

Accuracy Assessment of Alos W3d30, Aster Gdem and Srtm30 Dem: A Case Study of Nigeria, West Africa

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Abstract

Digital Elevation Models (DEMs) depict the configuration of the earth surface and are being applied in many areas in earth and environmental sciences. In this study, the accuracy of the Advanced Land Observing Satellite World 3D Digital Surface Model version 2.1 (ALOS W3D30), the Shuttle Radar Topography Mission Digital Elevation Model version 3.0 (SRTM30) and the Advanced Space borne Thermal Emission and Reflection Radiometer Global DEM version 2.0 (ASTER GDEM2) was statistically assessed using high accuracy GPS survey data. Root-Mean-Square errors of ~5.40 m, ~7.47 m and ~20.03 m were obtained for ALOS W3D30, SRTM30 and ASTER GDEM2 respectively. In further analyses, we discovered that ALOS W3D30 and SRTM30 were much more accurate in regions where the height intervals were within 201 m - 400 m and >801 m. ALOS W3D30 proved to be the most accurate DEM that best represents the topography of the earth's surface and could be used for some earth and environmental applications in Nigeria. We recommend that this study should serve as a guide in the use of any of these DEMs for earth and environmental applications in Nigeria.

Keywords

ALOS W3D30, ASTER GDEM2, SRTM30, Nigeria, DEMs, Accuracy Assessment, Root-Mean-Square Error

1. Introduction

Digital Elevation Models (three-dimensional representation of the earth surface) are chief sources of height information which are greatly applied in many disciplines. Many areas where DEMs are applied include: flood inundation modeling

[1]; vegetation mapping [2] [3]; mapping of Coral Reef Environments [4]; development of Geopotential Global Models [5]; evaluation of glacier volume change [6]; navigation systems for commercial aviation [7]; climatic modeling [8]; archeology [9]; glacier surface change [10]; hydrological analysis and simulations [11]; soil science and geology [12]; Catchment Geomorphology and Hydrology [13]; and monitoring coastal erosions and sedimentations [14]. In another study, the author further categorized the various areas where global or near global DEMs can be applied [15].

It is true that DEMs have become very useful sources of data for a range of applications in Earth and environmental sciences [16] but despite their usefulness, there are many sources of errors inherent in them [17]. Owing to this fact, and as a result of recent improvement and release of newer versions of the Advanced Land Observing Satellite World 3D Digital Surface Model version 2.1 (ALOS W3D30); the Shuttle Radar Topography Mission Digital Elevation Model version 3.0 (SRTM30) and the Advanced Spaceborne Thermal Emission and Reflection Radiometer Global DEM version 2.0 (ASTER GDEM2), it is very important to assess and compare the quality of these data in order to see how well the DEMs fit the locally available or acquired data. This will help in determining the size of their errors within an area of application.

Several researchers [15] [17]-[24] from different regions of the world assessed the accuracy or fitness of these DEMs with respect to their locally available or acquired data and reported the most accurate DEM in their region. **Table 1** presents the results obtained by these authors from different countries of the world. Although ALOS W3D30 is reported as the most accurate DEM in almost all the studies, there is need to determine its actual level of accuracy per study area since the studies show varying levels of accuracy. This is because the accuracy of DEMs depends on region of study, nature of environment, methods of algorithm development, input data, data processing and the resolution of the sensor. For example from **Table 1**, the RMSE of ALOS W3D30 in Philippines, Cameron and Russia is 5.68 m, 13.06 m and 7.87 m respectively.

Presently, there is no readily available topographic map that can easily provide topographic information for various scientific applications in Nigeria and it is a well known fact that terrestrial acquisition of geospatial data is more laborious, time-consuming and very expensive than doing same remotely. Although several studies have been carried out on the accuracy assessment of DEMs in different parts of the world, yet there is no comprehensive study on the vertical accuracy of these freely available DEMs over Nigeria. This is despite the fact that these DEMs are being used as chief sources of topographic information for numerous applications in earth and environmental sciences. This study, therefore, is aimed at assessing the accuracy of these DEMs over Nigeria by using terrestrially acquired GPS (Global Positioning System) survey data since it provides an independent way of assessing the quality of these three DEMs over Nigeria. This validation will also serve as a feedback to the research groups and/or gov-

ernment agencies that developed these DEMs and it is intended to complement all the other studies that have been carried out in other countries to assess their quality.

2. Materials and Method

2.1. Data Sets

The data sets used in this study are: sixty five (65) GPS points, ALOS W3D30, SRTM30 and ASTER GDEM2. The sixty five (65) GPS points are geodetic coordinates which form part of Nigerian geodetic network. The ellipsoidal heights range from 22.84 m to 1793.41 m. The Root-Mean-Square Errors (RMSE) of the ellipsoidal heights at the reference epoch, (01. JAN.2012), range from 0.00101 m to 0.0244 m for the sixty five (65) GPS points. These GPS points were obtained from the Office of Surveyor General of the Federation (OSGoF) in Nigeria. **Figure 1** shows the distribution of the GPS points over Nigeria.

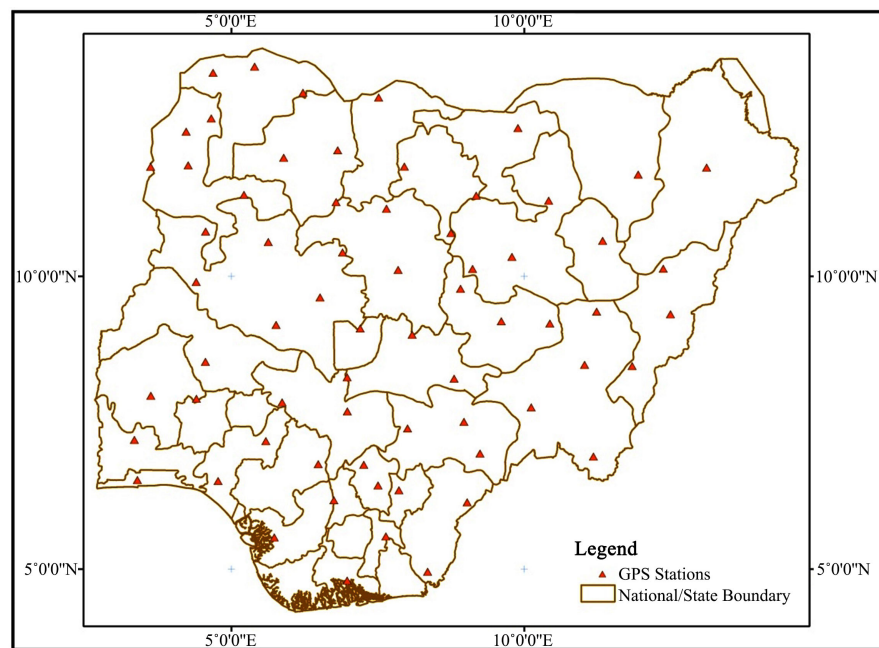
We downloaded related portions of the ALOS W3D30 DSM [25], SRTM30 DEM and ASTER GDEM2 [26] over Nigeria. The Raster values (heights) of these DEMs were extracted to the coordinates of the GPS points. These heights are referred to as heights obtained from each of the DEMs. **Table 2** gives a summary of the characteristics of the DEMs used.

Table 1. Results obtained from other regions.

COUNTRY	Authors	STD	RMSE	Sample_Points
Croatia	[17]		SRTM = 3.8 m ASTER = 7.1 m	7725
Philippines	[18]		SRTM = 8.28 m ASTER = 11.98 m ALOS = 5.68 m	274
Ca meron	[15]		SRTM = 13.25 m ASTER = 18.87 m ALOS = 13.06 m	555
Russia	[22]		SRTM = 17.91 m ASTER = 9.1 m ALOS = 7.87 m	69
Argentina	[20]	ASTER = 9.48 m ALOS = 2.81 m		307,509
Egypt	[23]	SRTM = 2.6 m ASTER = 5.7 m ALOS = 2.4 m		416
Saudi Arabia	[23] [24]	SRTM = 6.8 m ASTER = 6.9 m ALOS = 6.8 m	SRTM = 7.92 m ASTER = 7.45 m	137; 50

Table 2. Summary of the DEMs used.

MODEL	ALOS W3D30	ASTER GDEM2	SRTM30
COVERAGE	82N-82S, 180E-180W	83N-83S, 180E-180W	60N-56S, 180E-180W
RESOLUTION	1"	1"	1"
HORIZONTAL DATUM	GRS 80	WGS84	WGS84
VERTICAL DATUM	EGM96	EGM96	EGM96
VERSION	2.1	2.0	3.0
YEAR OF RELEASE	2017	2011	2015
VERTICAL ACCURACY	RMSE, 5 m	RMSE, 17 m	RMSE, 16 m
IMAGING SYSTEM	Optical	Optical	SAR C-band
SOURCE	[25] [27] [28]	[26] [29]	[26] [30]
WEBSITE	http://www.eorc.jaxa.jp/ALOS/en/aw3d30	http://earthexplorer.usgs.gov	http://earthexplorer.usgs.gov

**Figure 1.** Distribution of GPS points over Nigeria.

2.2. Methods of Accuracy Assessment

As presented in **Table 2**, heights obtained from these three DEMs are vertically referenced to the Earth Gravitational Model 1996 (EGM96) and this led to the transformation of ellipsoidal heights using geoid undulations computed from EGM96 [31]. Mathematically, Equation (2) shows the relationship between ellipsoidal height and EGM96 derived height:

$$h^{\text{GPS}} - N^{\text{EGM96}} = H^{\text{Ortho}} \quad (1)$$

where: h^{GPS} = Ellipsoidal height ,

N^{EGM96} = Geoid undulation derived from EGM96, H^{Ortho} = height derived from EGM96.

The Mean error (Equation (2)), standard deviation error (Equation (3)),

Root-Mean-Square Error (Equation (4)), and correlation coefficient (Equation (5)) are the statistical tools that were used in assessing the vertical accuracy of the heights obtained from these three DEMs as adopted by other researchers [32] [33] [34] [35]. The differences in heights obtained from each of the DEMs and GPS points are referred to as “errors” on the ground that the terrestrially acquired GPS points are of higher accuracy.

$$\text{ME (Mean Error)} = \frac{\sum_{i=1}^N (E)}{N} \quad (2)$$

where; $E = \text{Error} = H^{\text{GPS}} - H^{\text{DEM}}$, H^{GPS} = EGM96-derived heights from the GPS survey data, H^{DEM} = heights obtained from each of the DEMs, N = number of test points.

$$\text{STDE (Standard Deviation Error)} = \sqrt{\frac{\sum_{i=1}^N (E - \text{ME})^2}{N - 1}} \quad (3)$$

$$\text{RMSE (Root-Mean-Square Error)} = \sqrt{\frac{\sum_{i=1}^N (E^2)}{N}} \quad (4)$$

The closer the value of the RMSE to zero, the more accurate are the heights obtained from DEMs while the farther the value of the RMSE from zero, the less accurate are the heights obtained from DEMs.

$$\text{Correl}(X, Y) = \frac{\sum (x - \bar{x})(y - \bar{y})}{\sqrt{\sum (x - \bar{x})^2 \sum (y - \bar{y})^2}} \quad (5)$$

where; X = EGM96-derived heights from the GPS survey data, Correl = Correlation Coefficient, Y = heights obtained from each of the DEMs, \bar{x} and \bar{y} are sample means.

The closer the value of correlation coefficient to ± 1 , the more the level of agreement of the heights obtained from each of the DEMs are to EGM96-derived heights from the GPS survey data and vice versa.

Furthermore, the Linear Errors (LE) of each of the three DEMs were calculated at 90% (Equation (6)), 95% (Equation (7)) and 99.73% (Equation (8)) confidence levels on the assumption that the vertical errors are normally distributed and that the linear errors are directly proportional to the standard deviation errors [35] [36].

$$\text{LE@90\%} = 1.6449 \times \text{STDE} \quad (6)$$

$$\text{LE@95\%} = 1.9000 \times \text{STDE} \quad (7)$$

$$\text{LE@99.73\%} = 3.0000 \times \text{STDE} \quad (8)$$

The sixty five (65) GPS points and each of the corresponding heights obtained from the three DEMs were classified into 200 m height intervals for a more intensive performance evaluation of the DEMs. The height intervals are 0 - 200 m, 201 - 400 m, 401 - 600 m, 601 - 800 m and >800 m. The statistical results obtained from each of these classes were used to assess the effect of the undulating terrain on the vertical accuracy of each of the three DEMs.

3. Results and Discussions

The EGM96-derived geoid undulations at the sixty five (65) GPS stations are shown in **Figure 2**. These were the values subtracted from the ellipsoidal heights at each of the sixty five (65) GPS points to obtain the heights referred to as EGM96-derived heights.

The EGM96-derived heights from the GPS survey data and the heights obtained from each of the DEMs are shown in **Figure 3**.

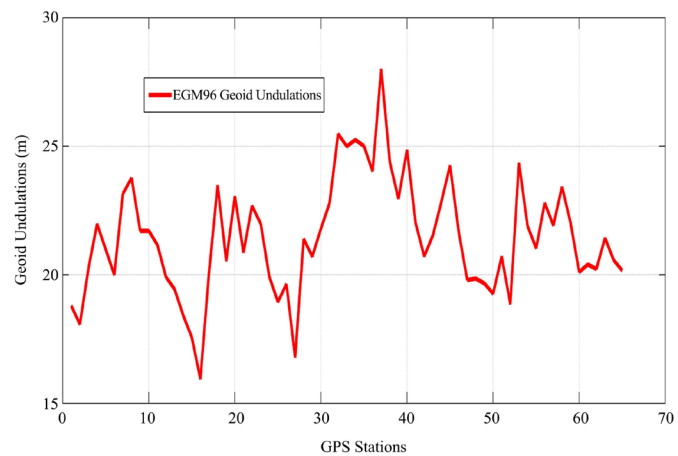
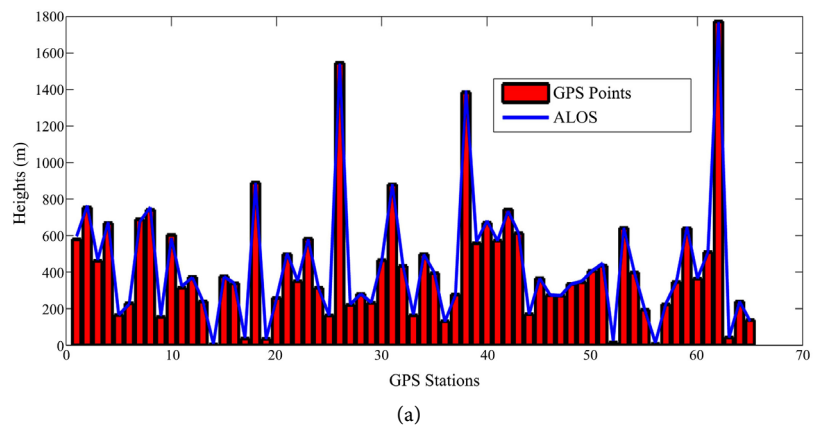
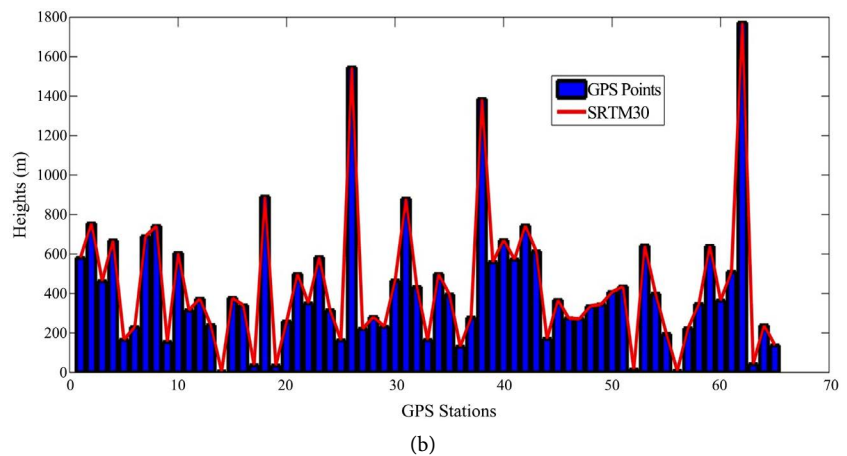


Figure 2. Geoid undulations.



(a)



(b)

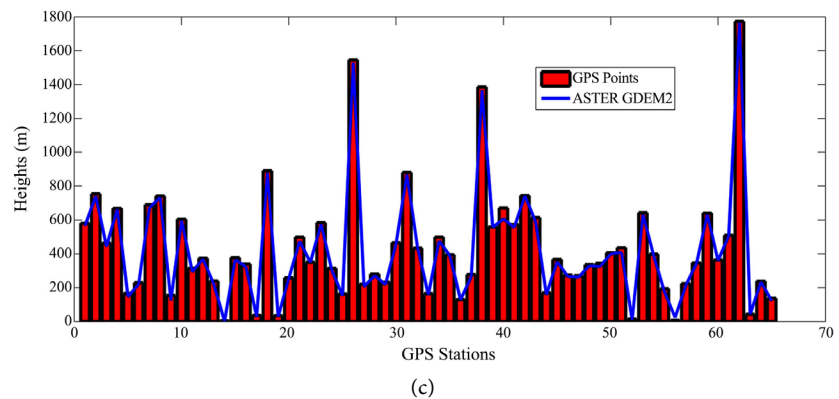


Figure 3. (a-c): Heights (a) GPS versus ALOS W3D30 (b) GPS versus SRTM30 (c) GPS versus ASTER GDEM2.

A closer look at **Figure 3** reveals that there is a sharp difference at stations 42, 1 and 40 for ALOS W3D30, SRTM30 and ASTER GDEM2 respectively. These are the stations that have the maximum differences in heights between each DEM and the GPS points. The differences (errors) obtained in the heights between each of the DEMs and the sixty five (65) GPS points are shown in **Figure 4**. The statistical results of these errors are shown in **Table 3**. The coefficients of correlation between the EGM96-derived heights from the GPS survey data and that of ALOS W3D30, SRTM30 and ASTER GDEM2 are 0.9999, 0.9998 and 0.9993 respectively meaning that each of the DEMs are highly correlated to the EGM96-derived heights of the GPS points but ALOS W3D30 has the highest level of agreement.

From the results shown in **Table 3**, it can be inferred that ALOS W3D30 is more accurate than STRM30 and ASTER GDEM2 in Nigeria. Overall, the RMSE obtained from ALOS W3D30 is 40 cm different from the specified 5 m [28]. It is noteworthy that SRTM30 performed far better than the specified vertical accuracy of 16 m.

Furthermore, the heights were classified into 200 m height intervals in order to detect the height interval that better fits the locally observed GPS survey data. The corresponding statistical results of the errors within each height interval are presented in **Figure 5** while the linear errors are listed in **Table 4**.

At all the height intervals, ALOS W3D30 performed better in accuracy, followed closely by SRTM30 and lagging far behind is the ASTER GDEM2. As confirmed by other studies [15] [18] [22] [23] ALOS W3D30 is better in accuracy than the other two DEMs evaluated in Nigeria. This means that ALOS W3D30 best represents the topography of the earth's surface within the study area especially in regions where the height are >801 m.

There is a steady increase in the accuracy of ALOS W3D30 and SRTM30 at height intervals of 0 - 200 m; 201 - 400 m and a sharp increase at 601 - 800 m and >801 m. This shows that regions or states, whose heights are within 201 - 400 m, have better terrain modeling by ALOS W3D30 than regions within 0 - 200 m; 401 - 600 m and 601 - 800 m. Based on all the statistical values obtained

at 601 - 800 m height interval, ALOS W3D30 and ASTER GDEM2 performed poorly with ALOS W3D30 having more than two times the expected accuracy while ASTER GDEM had almost twice its expected accuracy.

Although five (5) GPS points fell within the height interval of >801 m, ALOS W3D30 performed two and half times better than its expected accuracy, SRTM30 performed more than three times better than its expected accuracy while ASTRE GDEM2 stays within its expected accuracy. It is evident and as corroborated by other authors [15] [18] [22] [23] that vertical accuracy of global DEMs is greatly affected by the slope of the terrain. The linear errors (Table 4) computed from each height intervals confirmed the superiority of ALOS W3D30 to the other two DEMs evaluated in this study and this clearly shows that ALOS W3D30 can be used alone or in combination with terrestrial data for some earth and environmental applications.

Table 3. Statistical results of the errors.

DEMs	MIN (m)	MAX (m)	ME (m)	STDE (m)	RMSE (m)	LE@90% (m)	LE@95% (m)	LE@99.73% (m)
SRTM30	-5.05	24.84	3.96	6.38	7.47	10.49	12.12	19.14
ASTER GDEM2	-5.05	76.95	15.45	12.85	20.03	21.14	24.42	38.55
ALOS W3D30	-3.45	20.29	2.88	4.60	5.40	7.57	8.74	13.80

Table 4. Linear errors of the DEMs based on height intervals.

Height Intervals (m)	Count	Confidence Levels								
		LE@90% (m)			LE@95% (m)			LE@99.73% (m)		
		ALOS	ASTER	SRTM	ALOS	ASTER	SRTM	ALOS	ASTER	SRTM
0 - 200	14	5.67	15.40	9.21	6.56	17.78	10.64	10.35	28.08	16.80
201 - 400	22	4.38	13.80	6.79	5.05	15.94	7.85	7.98	25.17	12.39
401 - 600	13	5.72	21.53	10.79	6.61	24.87	12.46	10.44	39.27	19.68
601 - 800	11	10.79	30.46	11.55	12.46	35.19	13.34	19.68	55.56	21.06
>801	5	1.86	13.85	7.42	2.15	16.00	8.57	3.39	25.26	13.53

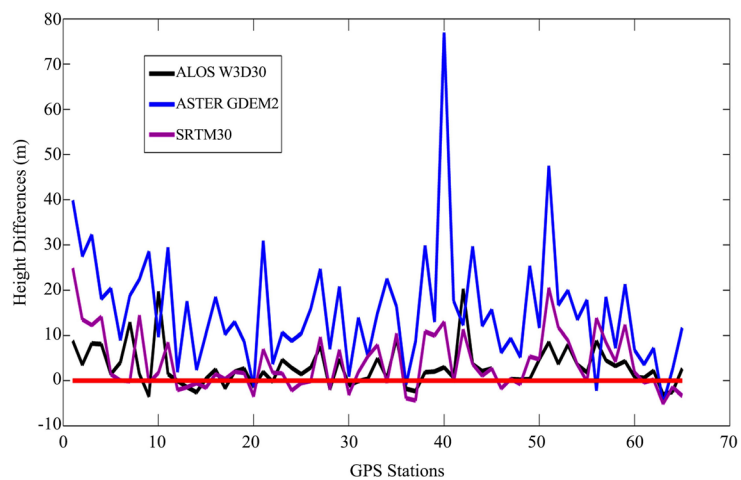
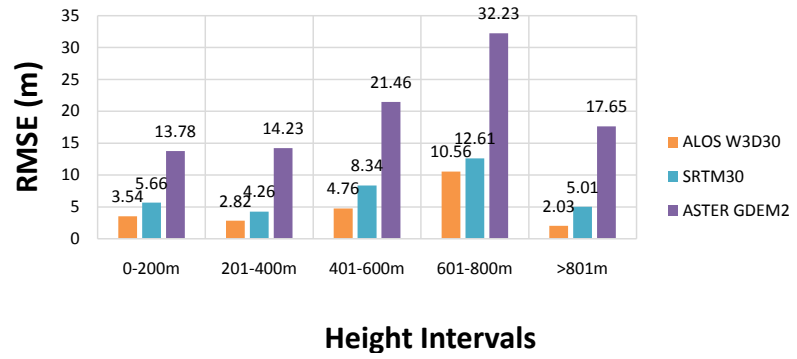
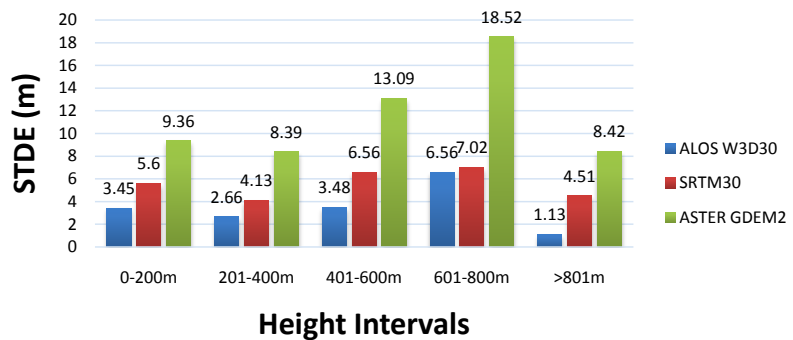


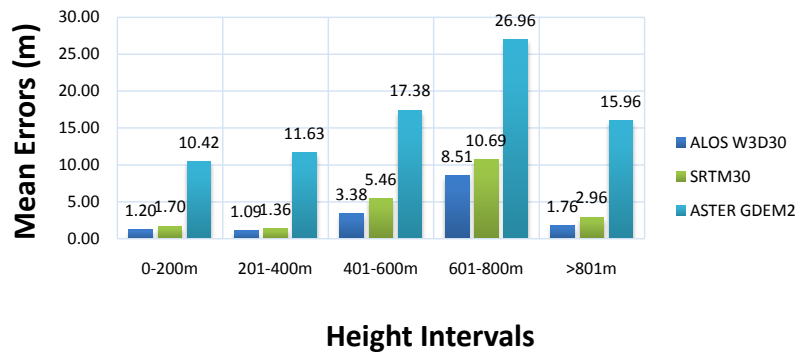
Figure 4. Errors in heights obtained from each of the DEMs.



(a)



(b)



(c)

Figure 5. (a-c) Statistical results of the height intervals (a) Root-Mean-Square Errors (b) Standard Deviation Errors (c) Mean Errors.

4. Conclusions

This study which aimed at assessing the quality of global or near global DEMs applied several statistical tools to determine the accuracy of heights obtained from ALOS W3D30, ASTER GDEM2 and SRTM30 using high accuracy GPS survey data over Nigeria. In all the analyses, ALOS W3D30 proved to be the most accurate DEM that can relatively depict the topography of the earth’s surface in Nigeria. We discovered that regions or states, within the study area, where the height intervals are >801 m, have improved statistical results than others while regions within 601 m - 800 m height interval have worse statistical results when using ALOS W3D30 in Nigeria.

Accuracy assessment of DEMs is of utmost importance in earth and environmental sciences for it shows how the DEMs best approximate the dynamic earth surface. Generally, the accuracy of DEMs depends on region of study, nature of environment, methods of algorithm development, input data, data processing and the resolution of the sensor. This explains the varying levels of accuracy recorded by each of the DEMs. We, therefore, recommend that this study should serve as a guide in the use of any of these DEMs for earth and environmental applications in Nigeria.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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