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Accuracy Assessment of Digital Elevation Models Produced From Different Geomatics Data

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K E Y W O R D S

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A B S T R A C T

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 ortho-rectification. 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 Space borne 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 the ASTER 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 6 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].

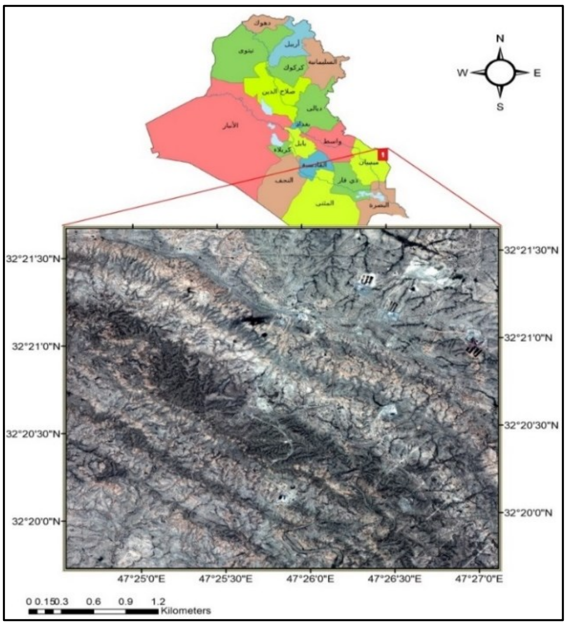

Figure 1: Case Study Location

3. Data Set and Methodology

I. Dataset; The following dataset have been used in this study: 1) ALOSV1.1, 2) SRTM V3and 3) ASTERV2

A. SRTM V3 as shown in Figure٢

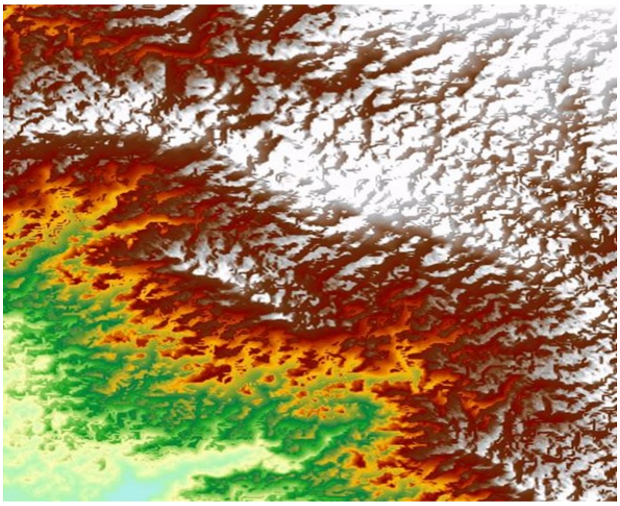

Figure 2: Hill shade SRTM V3 DEM

B. ASTER as shown in Figure٣

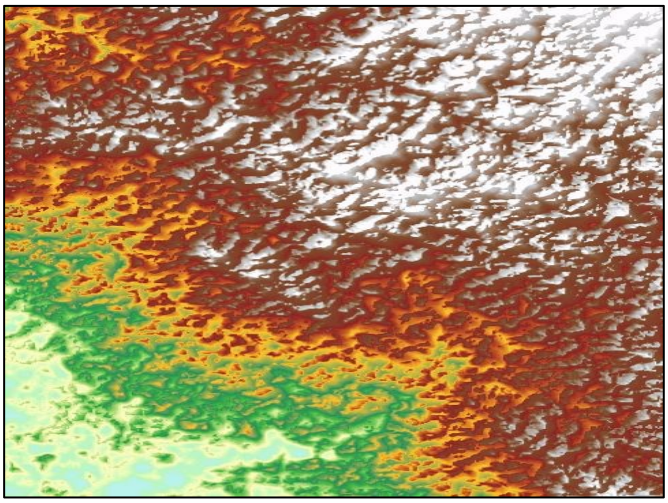

Figure ٣: Hill shade ASTER V2 DEM

C. ALOS V1.1 as shown in **Figure 4**

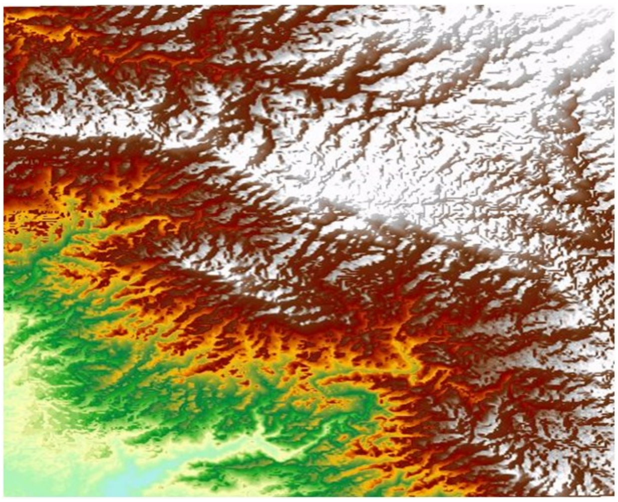

Figure ٤: Hill shade ALOS V1.1 DEM

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

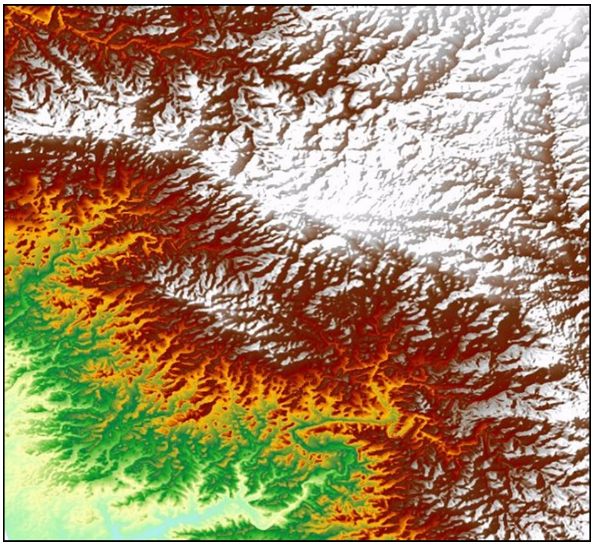

Figure 5: Hill shade PHR DEM

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 10mm±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 in to 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

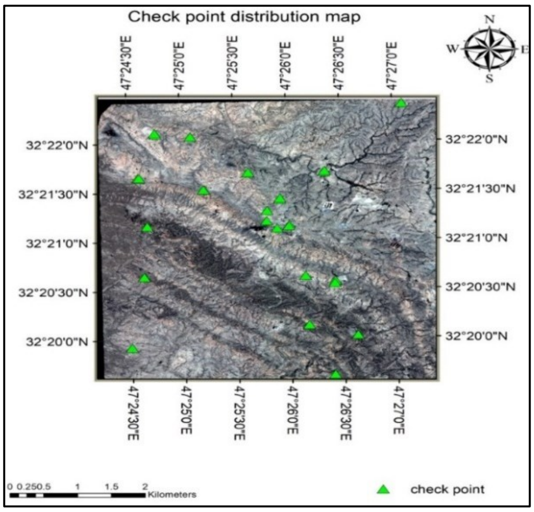

Figure 7: Check point distribution

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.

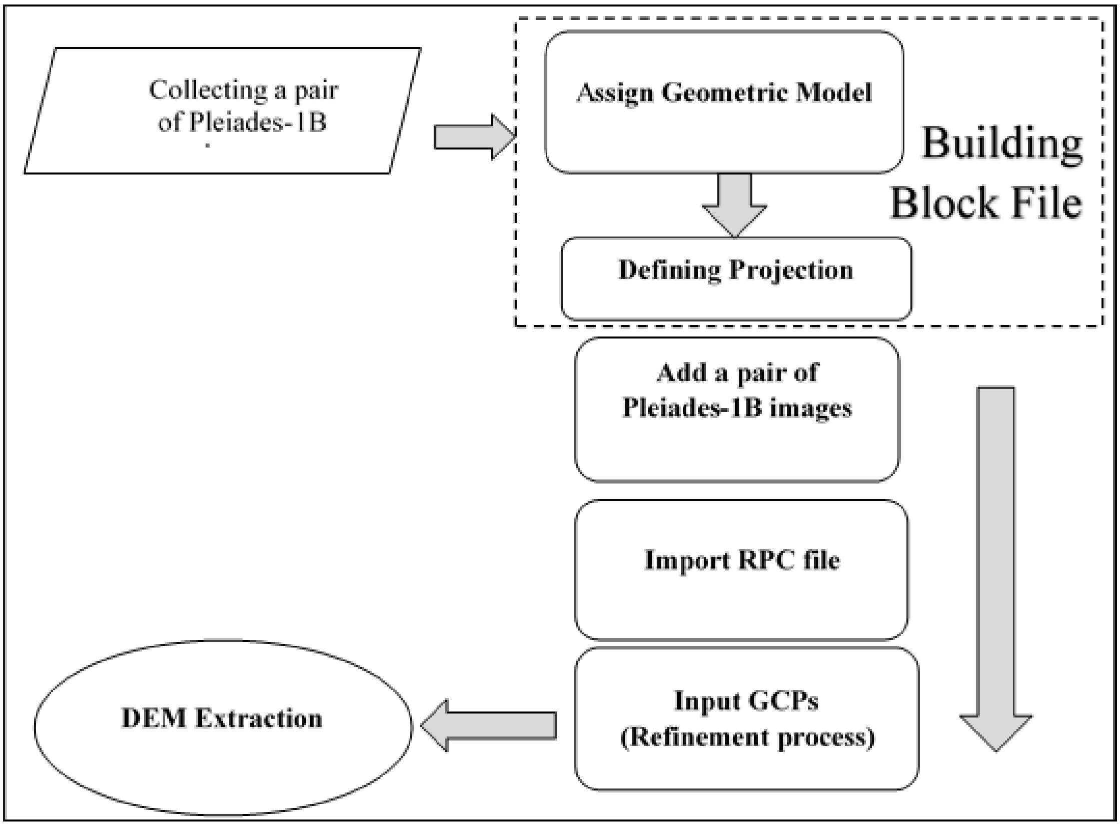

Figure 8: Pleiades DEM extraction flowchart

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.

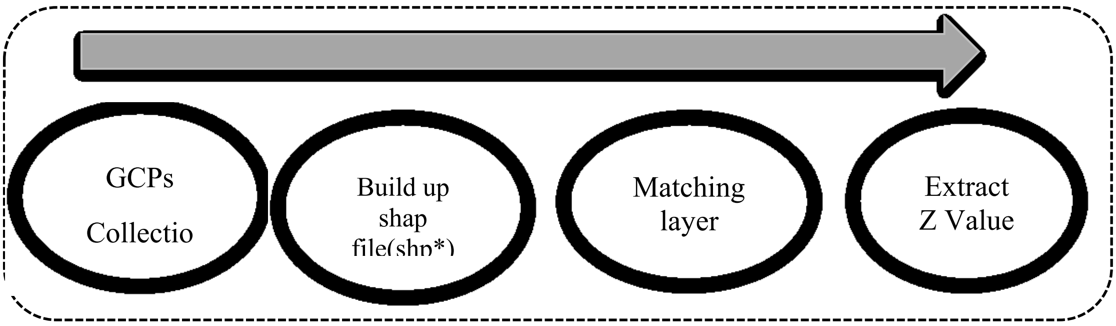

Figure 9: Z-Extract flow chart

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.

$$RMSE=\sqrt{\frac{1}{n}\sum_{i=1}^{n}(ZDEM-ZGCP)^{2}}\ldots\ldots.(1)$$

n=The number of samples (points).
$RMSE$ Indicates accuracy as in equation (2)

$$\text{Accuracy} = \text{RMSE} \times 1.96\ldots\ldots\ldots\ldots\ldots\ldots..(2)$$

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]:

$$Z=a.u+b.v+c.w+Z0\ldots\ldots\ldots (3)$$

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

$$Z1=a.u1+b.v1+c.w1+Z0\ldots\ldots(3a)$$

$$Z2=a.u2+b.v2+c.w2+Z0\ldots\ldots(3b)$$

$$Zn=a.un+b.vn+c.wn+Z0\ldots\ldots(3c)$$

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

$$\sum_{i=1}^{n}Z_i=\sum_{i=1}^{n}(a.u_n+b.v_n+c.w_n+Z0)\ldots\ldots\ldots\ldots\ldots\ldots\ldots(4)$$

The sum of the squares of deviation is given by:

$$(a,\ldots,0)=\sum(ei)2=\sum_{i=1}^{n}(a.u_i+b.v_i+c.w_i+Z_0-Z_i)^2\ldots\ldots\ldots\ldots\ldots\ldots..(5)$$

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

$$\frac{\partial s}{\partial a}=2\sum(a.u_i+b.v_i+c.w_i+Z_0-Z_i)*(u_i)=0\ldots(6a)$$

$$\frac{\partial s}{\partial b}=2\sum(a.u_i+b.v_i+c.w_i+Z_0-Z_i)*(v_i)=0\ldots(6b)$$

$$\frac{\partial s}{\partial c}=2\sum(a.u_i+b.v_i+c.w_i+Z_0-Z_i)*(w_i)=0\ldots(6c)$$

$$\frac{\partial s}{\partial z_0}=2\sum(a.u_i+b.v_i+c.w_i+Z_0-Z_i)*(1)=0\ldots.(6d)$$

Dividing equation (6) by 2 and rearranging yields the normal equation then it solved as matrix system

$$AX=B \ldots\ldots\ldots \ldots\ldots\ldots\ldots\ldots\ldots (7)$$

$$A = \begin{bmatrix} \sum_{i=1}^{n} u_i \, . u_i & \sum_{i=1}^{n} v_i \, . u_i & \sum_{i=1}^{n} w_i \, . u_i & \sum_{i=1}^{n} u_i \\ \sum_{i=1}^{n} v_i \, . u_i & \sum_{i=1}^{n} v_i \, . v_i & \sum_{i=1}^{n} v_i \, . w_i & \sum_{i=1}^{n} v_i \\ \sum_{i=1}^{n} w_i \, . u_i & \sum_{i=1}^{n} v_i \, . w_i & \sum_{i=1}^{n} w_i \, . w_i & \sum_{i=1}^{n} w_i \\ \sum_{i=1}^{n} u_i & \sum_{i=1}^{n} v_i & \sum_{i=1}^{n} w_i & N \end{bmatrix} \ldots (7a)$$

$$X = \begin{bmatrix} a \\ b \\ c \\ z_0 \end{bmatrix} \ldots . (7b) \ , B = \begin{bmatrix} \sum_{i=1}^{n} z_i \, . u_i \\ \sum_{i=1}^{n} z_i \, . v_i \\ \sum_{i=1}^{n} z_i \, . w_i \\ \sum_{i=1}^{n} z_i \end{bmatrix} \ldots . (7c)$$

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	zo
SRTM	2.24E-04	-1.54E-04	0.977	394.177
ALOS	-3.77E-04	-1.33E-04	1.014	749.861
ASTER	-3.13E-04	3.68E-05	0.887	136,565
PHR	-3.09E-05	-9.51E-05	1.004	362.963

5. Results and Analysis

I. 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.

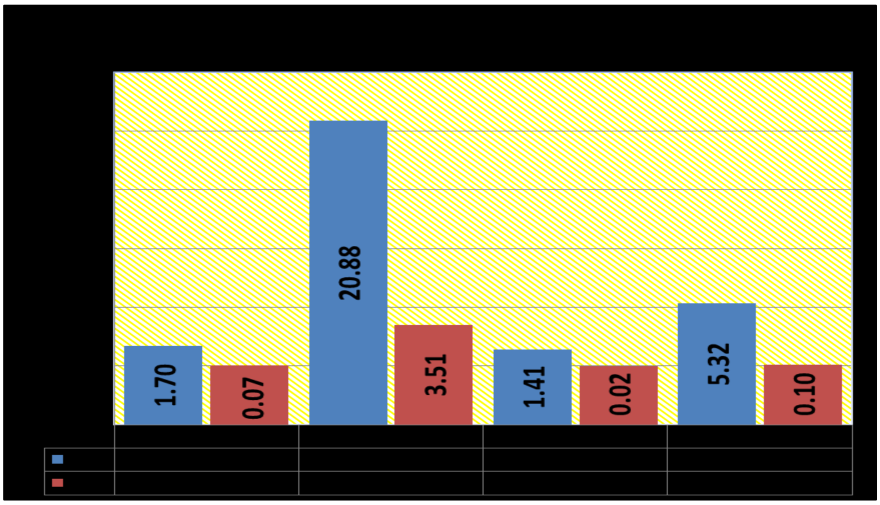

Figure 10: Minimum and maximum value of the error (Absolute value)

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 table4.

TABLE IV::Vertical Accuracy Class[9]

Vertical Accuracy Class	Absolute Accuracy		
	RMSEz Non-Vegetated (cm)	VVA at 95% confidence level(cm)	VVA at 95 th 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 Figure12 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

Vertical accuracy standards classes for original results				Vertical accuracy standards classes 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

Tests of Normality level of significance at a confidence level 95%						
DEM TYPE	Kolmogorov-Smirnov			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
ALOS	0.094	30	.200	0.976	30	0.717
ASTER	0.131	30	.200	0.926	30	0.038
SRTM	0.130	30	.200	0.955	30	0.227
PHR	0.093	30	.200*	0.947	30	0.139

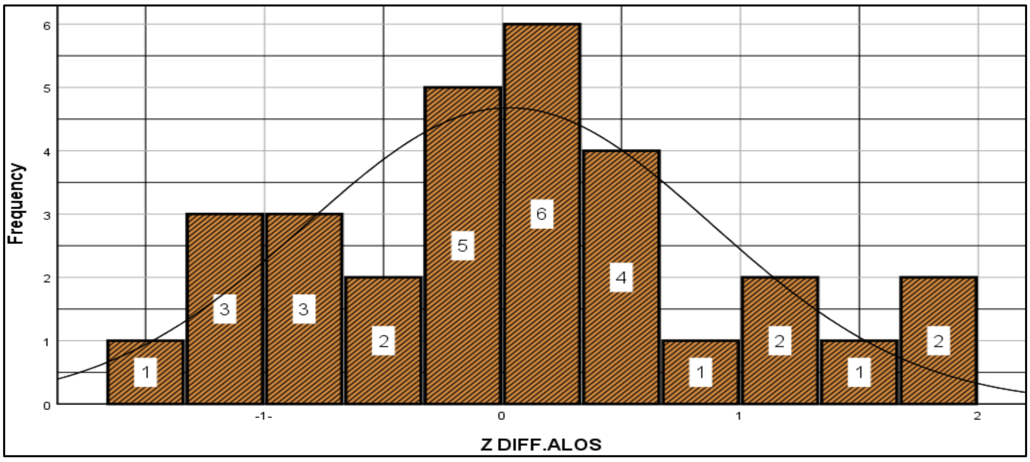

Figure 11: Histogram with Normality curve for ALOS DEM.

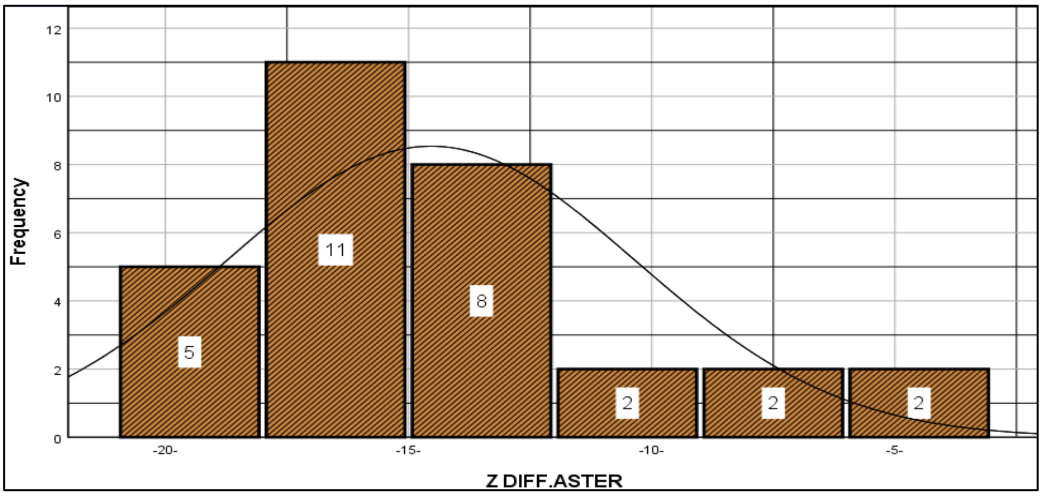

Figure 12: Histogram with Normality curve for ASTER DEM.

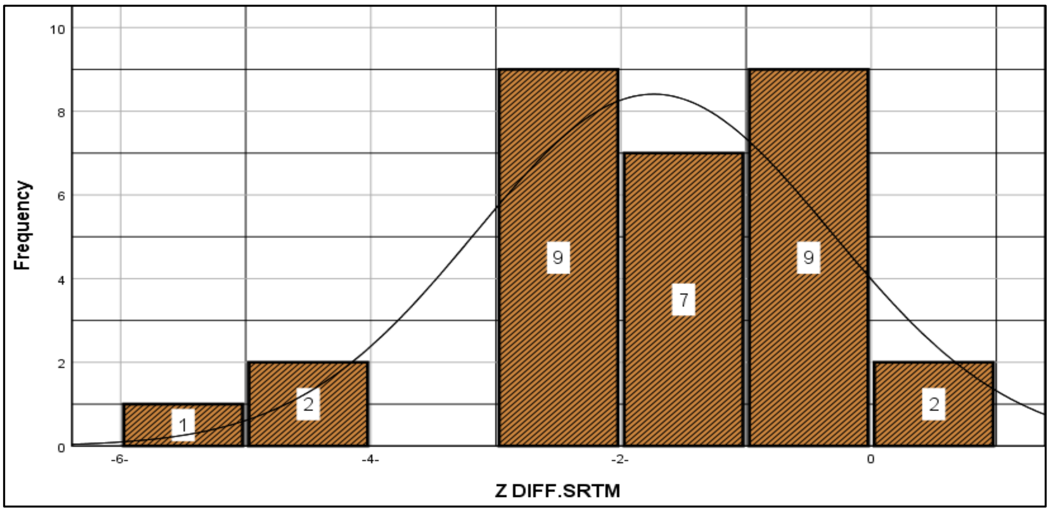

Figure 13: Histogram with Normality curve for SRTM DEM.

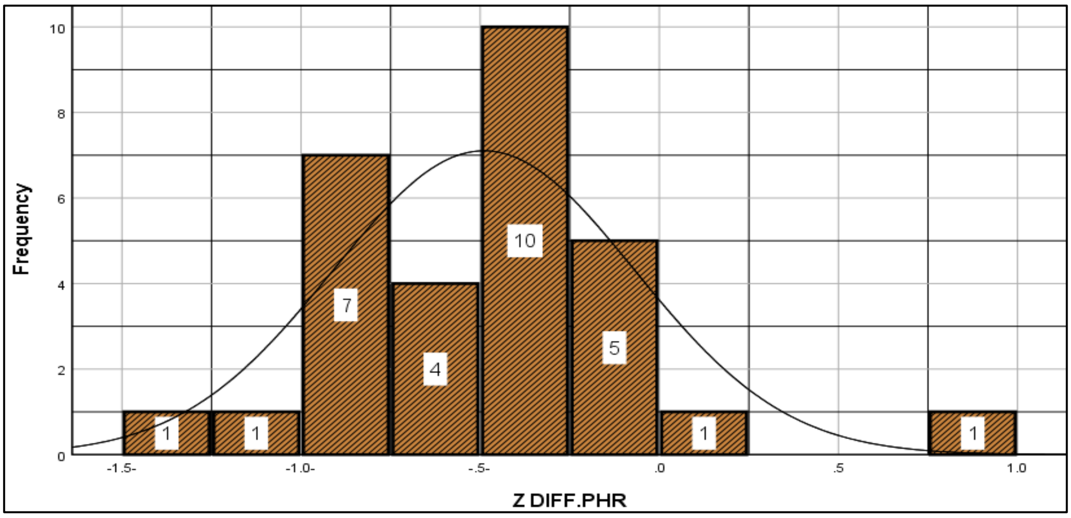

Figure 14: Histogram with Normality curve for PHR DEM.

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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References

[1] A. A. A. Hassan, "Accuracy Assessment of Open Source Digital Elevation Models," J. Univ. Babylon, vol. 26, no. 3, pp. 23–33, 2018.

[2] S. Nasir, I. A. Iqbal, Z. Ali, and A. Shahzad, "Accuracy assessment of digital elevation model generated from pleiades tri stereo-pair," RAST 2015 - Proc. 7th Int. Conf. Recent Adv. Sp. Technol., pp. 193–197, 2015.

[3] U. Alganci, B. Besol, and E. Sertel, "Accuracy assessment of different digital surface models," ISPRS Int. J. Geo-Information, vol. 7, no. 3, pp. 1–16, 2018.

[4] K. Zhang, D. Gann, M. Ross, Q. Robertson, J. Sarmiento, S. Santana, J. Rhome, and C. Fritz, "Accuracy assessment of ASTER, SRTM, ALOS, and TDX DEMs for Hispaniola and implications for mapping vulnerability to coastal flooding," Remote Sens. Environ., vol. 225, no. November 2018, pp. 290–306, 2019.

[5] S. Zhao, W. Cheng, C. Zhou, X. Chen, S. Zhang, Z. Zhou, H. Liu, and H. Chai, "Accuracy assessment of the ASTER GDEM and SRTM3 DEM: An example in the Loess Plateau and North China plain of China," Int. J. Remote Sens., vol. 32, no. 23, pp. 8081–8093, 2011.

[6] L. J. M. Di Gregorio, A., and Jansen, "Land Cover Classification System (LCCS): Classification Concepts and User Manual," Fao, vol. 53, no. January 2000, p. 179, 2000.

[7] D. Acquisition, K. Heidemann, U. S. G. Survey, D. Smith, and D. S. Mapping, "ASPRS Positional Accuracy Standards for Digital Geospatial Data," Photogramm. Eng. Remote Sens., vol. 81, no. 3, pp. 1–26, 2015.

[8] K. Pakoksung and M. Takagi, "Digital elevation models on accuracy validation and bias correction in vertical," Model. Earth Syst. Environ., vol. 2, no. 1, pp. 1–13, 2016.

[9] D. Maune, "Digital Elevation Model Technologies and Applications. The DEM Users Manual," Am. Soc. Photogramm. Remote Sensing, Bethesda, p. 540 pp., 2001.