VERTICAL ACCURACY ASSESSMENT FOR OPEN-SOURCE DIGITAL ELEVATION MODEL: A CASE STUDY OF BASRAH CITY, IRAQ

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Abstract

In the diverse domains of earth observation, elevation data are essential for a wide range of applications with various technical requirements and use cases. The Advanced Spaceborne Thermal Emission and Reflection Radiometer-Global Digital Elevation Model (ASTER GDEM), Global Multi-resolution Terrain Elevation Data 2010 (GMTED2010), Shuttle Radar Topography Mission (SRTM), and other projects have made a large number of global Digital Elevation Model (DEM) datasets for environmental modelling and studies freely available. Global DEMs have undergone an accuracy review to measure their inherent vertical uncertainty to show how accurate information should be considered while planning and analysing. Comparing the DEMs with highly accurate geodetic control points as the independent reference data one of the best methods in the evaluation process. SRTM 30m, SRTM 90m, ALOS World 3D-30, Aster-GDEM, GMTED2010, and NASADEM are among the worldwide DEMs that were examined. Comparisons are made between 793 geodetic control points values and those from SRTM 30m, SRTM 90m, ALOS World 3D-30, Aster-GDEM, GMTED2010, and NASADEM. The statistical analysis of global DEMs from GPS reference elevations gave us that the accuracy of the ALOS World 3D-30m is much better than other models with RMSE and STD values of 1.2497 and 1.235 m, respectively. In contrast, Aster-GDEM exhibited the highest RMSE and residual error of STD values of 5.793 m and 3.394 m, respectively.

1. INTRODUCTION

Digital elevation models (DEMs) are now an essential part of GIS and remote sensing applications. By combining cutting-edge methods and high-resolution satellite images to analyze the landscape, DEM, which represents the actual surface of the earth, helps to understand the terrain's characteristics. DEM is used in many industries, including improving product development and decision-making, mapping for purposes, producing contour maps to extract elevation, constructing 3D simulations, and so forth, to comprehend and evaluate the nature of the terrain (Lakshmi & Yarrakula, 2018).

Due to its extensive potential applicability, many DEM validations have been completed on a global and regional basis. Gyeltshen et al., 2021 assessed the accuracies of globally available DEMs (SRTM v3, ASTER GDEM v2 and ALOS PALSAR DEM) with respect to Topo-DEM derived from topographic map of 5m contour interval. The result SRTM DEM was found to be highly accurate in terms of RMSE and displacement compared to other DEMs. Zhang et al. (2019) looked at the accuracy of DEMs derived from ASTER, SRTM, ALOS, TDX, and TDX for Hispaniola. Comparisons were made between DEMs (ASTER, ALOS, SRTM, and TanDEM-X) for Hispaniola with GPS and LiDAR data. Several error measures, such as root-mean-square error (RMSE) and absolute error at the 90% percentile, were used to make the comparisons (LE90). ASTER, ALOS, SRTM, and TDX DEMs had RMSE and LE90 values of 8.44, 3.82, 14.29, and 5.85, 3.64, 2.08, 1.74, and 3.20 m when compared to more than two thousand GPS observations with elevations of less than 7 meters. For the same DEMs, the RMSE and LE90 values were 4.24, 4.81, 6.70, and 7.16, 6.82, 4.91, 2.27, and 3.66 m when compared to DEMs constructed using LiDAR data spanning 150 km^2. The difference between DEMs and LiDAR data was used to get these values. Santillan & Makinano-Santillan (2017) evaluated the vertical levels of accuracy and uncertainties of three publicly accessible global DEMs as sources of elevation-based sea level rise vulnerability assessments in the Philippines. For the Shuttle Radar Topography Mission (SRTM) DEM, ASTER Global DEM (GDEM Version 2), and ALOS World 3D-30 DEMs, they calculated vertical levels of accuracy and variances (AW3D30). Ground control points totaled 2,076. There were RMSEs of 9.80 m, 5.16 m, and 4.32 m in the vertical evaluation of the ASTER GDEM V2, ASTER DEM, and AW3D30. This paper aims to estimate the accuracy of SRTM 30m, SRTM 90m, AlOS World 3D-30, Aster-GDEM, GMTED2010, and NASADEM in Basrah City (Iraq) by comparing DEMs with GPS measurements.

2. STUDY AREA AND DATA

2.1. Study Area

Basrah is located in southern Iraq and represents its international border with both Kuwait and Iran. It is the only port of Iraq overlooking nearly 60 km on the Gulf coast. In addition to its strategic location, the oil industry makes this city one of the most attractive region in the world for foreign investment. Until a few years ago, the majority of the city's population is located nearby rivers (Al-abboodi et al. 2020). Recent economic developments of the city have heightened the need for exploring the topographic data to gain more detailed elevation for future construction projects. Available information concerning the topographic aspects of Basrah is rather limited and mainly refers to limited areas of the city. Little is known about topographic data in the city center, or other districts like Qurna, Fao and Abu Al-Khaseeb, as shown in Figure 1.

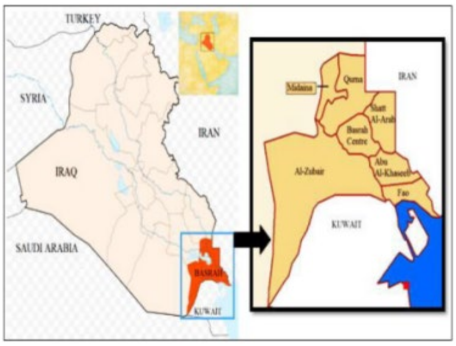

Figure 1. Case Study.

2.2. SRTM DEM

The goal of the Shuttle Radar Topography Mission (SRTM) was to construct the most complete and high-resolution digital topographic database in the world. This was accomplished by collecting elevation data on a scale that was practically worldwide. In February of 2000, a specially modified radar system known as the SRTM was carried on the Space Shuttle Endeavour for a mission that lasted for a total of 11 days. The National Geospatial-Intelligence Agency (NGA) and the National Aeronautics and Space Administration (NASA) collaborated on the development of a universal project known as SRTM (NASA). Figure 2 indicates that the SRTM dataset has a 30-m (one-arc-second) position accuracy between 31°N and 29°N, encompassing the Persian Gulf. It has a 16-meter vertical accuracy (90 per_cent linear error) and 20-meter horizontal accuracy (90 per_cent circular error) (NASA, 2015).

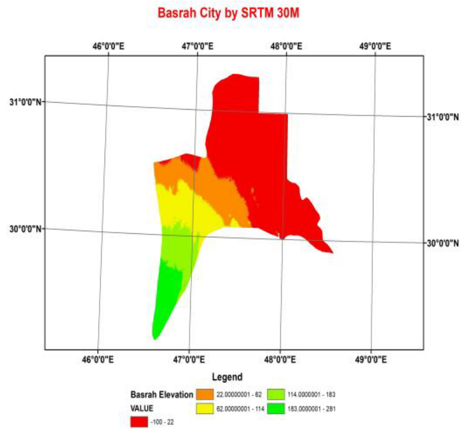

Figure 2. SRTM elevation model.

2.3. ASTER-GDEM

Using nadir- and aft-looking near-infrared cameras, NASA's Terra spacecraft's Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) captures in-track stereo. In June 2009, the initial edition of the ASTER Global Digital Elevation Model (GDEM v1) refer to Figure 3, This “version 1” ASTER GDEM (GDEM1) was compiled from over 1.2 million scene-based DEMs covering land surfaces between 83°N and 83°S latitudes. The GDEM1 was found to have an overall accuracy of around 20 meters at the 95% confidence level (Tachikawa al et, 2011). The RMSE for the GDEM2 is 8.68 meters (compared to 9.34 meters for v1). a collaborative project of NASA and Japan's Ministry of Economy, Trade, and Industry (METI), was released. Even though NASA and METI stated that GDEM v1 is a "research-grade" dataset with anomalies and abnormalities that may hinder its utility for some tasks, the user community reacted positively to its release. Many validation studies on GDEM v1 found that the dataset fulfilled the declared reliability target (±20 metres at 95% reliability) in the vast majority of cases, but that some dataset characteristics affect how the terrain is described and how the DEM operates in implementations (Hvidegaard et al., 2012; Miliaresis & Paraschou, 2011; Slater et al., 2011; Wang et al., 2012; ASTER GDEM Validation Team, 2009).

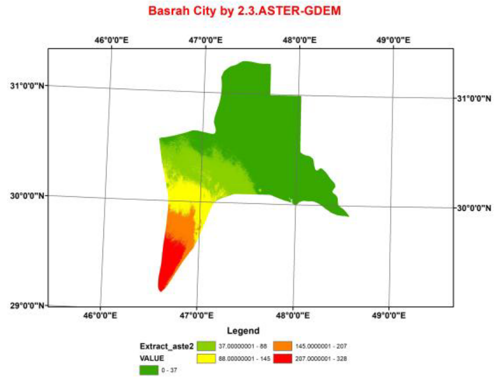

Figure 3. ASTER elevation model.

2.4. GMTED2010

USGS and the National Geospatial-Intelligence Agency (NGA) have collaborated to produce an updated alternative for GTOPO30, the Global Multi-resolution Terrain Elevation Data 2010 (GMTED2010). GMTED2010 is the name of the new model. This new product suite covers all geographical regions from 84°N to 56°S for most products and from 84°N to 90°S for other products, using WGS84 as a horizontal reference. Most GMTED2010 vertical heights reflect the EGM 96 geoid. Vertical accuracy was determined by comparing GMTED2010 products to an NGA control point dataset. The vertical accuracy of control points is better than 10 meters with 90% confidence, or 6-meter RMSE (Danielson and Gesch, 2011; NGA, 2010).

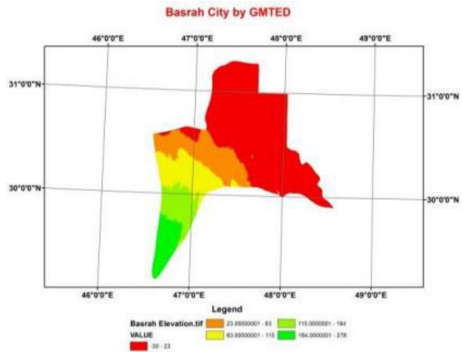

Figure 4. GMTED2010 elevation model for Basrah City.

2.5. ALos World 3D – 30m

The Advance Land Observation System (ALOS) World 3D - 30 m Digital Elevation Model (DEM), commonly known as AW3D30, was made available for free download by the Japan Aerospace Exploration Agency (JAXA) in 2015. This model is part of the Advanced Land Observation System (ALOS). The

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horizontal resolution of this dataset derived from the global digital surface model is roughly 30 meters mesh (1 arcsec). The AW3D30 is essentially a resampling of the World 3D Topographic Data5_meters mesh version, which is currently thought to be the most accurate global-scale elevation data. The RMSE is 5m and reference ellipsoid used GRS80 for the vertical reference, as shown in Figure 5 (Kilinc and Alazaiza, 2019; JAXA, 2015).

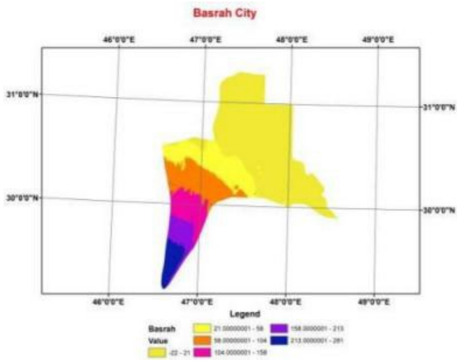


Figure 5. Map showing the ALOS World 3D – 30 m of the Basrah city

2.6. NASA DEM

SRTM and other datasets such as ASTER DEM, ICESat-GLAS elevation datasets, National Elevation Data for the United States and Mexico, Canadian Digital Elements Data, Global Multi-resolution Terrain Elevation Data 2010 (GMTED2010), and ALOS-PRISM DEM datasets are used to produce NASADEM products, which can be found at various locations around the world This new product suite covers all geographical regions from 60°N to 65°S, using WGS84 as horizontal reference and EGM96 geoid as vertical reference (Buckley, 2020 .An analysis of seven publicly available free DEM datasets (ASTER GDEM V2, SRTM-3 V4.1 DEM, VFP-DEM, MERIT DEM, Seamless SRTM-1 DEM) over the HMA region (Hengduan Mountains and the Himalayas) has shown that the AW3D30 DEM is the most promising (Liu et al., 2019).

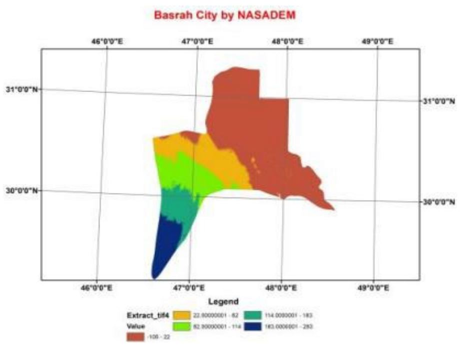


Figure 6. Map showing the NASA DEM m of the Basrah city

2.7 Ground Truth Data

Accuracy assessment is needed to determine the inherent vertical uncertainty in free digital elevation models in order to show how accurate information is considered when planning and implementing. The DEMs were evaluated using high-resolution geodetic control points as independent reference data GPS surveys were utilised to collect these points, which covered a wide range of topography, including flat ground, hills, and the coastline. There are many observation methods in the Global Positioning System, but in this study, the Fast Static and Real-Time Kinematic (RTK) were used to observe all points. The Fast-Static method was selected since it can produce the best accuracy in a short amount of time. Where the accuracy of these methods corresponds to the required evaluation in addition to that, it does not require a large time for observation. The accuracies of ± 3 to 5 mm + 1 ppm can be achieved with fast static relative positioning. Kinematic surveys often use 1-second epoch rates, which means that the RTK method can determine where a rover is every second or less. The accuracy of intermediate points is between (1–2 cm + 2 ppm) (Ghilani and Wolf, 2012).

3. METHOD

3.1 Data preparation

The same vertical datum should be used for both sets of data. Any given GPS raw data is subtracted from the geoid elevation in this scenario. The research site's reference data were converted into the same projection system, zone 38 north of the Universal Transverse Mercator (UTM). We chose WGS1984 as our geodetic and spheroid. The data was transformed and prepared using ArcGIS 10.1. For this investigation, the reference elevation values were compared with digital elevation models (DEMs) created in a GIS context (pixel values corresponding to GCPs).

3.2 Assessment DEMs with GPS Observation.

American Society for Photogrammetry and Remote Sensing goes on to say that vertical accuracy is the most important thing to look for when determining the quality of elevation data (Bethesda, MD, USA, 2004). Accuracy is defined in this evaluation as the characterisation of systematic and random errors. A statistical bias is used to estimate systematic error, and the deviation difference in height between orthometric height and DEMs is used to estimate random error. In order to define an orthometric height (H), GNSS can be employed as one of the geodetic techniques to calculate high precision geoid. It entails converting GNSS-derived ellipsoidal height (h) to orthometric height (h) (H).

Using well-defined geoid models, orthometric heights can be estimated. With the help of these geoid models, we can calculate the geoid height (N), which is the distinction between the ellipsoidal and orthometric height values in Equation 1. Then, using geoid heights and known ellipsoidal heights, orthometric heights can be calculated (Jekeli et al., 2012). Figure 7 depicts the relationship between ellipsoidal, orthometric, and geoid heights. The basic formula for this conversion is (Milbert, 1991):

$$H = h - N \quad (1)$$

Where:

H = Orthometric Height

h = Ellipsoidal Height

N = Geoid Height (EGM96)

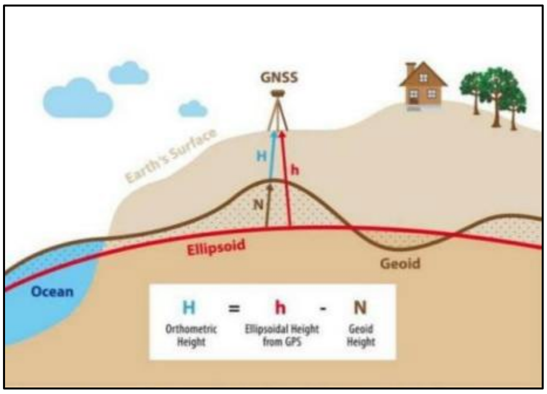


Figure 7. Relationship between ellipsoidal, orthometric and geoid heights (Albayrak et al., 2020).

This conversion was performed according to open-source DEMs utilising the same references, which is EGM96 for vertical datum. Data from DEM and GPS were compared using statistical indices in this study. This statistical approach was used to assess the DEM's vertical accuracy. This also improves the interpretation of DEM and GPS dataset correlations, trends, and error propagation. An elevation error is determined for each point as the difference between the model and reference values in Equation 2.

$$H_{Diff} = H_{Model} - H_{Reference} \qquad (2)$$

Eq. 2: H Diff denotes the elevation difference, H Model the DEM's investigated point's elevation, and H Reference represents the GPS's observed elevation. This was followed by computing the Mean Error (ME) see Equation 3, Standard Deviation (STD) see Equation 4, and Root Mean Square Error (RMSE) for each model see Equation 5. When it comes to assessing the precision of continuous variables, these are the most used statistical measurements.

$$\text{ME} = \sum \frac{H_{diff}}{N} \qquad (3)$$

$$\text{STD} = \sqrt{\frac{(H_{diff} - ME)^2}{N-1}} \qquad (4)$$

$$\text{RMSE} = \sqrt{\sum \frac{(H_{diff}{}^2)}{N}} \qquad (5)$$

RMSE is the assessment of surface quality and gives knowledge of the differences between 2 variables (predicted by the model and observed data), where N indicates the total element number (Athmania & Achour, 2014).

This study used Pearson correlation coefficient (r) to measure the linear correlation between GPS and each global DEMs dataset. The formula for computing the correlation coefficient to find out how strong a relationship is between two data sets is written as Equation 6 (Jackson, 2008):

$$r = \frac{\Sigma_{i-1}^{n}(x_i - x^-)\,(y_i - y^-)}{\sqrt{\Sigma_{i-1}^{n}\,(x_i - x^-)^2}\;\sqrt{\Sigma_{i-1}^{n}(y_i - y^-)^2}} \qquad (6)$$

where:

n = the number of samples data

xi , yi = single samples indexed with i

$x^- = \frac{1}{n}\,\Sigma_{i-1}^{n}\,x_i$ is mean of the sample and it is same goes.

4. RESULTS AND DISCUSSION

Statistical analysis in this study focused on the elevation values for each model in terms of the standard deviation (STD) and root mean square error (RMSE) between GPS and global DEMs. GIS and Excel technologies are used for this purpose where free DEMs were collected from various sources and the elevations were extracted using GIS, the (Add Surface Information - 3D Analyst) used as a tool to extract height from DEMs. The results were compared with the height from Ground Truth Data to obtain statistical information (see Figure 8). The methodology demonstrated a positive correlation between the DEMs and the GPS data via correlation coefficient values and a histogram of error distribution. A low RMSE value indicates that the elevation difference between GPS levelling and global DEM is small.

A summary of the statistical analysis of global DEMs highlighted that the accuracy of the ALOS World 3D-30m is much better than other models with RMSE and STD values of 1.2497 and 1.235 m, respectively. In contrast, Aster-GDEM exhibited the highest RMSE and residual error of STD values of 5.793 m and 3.394 m, respectively.

In regression analysis, r is the statistic value that provides information on the goodness of fit, which describes how well a regression line approximates actual data points between global DEMs and GPS. The regression line is practically close to data points with an R-value of 1 or -1. Normally, the regression model fits the data very closely if the differences between the observed and expected values are small and unbiased. By referring to the results from the regression model, the relationship between GPS observation data and global DEM expected values could be determined as strong or weak. Elevation scatter plots from GPS orthometric height and each global DEMs used in this study are shown in Figure 9.

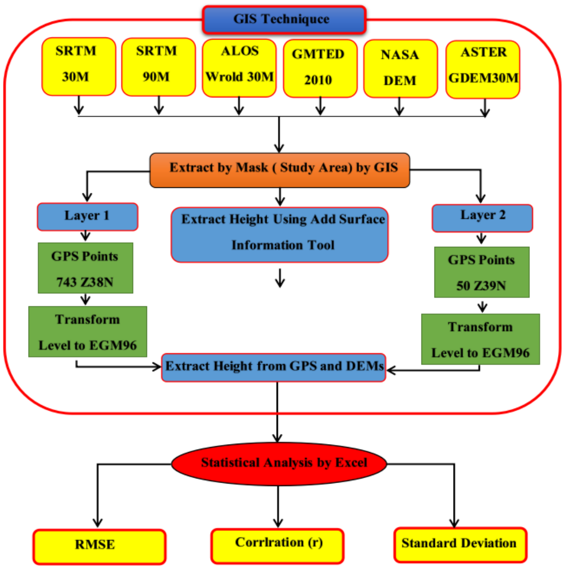
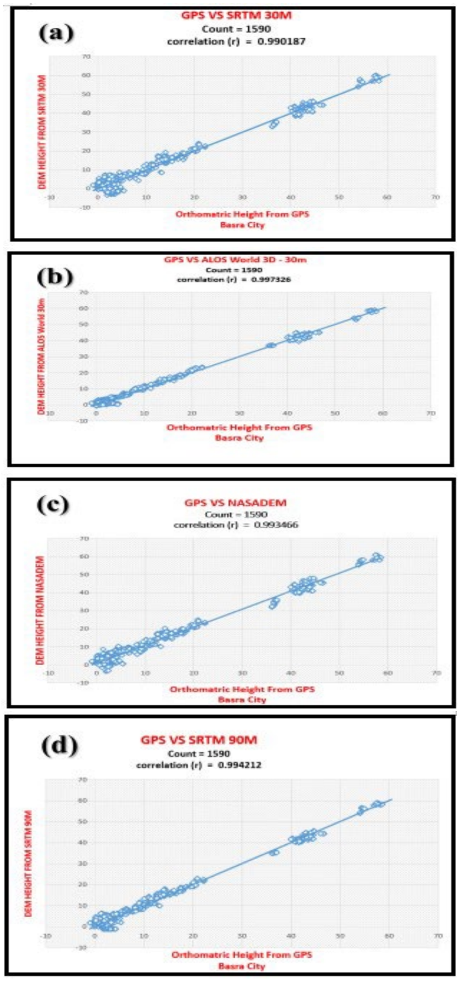


Figure 8. Flowchart for used methodology.



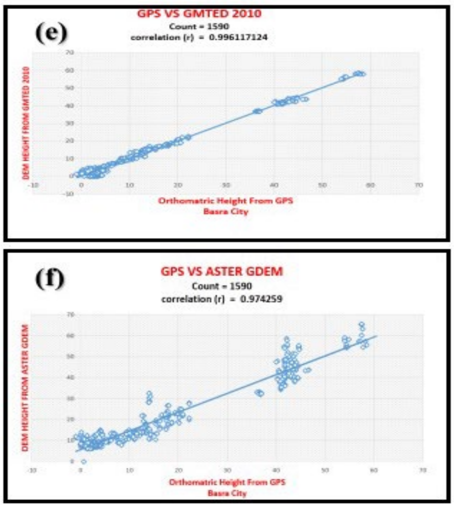


Figure 9. Scatter graphs illustrating the correlation coefficient between (a) SRTM 30m, (b) ALOS World 3D-30M, (c) NASA DEM, (d) SRTM 90M, (e) GMTED2010, and (f) Aster-GDEM elevation data and GPS data.

Correlation analysis was done between GPS and global DEMs elevation data over Basrah City. Results in the form of a linear regression scatterplot are presented in Figure 9. From coefficient analysis, an early assumption stated that elevation values from the SRTM 30m, SRTM 90m, ALOS World 3D-30, Aster-GDEM, GMTED2010, and NASADEM datasets were positively correlated with GPS observation data. Comparisons of ALOS World 3D-30m with GPS datasets show an r of 0.9973, higher than compared other models. SRTM 30M, SRTM 90M, GMTED2010, NASADEM and Aster-GDEM showed coefficient values of 0.9902, 0.9942, 0.9961, 0.9934 and 0.9742, respectively See Table 1. Error distribution was visualised using a histogram, plotting the number of mean errors (frequency) within an elevation difference. Figure 10 depicts a histogram that indicates error distribution normality for the ground truth observations from GPS compared with the elevation values from global DEMs. In order to compare the error distribution normality, the curve of the error distribution (Gaussian bell curve) obtained from the normal estimation of standard deviation and mean error was superimposed onto the histogram. The errors of SRTM 30m, SRTM 90m, ALOS World 3D-30, GMTED2010, and NASADEM delineate a similar frequency distribution. Error for SRTM 30m, SRTM 90m, and GMTED2010 are more concentrated on the median value than Aster-GDEM. Aster-GDEM shows a positive mean error value of 5.041 m. The minimum and maximum values of ALOS DEM 30M are between -4.2195m and 3.2127m, respectively. From this basic statistical analysis, the elevation value of ASTER GDEM shows the lowest and the highest value of -6.6197m and 18.4461m, respectively.

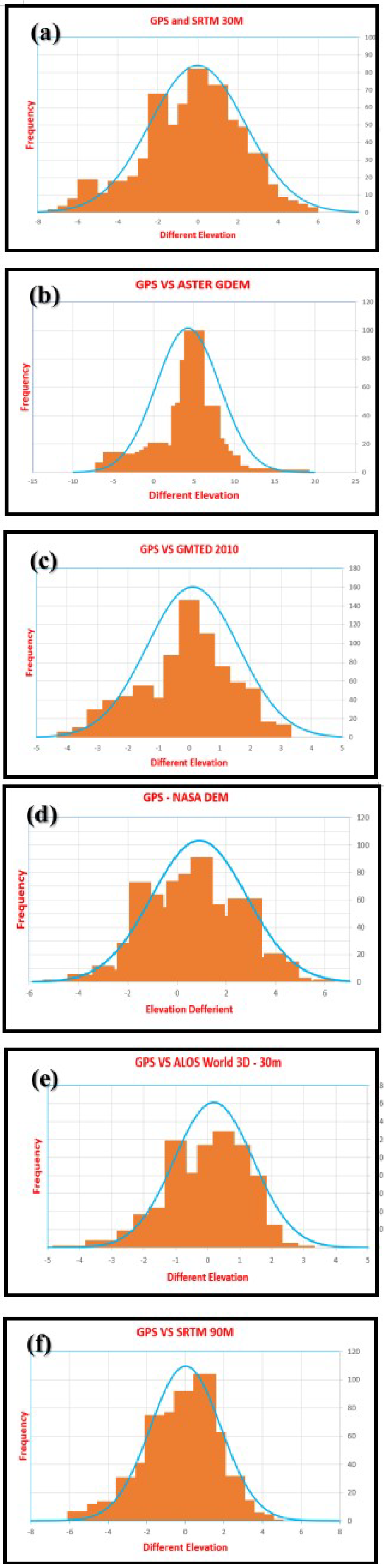


Figure 10. Histogram analysis of elevation difference between global DEMs from (a) SRTM 30m, (b) Aster-GDEM, (c) GMTED2010, (d) NASA DEM, (e) ALOS World 3D-30M, and (f) SRTM 90M datasets and GPS data.

Table 1. Summary of statistical analysis of the validation of elevation values for the selected global DEMs.

DEM	Min	Max	ME	STD	RMSE	Correlation (r)
SRTM 30 M	-6.6131	5.9135	1.879	2.379	2.380	0.990187
SRTM 90 M	-5.3205	5.1199	1.448	1.821	1.822	0.994212
ASTER GDEM	-6.6197	18.4461	5.041	3.394	5.793	0.974259
ALOS DEM 30M	-4.2195	3.2127	1.03	1.235	1.2497	0.997326
GMTED2010 DEM	-3.7803	3.4636	1.201	1.494	1.499	0.996177
NASA DEM	-5.6445	7.2288	1.715	1.950	2.135	0.993466

5. CONCLUSION

This research provides an accurate statistical evaluation to determine the error inherent in the free DEMs and helps decision makers and researchers develop and analyse data. This study examined six free global DEMs (SRTM 30m, SRTM 90m, ALOS World 3D-30, Aster-GDEM, GMTED2010, and NASADEM) as reference elevation data for GPS points. After removing outliers and utilising GPS elevations as reference data, the statistical computation for vertical accuracy shows that ALOS World 3D-30m has the highest vertical accuracy among the other models, with an RMSE of 1.2497m. However, the RMSE between ground truth elevations and GMTED 2010, SRTM 90, NASADEM, and SRTM 30 m still yielded a high RMSE of 1.499m, 1.822m, 2.135m and 2.380m, respectively. In contrast, the data of the ASTER DEM was far away compared to the other models with RMSE 5.793m.

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