To achieve the main objective, it is an evaluation of the results of these methods after comparing them with the most probable value and according to specifications. Many researchers gave their advice in this field and in different regions of the world where we can pass these experiments because of their importance in giving the research reliability.

In the work of Nasir et al. [2], 15 cm accuracy of LiDAR points were adopted as a level to compare the different sources of DEM, the open source model, ASTER 30m DEM, SRTM 90m DEM, were used with DEM generated from Pleiades Tri Stereo-pair imagery possess 0.5m spatial resolution. The comparison between Pleiades-10 m DEM and LiDAR point elevation output were RMSE 5.2m, the comparison of ASTER-30m & SRTM-90m DEMs with the Level of comparison RMSE 6.65 as and 7.5 m respectively[2].

Twenty five checkpoints that were collected from 30 cm resolution HGK orthophotos, were used by Alganci et al. [3], to compare the different sources of DEM. DEM evaluated were; ASTER 30m DEM, (SRTM) 30m DEM, (ALOS) 30m resolution DEM, 3 m and 1 m resolution DSMs were produced from tri-stereo images from the SPOT's and Pleiades high-resolution (PHR) 1A satellites, respectively. The results of RMSE was PHR DSM(1.57), ALOS(2.14), SPOT DSM(2.26), SRTM(3.53) and ASTER(5.72) of the comparison showed that the DEM produced from PHR is closer to the real value than the rest of the results[3].

According to Zhang et al. [4], Real Time Kinematic Global Positioning System (RTK GPS) points were adopted as a level to compare the different sources of DEM. The free online models; ASTER 30m DEM, SRTM-90m, RMSE 8.44m (ASTER), 3.82m(SRTM), 2.08m(ALOS), and 1.74m(TDX DEM)[4].

2. THE STUDY AREA

The study area is located East of the Amarah city (Maysan governorate) in the south of Iraq which is outlying the capital (Baghdad), 300-kilometer south. The study area is about 30 Km2 located between (47.40°,47.46°) East and (32.31°,32.38°) North close to the border line between Iraq and Iran. The current study area was chosen due to the availability of data (PHR) and the presence of variation in the terrain, which gives sample room for comparison in contrast to flat terrain. The
region consists of a group of hills abandoned by some of the valleys. There are pools of water, especially in the rainy and flood season, and a fertile environment for the growth of seasonal natural plants in it. It contains military wastes from the Iran-Iraq War era in the 1980s and it include oil fields of the Maysan Oil Company. The area can be classified as Primarily Non-Vegetated because of an absence of Woody or Herbaceous life forms and with less than 25% cover of Lichens/Mosses[6].

3. DATA SET AND METHODOLOGY

I. Dataset; The following dataset have been used in this study: 1) ALOS V1.1, 2) SRTM V3 and 3) ASTER V2

A. SRTM V3 as shown in Figure 2
B. ASTER as shown in Figure 3

![ASTER V2 DEM](image)

**Figure 3**: Hill shade ASTER V2 DEM

C. ALOS V1.1 as shown in Figure 4

![ALOS V1.1 DEM](image)

**Figure 4**: Hill shade ALOS V1.1 DEM

D. Extracted digital elevation model of a pair from Pleiades satellite available for study area.

![PHR DEM](image)

**Figure 5**: Hill shade PHR DEM
II. Methodology

In order to evaluate the vertical accuracy, an independent, high-precision source must be selected in accordance with ASPRS standards. The independent source of higher accuracy for QA/QC check points should be at least three times more accurate than the required accuracy of the geospatial dataset being tested. (RTK/GNSS) technique to achieve these criteria was used in this study. The steps are summarized by the following:

A. More than thirty check points were observed by using dual frequency GNSS using Real Time Kinematic (RTK) observation technique. The horizontal accuracy was 10 mm± ppm and a vertical accuracy was 15 mm± 1.0 ppm. The base point for the RTK measurement is a boundary pillar obtained from the State Commission of Survey. Its coordinates were adopted as is, without static survey, see Figure 6. The observed points (RTK check point) were collected from the field surveys of the same researcher. The collected points were divided into two groups. The first group were not clear objects on the ground and used as a checkpoint for vertical accuracy assessment because of check point normally not well-defined[7]. It was 30 checkpoints (sample size), see Figure 7. The second group were clear features (well defined) on the ground. The second group were used to carry out the geometrical correction for the images of Pleiades during the process of processing and extraction of DEM. The horizontal and vertical coordinates of each point were referenced to UTM, WGS84, and EGM96.

![Figure 6: Boundary pillar used as base point for the RTK measurement](image)

![Figure 7: Check point distribution](image)
B. Extraction of the DEM from a pair of images of the satellite Pleiades 1B with high resolution, see Table 1. The process can be summarized in the following steps using ERDAS IMAGINE 2015 software, see Figure 8.

- **Building Block File:**
  Block file (*.blk) is an extension file that stores all the steps of processing for DEM extraction.

- **Geometric Model:**
  Pleiades RPC set as Geometric Model, RPC file contain the necessary information to determine interior and exterior orientation.

- **Defining Projection:**
  Universal Transverse Mercator (UTM) North zone-38, projection was defined as Metric Coordinate system, WGS-1984 projection was defined as Geographic Coordinate System and EGM96 as vertical datum.

- **Add pair of Pleiades-1B images.**
- **Import RPC file.**
- **Input GCPs (well-defined) find out in the two images.**
- **Start automatic tie point process.**
- **Start triangulation.**
- **DEM extraction.**

![Figure 8: Pleiades DEM extraction flowchart](image-url)
TABLE I: Illustrates the specifications of Pleiades-1B satellite (AIRBUS Defense & Space 2012)

| Imagery Products | 50-cm panchromatic  
|                 | 50-cm color (pansharpened)  
|                 | 2-meter multispectral  
| **Bundle:** | 50-cm panchromatic and 2-meter multispectral  
| Spectral Bands | P: 480-830 nm, Blue: 430-550 nm  
|                 | Green: 490-610 nm, Red: 600-720 nm, Near Infrared: 750-950 nm  
| Preprocessing Levels | Sensor  
|               | Ortho  
| Image Location Accuracy | With ground control points: 1m  
|                       | Without ground control points: 3m (CE90)  
| Imaging Capacity | Daily constellation capacity: 1,000,000 sq.km.  
|                   | Strip mapping (mosaic): 100 km x 100 km  
|                   | Stereo imaging: 20 km x 280 km  
|                   | Max. spots over 100 km x 200 km: 30 (crisis mode)  
| Imaging Swath | 20 km at nadir  
| Revisit Interval | Daily (Pleiades-1A and 1B)  

C. Extract Z-Value from the different datasets of DEMs. Four basic steps were used to extract the value of elevation (Z DEM) using GIS environment, Enter the different layer of the DEMs simultaneously with creation of shapefile(shp*) that contains thirty Ground control points information (Enter and data management stage). Matching layers, DEM layers and feature point layer, use Spatial Analyst Tools to extract the Z value as in Figure (9) and Table2.

![Z-Extract flow chart](image)

**Figure 9: Z-Extract flow chart**

TABLE II: Preliminary values of Z extracted from (SRTM, ASTER, ALOS and PHR) DEM for study area.

| Point Number | Z GNSS | Z ALOS | Z ASTER | Z PHR | Z SRTM | Point Number | Z GNSS | Z ALOS | Z ASTER | Z PHR | Z SRTM |
|--------------|--------|--------|---------|-------|--------|--------------|--------|--------|---------|-------|--------|
| 1            | 164.78 | 165    | 150     | 163.79| 164    | 16           | 167.22 | 167    | 155     | 167.10| 168    |
| 2            | 164.24 | 164    | 149     | 163.81| 164    | 17           | 140.32 | 140    | 122     | 140.01| 135    |
| 3            | 163.08 | 163    | 150     | 162.24| 161    | 18           | 128.84 | 129    | 112     | 128.45| 128    |
| 4            | 162.54 | 162    | 152     | 162.06| 160    | 19           | 129.32 | 130    | 112     | 129.24| 128    |
| 5            | 138.63 | 138    | 124     | 138.46| 138    | 20           | 107.79 | 108    | 93      | 107.25| 107    |
| 6            | 141.16 | 140    | 122     | 140.98| 138    | 21           | 151.93 | 152    | 132     | 151.43| 150    |
| 7            | 140.91 | 140    | 122     | 140.53| 138    | 22           | 148.60 | 150    | 140     | 147.60| 147    |
| 8            | 158.80 | 158    | 141     | 157.42| 156    | 23           | 148.75 | 149    | 138     | 147.72| 146    |
| 9            | 159.88 | 159    | 139     | 158.91| 159    | 24           | 144.33 | 146    | 127     | 144.41| 143    |
| 10           | 174.04 | 173    | 157     | 174.89| 172    | 25           | 142.65 | 143    | 122     | 141.97| 140    |
| 11           | 174.12 | 174    | 159     | 173.53| 174    | 26           | 142.53 | 143    | 122     | 142.27| 140    |
| 12           | 177.93 | 178    | 164     | 177.44| 176    | 27           | 140.36 | 139    | 126     | 139.83| 136    |
| 13           | 161.30 | 163    | 158     | 160.48| 157    | 28           | 169.23 | 170    | 156     | 169.04| 169    |
| 14           | 160.51 | 161    | 157     | 159.74| 158    | 29           | 168.50 | 170    | 152     | 168.49| 168    |
| 15           | 168.10 | 167    | 157     | 167.59| 168    | 30           | 172.73 | 174    | 165     | 172.81| 171    |
4. ACCURACY ASSESSMENT:

I. The evaluation criteria according to the standards

The National Standard for Spatial Data Accuracy (NSSDA) uses root mean square error (RMSE) to estimate positional accuracy and an indicator of evaluation. RMSE is the square root of the average set of square variations between coordinate values and coordinate values for similar points from an independent source with higher accuracy [7] (RTK) observation. It is an independent, high-resource used in this study.

\[
RMSE = \sqrt{\frac{1}{n} \sum_{i=1}^{n} (Z_{DEM} - Z_{GCP})^2} \quad \ldots (1)
\]

\(n\) = The number of samples (points).

RMSE Indicates accuracy as in equation (2)

\[
Accuracy = RMSE \times 1.96 \quad \ldots (2)
\]

II. Bias Correction

To reduce the variation between the observed \( Z (Z_{GNSS}) \) and the calculated \( Z (Z_{DEM}) \), a linear transformation function will be used to derive bias corrected of the DEMs elevation as follows[8]:

\[
Z = a \cdot u + b \cdot v + c \cdot w + Z_0 \quad \ldots (3)
\]

\(Z\) is observation data, \(w\) is estimation data, \(u, v\) are UTM coordinate of estimation, \((a, b, c, Z0)\) are linear transformation coefficients.

Apply the equation (3) on the first point until \(n\) Points

\[
Z1 = a \cdot u1 + b \cdot v1 + c \cdot w1 + Z0 \quad \ldots (3a)
\]

\[
Z2 = a \cdot u2 + b \cdot v2 + c \cdot w2 + Z0 \quad \ldots (3b)
\]

\[
Zn = a \cdot un + b \cdot vn + c \cdot wn + Z0 \quad \ldots (3c)
\]

Summarize the equation (3a) to (3b) as follows:

\[
\sum_{i=1}^{n} Z_i = \sum_{i=1}^{n} (a \cdot u_n + b \cdot v_n + c \cdot w_n + Z_0) \quad \ldots (4)
\]

The sum of the squares of deviation is given by:

\[
(a, \ldots, 0)^2 = \sum_{i=1}^{n} (a \cdot u_i + b \cdot v_i + c \cdot w_i + Z_0 - Z_i)^2 \quad \ldots (5)
\]

The function \(S (a, b, c, Z0)\) is a minimum when

\[
\frac{\partial S}{\partial a} = 2 \sum (a \cdot u_i + b \cdot v_i + c \cdot w_i + Z_0 - Z_i) \cdot (u_i) = 0 \quad \ldots (6a)
\]

\[
\frac{\partial S}{\partial b} = 2 \sum (a \cdot u_i + b \cdot v_i + c \cdot w_i + Z_0 - Z_i) \cdot (v_i) = 0 \quad \ldots (6b)
\]

\[
\frac{\partial S}{\partial c} = 2 \sum (a \cdot u_i + b \cdot v_i + c \cdot w_i + Z_0 - Z_i) \cdot (w_i) = 0 \quad \ldots (6c)
\]

\[
\frac{\partial S}{\partial Z_0} = 2 \sum (a \cdot u_i + b \cdot v_i + c \cdot w_i + Z_0 - Z_i) \cdot (1) = 0 \quad \ldots (6d)
\]
Dividing equation (6) by 2 and rearranging yields the normal equation then it solved as matrix system

\[ AX = B \]  

\[ \begin{align*} 
A &= \begin{bmatrix}
\sum_{i=1}^{n} u_i \cdot u_i & \sum_{i=1}^{n} v_i \cdot u_i & \sum_{i=1}^{n} w_i \cdot u_i \\
\sum_{i=1}^{n} v_i \cdot u_i & \sum_{i=1}^{n} v_i \cdot v_i & \sum_{i=1}^{n} v_i \cdot w_i \\
\sum_{i=1}^{n} w_i \cdot u_i & \sum_{i=1}^{n} w_i \cdot v_i & \sum_{i=1}^{n} w_i \cdot w_i \\
\sum_{i=1}^{n} u_i & \sum_{i=1}^{n} v_i & \sum_{i=1}^{n} w_i & N
\end{bmatrix} \\
X &= \begin{bmatrix}
a \\
b \\
c \\
z_0
\end{bmatrix}, \quad B = \begin{bmatrix}
\sum_{i=1}^{n} z_i \cdot u_i \\
\sum_{i=1}^{n} z_i \cdot v_i \\
\sum_{i=1}^{n} z_i \cdot w_i \\
\sum_{i=1}^{n} z_i
\end{bmatrix}
\end{align*} \]  

\(...(7a)\)  

\(...(7b)\)  

\(...(7c)\)  

The above system has been mathematically resolved and found the value of the matrix \([X]\), the direct linear transformation coefficients for each type of DEM were calculated as in Table 3.

**TABLE III: Linear Transformation Coefficients**

| DEMS Source | a     | b      | c     | z0  |
|------------|-------|--------|-------|-----|
| SRTM       | 2.24E-04 | -1.54E-04 | 0.97  | 394.17 |
| ALOS       | -3.77E-04 | -1.33E-04 | 1.01  | 749.86 |
| ASTER      | -3.13E-04 | 3.68E-05  | 0.88  | 136.56 |
| PHR        | -3.09E-05 | -9.51E-05 | 1.00  | 362.96 |

5. RESULTS AND ANALYSIS

1. Absolute Error value

As shown in Figure 10, the maximum errors recorded for PHR and ASTER DEM were 1.41 m and 20.88 m respectively; while the minimum errors recorded for PHR and ALOS DEM were 0.02 m and 0.07 m respectively.
**II. Analysis of the results under the standards**

According to the generic ASPRS, 2014 vertical accuracy standards for digital elevation data, enabling an unlimited number of vertical accuracy classes for non-vegetated vertical accuracy (NVA) and vegetated vertical accuracy (VVA), as shown in table 4.

TABLE IV: Vertical Accuracy Class[9]

| Vertical Accuracy Class | RMSEz Non-Vegetated (cm) | VVA at 95% confidence level (cm) | VVA at 95th percentile (cm) |
|-------------------------|--------------------------|-------------------------------|-----------------------------|
| X-cm                    | ≤ X                      | 1.96*X                        | ≤ 3*X                       |

**III. Statistical Analysis**

There are many statistical tests that give an indication of the normal sample distribution, Kolmogorov-Smirnova and Shapiro-Wilk test are used, under confidence level of 95%, the null hypothesis (H0) (samples with normal distribution). The null hypothesis was rejected in the test Shapiro-Wilk to the ASTERV2 DEM error (Data are not subject to normal distribution) because the level of significance below 5%; see Figure 12 and Table 5. The null hypothesis (H0) for DEM error Pleiades, SRTM and ALOS were accepted. Therefore, data are subject to normal distribution, see Figure 11, 13, 14, and Table 5.

TABLE V: Vertical accuracy standards classes for original result and the result after correction biases

| DEM sources | Vertical Accuracy CLASS (cm) | Accuracy 1.96×RMSE (cm) | RMSE (cm) | DEM sources | RMSE (cm) | Accuracy 1.96×RMSE (cm) | Vertical Accuracy Class (cm) |
|-------------|-----------------------------|--------------------------|-----------|-------------|-----------|--------------------------|-----------------------------|
| SRTM        | 223                         | 437                      | 223       | SRTM        | 132       | 259                      | 132                         |
| ASTER       | 1512                        | 2963                     | 1512      | ASTER       | 382       | 749                      | 382                         |
| ALOS        | 84                          | 165                      | 84        | ALOS        | 83        | 163                      | 83                          |
| PHR         | 64                          | 125                      | 64        | PHR         | 43        | 80.36                    | 43                          |
TABLE VI: Normality Test Results

| DEM TYPE | Kolmogorov-Smirnov | Shapiro-Wilk |
|----------|--------------------|--------------|
|          | Statistic | df | Sig. | Statistic | df | Sig. |
| ALOS     | 0.094     | 3  | 0.200 | 0.976     | 3  | 0.71 |
|          | 0         | 0  | 0     | 0         | 0  | 0    |
| ASTER    | 0.131     | 3  | 0.200 | 0.926     | 3  | 0.03 |
|          | 0         | 0  | 0     | 0         | 0  | 0    |
| SRTM     | 0.130     | 3  | 0.200 | 0.955     | 3  | 0.22 |
|          | 0         | 0  | 0     | 0         | 0  | 0    |
| PHR      | 0.093     | 3  | 0.200 | 0.947     | 3  | 0.13 |
|          | 0         | *  | 0     | 0         | 9  | 0    |

Figure 11: Histogram with Normality curve for ALOS DEM.

Figure 12: Histogram with Normality curve for ASTER DEM.
6. CONCLUSIONS

1) The results of the preliminary data analysis showed that the digital elevation model ALOS V1.1 gave the highest accuracy among the free models accurately 1.65m, followed by SRTM V3 model 4.37m and then ASTER model 29.36 m.

2) The results of the corrections using direct linear transformation method was mixed. The model most responsive to corrections was ASTER V2 DEM (the value of RMSE is 15.12 m was decrease to 3.82 m). Next comes the model SRTM V3 DEM (the value of RMSE is 2.23 m was decrease to 1.32m). Then the PHR DEM (the value of RMSE is 0.64 m was decrease to 0.43 m), ALOS V1.1 DEM gives a poor response to the correction process using the direct linear transformation method from (RMSE 0.84 m to RMSE 0.83 m).

3) DEM extract from Pleiades high-resolution (PHR) 1B satellite gave high accuracy compared to open source models, the results were logical because of the high resolution of the images used as well as the adoption of ground control points during image processing.

4) As mentioned at the end of the introduction, most literature review showed that the digital elevation models produced by the Pleiades satellite are the most accurate compared to other free models. The ALOS model tops the free models with the highest accuracy, then the SRTM model follows. The ASTER model is less accurate than the other models. The obtained results agree with previous studies, which gives them reliability in obtaining data and processing processes.
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