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Assessing Vertical Accuracy of SRTM Ver 4.1 and ASTER GDEM Ver 2 Using Differential GPS Measurements – Case Study in Ondo State Nigeria

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Abstract— Digital Elevation Model (DEM) vertical accuracy is usually achieved by its comparison with elevation of well-defined Global Positioning System (GPS) ground control points. This accuracy varies spatially because of the various sources, from which they were derived, thus warrants the need for specific testing of their level of compliances for geomatic applications. This paper therefore investigates the quality of vertical accuracy of two DEMs covering Ondo state Nigeria. The DEMs which are currently dataset of choice from; Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) and Shuttle Radar Topographic Mission (SRTM), were assessed based on two independent GPS ground control points from two regions of the state. From the statistical analysis carried out, it was observed that in the mountainous region A, the Root Mean Squared Error (RMSE) was quite small for SRTM DEM; ±7.75 compared to ASTER DEM; ±12.72, while in the less mountainous region B, it was ±14.48 for SRTM and ±13.25 for ASTER. A 3D model of both DEMs compared with the referenced GPS data, revealed that ASTER DEM projects terrain features better than SRTM DEM. The results from both assessments revealed their level of suitability for geomatics application for the concerned region of the State.

Index Terms— Digital Elevation Model (DEM), Referenced GPS, Vertical Accuracy, SRTM, ASTER

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1 INTRODUCTION

Digital Elevation Models (DEM) are important data source for geomatic applications such as geoid modeling, digital generation of topographic cartography parameter, hydrological studies, geomorphology, orthorectification of aerial imagery and many more. They can be developed from ground survey, airborne photogrammetric imagery, airborne laser scanning (LIDAR), radar altimetry and interferometric synthetic aperture radar (InSAR). Base on the different methods from which they are sourced, there is a higher tendency of variability in their data quality [8]. However, the use of high quality DEM for geodetic surveys can not be over emphasized. This is because high quality DEM can reduce the difficulty of remotely sensed image classification while increasing the classification accuracy [9]. It is worth mentioning that DEM serves as a main source of surface height information [26] for geospatial professionals. Therefore high precision and fine resolution global covered DEM can therefore be considered as good data for land cover mapping project.

For over a decade, considerable progress in DEM has been made with the release of SRTM (Shuttle Radar Topographic Mission), and ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer). The DEM data from these two space missions considerably improve the knowledge of the Earth's surface in regions with poor geospatial infrastructure like Ondo State Nigeria.

The ASTER Global Digital Elevation Model (GDEM) covers land surfaces between 83°N and 83°S. The data which are in geographic decimal coordinates (latitude and longitude) are posted on a 1 arc-second (approximately 30-m at the equator) grid, distributed as 1° x 1° tiles and referenced to the World Geodetic System (WGS84)/1996 Earth Gravitational Model (EGM96) geoid. It has an overall accuracy of around 17m at the 95% confidence level, evaluated by the ASTER GDEM validation team [1]. Its preferable choice for this research is because of the additional scenes that has been added to reduce artifacts, higher horizontal resolution using a smaller correlation kernel (5 x 5 versus 9 x 9 used for GDEM 1.0), and an improved water mask. Also, a 5-m overall bias observed in GDEM 1.0 was removed in this version 2.

The SRTM version 4.1 from the USGS/NASA SRTM data covers up to 60 °N to_56 °S of the earth land surfaces. It is provided to promote the use of geospatial science and applications for sustainable development and resource conservation in the developing world. The data was made available at 1-arc second resolution (approximately 30m at the equator) for the United States, but for the rest of the world the 1-arc second product is degraded to 3-arc seconds (approximately 90m at the equator) DEM. The DEM has a vertical error reported to be less than 16m and it is available in 5 degree x 5 degree tiles, in Geographic decimal degrees (Latitude and Longitude) projection, with WGS84 horizontal datum and EGM96 vertical datum. This SRTM version 4.1 was chosen for this research over the previous version because it has been updated, and then released after using sophisticated interpolation and hole-filling algorithms which make use of ancillary data sources where they are available[23].

Moreover several publications on the accuracy of SRTM 90m resolution elevation data, affirm that its absolute vertical accuracy is in the order of ± 16m [11],[13],[14].These accuracies value have been extensively tested in different regions under different terrain characteristics by many researchers [7],[2],[6]. Some research work has been conducted in the area, but Ondo State Nigeria is yet to fully utilize the potential of these global DEMs in their survey and mapping activities. Scientific findings conclude that the values obtained vary from the specified range, and therefore advocating for regional evaluation of these vertical accuracy is of essence. This will further aid in revealing which of these DEMs is best suitable for substitute of the old existing 1:50000 topographic maps of the concerned region, since DEM has hitherto be known as a qualitative model of topographic surface in digital form, hence the need for this research in the study area.

2.0 Study Area

The study area lies between Latitudes 4^0 15′ E and 6^0 45′ E and Longitudes 6^0 45′ N and 8^0 30′ N. It is a state in the South-Western part of Nigeria, with a total area of: 14788.723 sq kilometers which covers low-level, midlevel and high-altitude terrain with elevation ranging from 288m to 414m in region **A** and 9m to 118m in region **B** as shown in figure1 below. In the state, there are several mountains and hills which present exposed rock surfaces at the north central and up towards the north east, while the southern part is closed to the Atlantic Ocean. The mean elevation for region **A** and **B** are 61m and 367m above mean sea level.

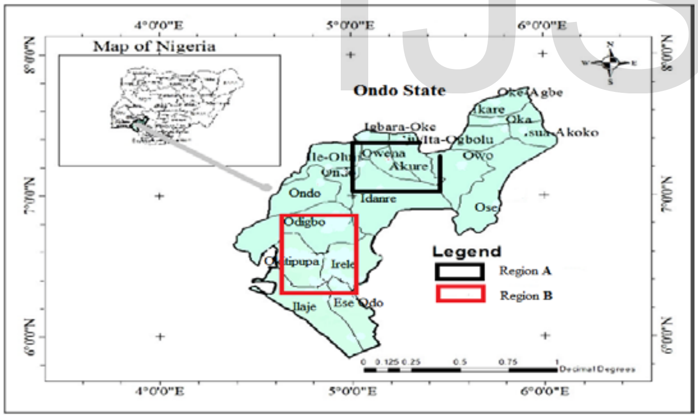


Figure 1. Map of Ondo State showing the two regions

3.0 Datasets

The ASTER DEM in Figure 2 corresponds to Ondo state area. It was downloaded from https://earthdata.nasa.gov/user-mgmt/, while the SRTM DEM in figure 3 which also corresponds to the same area was downloaded from http://srtm.csi.cgiar.org. A total number of six scene of ASTER and two scenes of SRTM DEM were used in this research. A total number of 119 and 118 differential GPS points for region A and B, were obtained from the Survey Department, Ministry of Lands, Housing and Environment, Akure, Ondo State, Nigeria. These dataset points were used to judge the accuracy of the DEM for both regions. Figure 4 and 5 show the GPS ground control point's distribution of the two regions.

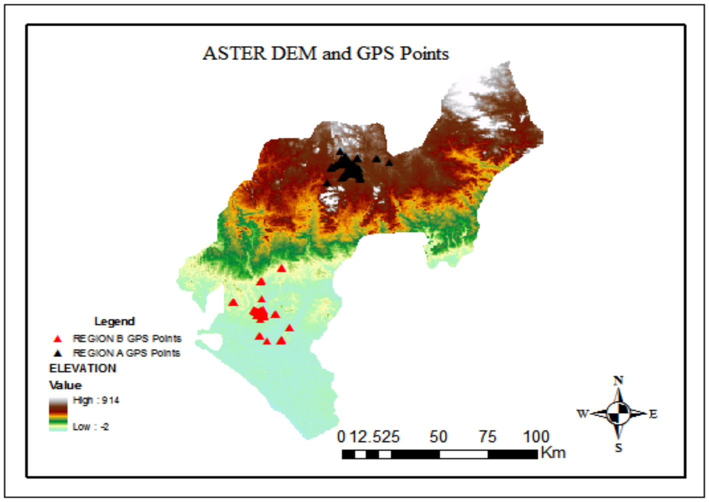


Figure 2: Map showing ASTER DEM and GPS Points

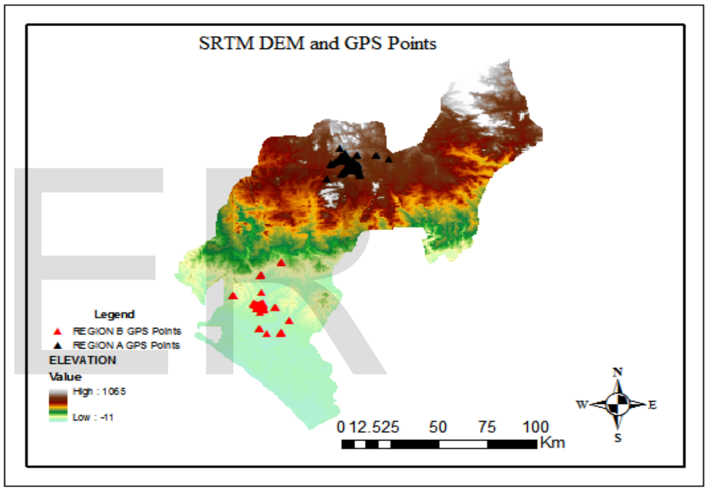


Figure 3: Map showing SRTM DEM and GPS Points

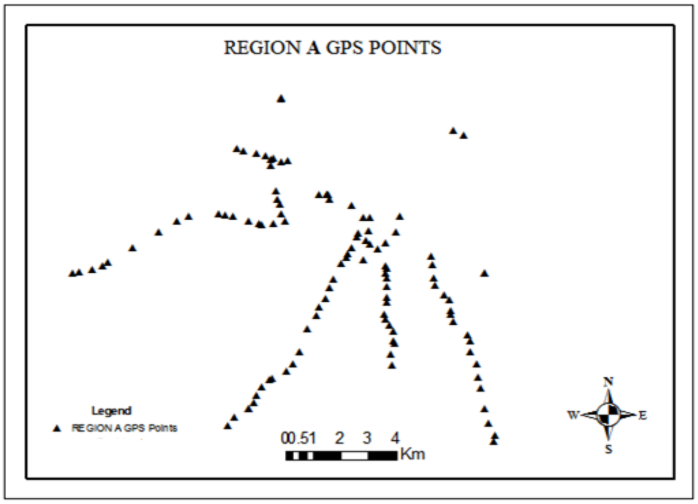


Figure 4: Map showing region A GPS Points

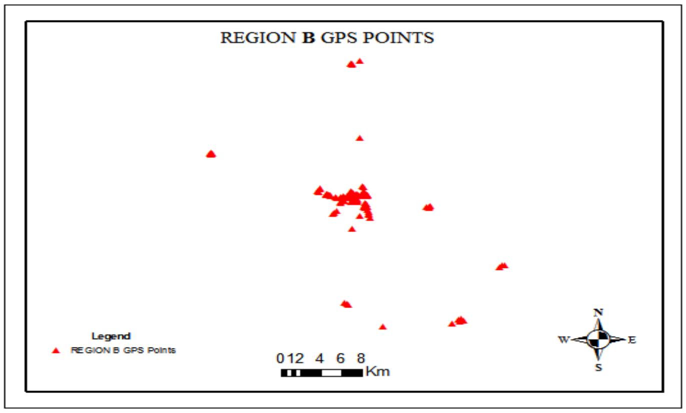


Figure 5: Map showing region B GPS Points

4.0 Materials

The processing and visualization of the data was carried out with six software which includes; Matlab for coordinate conversion and transformation, and then profile analysis display, ArcGIS 10 for mosaicing and processing of the DEM, and then checking the GPS points distribution, Surfer for 3D modeling, SPSS/Microsoft excel for the statistical analysis and NIMA EGM96 calculator ver1.0 was used to obtain GPS geoidal height since both DEM height are referenced to WGS84/EGM96 geoid.

5.0 Processing Methodology

The DEM scenes of ASTER and SRTM were independently mosaicked, and then Ondo state shapefile was overlaid on the mosaic DEM, followed by a clip operation which was carried out to extract the relevant portion of the DEM that falls within the boundary of Ondo state. Further processing was done to clearly reveal the spatial pattern of the topography. All these were done using ArcGIS 10.The transformation of all the data sets into a common system was inevitable to guarantee the desired result; the GPS data in their projected Earth Centered Earth Fixed (ECEF) form were transformed into Latitude and Longitude WGS84 system using Bowring inverse equation cited in Gerdan and Deakin, 1999. A computer programming algorithm was written in matlab to facilitate the transformation before using the NIMA EGM96 calculator to compute each point geoidal height since both DEM heights are referenced to WGS84/EGM96 geoid.

6.0 Determining the Absolute Vertical Accuracy of the DEMs

In mapping application, vertical accuracy is computed by vertical Root-Mean-Squared Error (RMSE) (also called the root mean square deviation, RMSD). This mathematical relation has been widely adopted since in the late 1970s, when the American Society for Photogrammetry and Remote Sensing's (ASPRS) Specifications and Standards Committee, cited in Greenwalt and Schultz (1962) and Greenwalt and Schultz (1968) in establishing RMSE as the pivotal map accuracy parameter [22]. It measures the difference between the values of the DEM elevations and the values of referenced GPS elevations. These individual point differences are also called residuals, and the RMSE serves to aggregate them into a single measure of predictive power;

$$RMSE_V = \sqrt{\sum_i^n (e_{vi})^2 / n} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

$$e_{vi} = v_{ri} - v_{mi} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

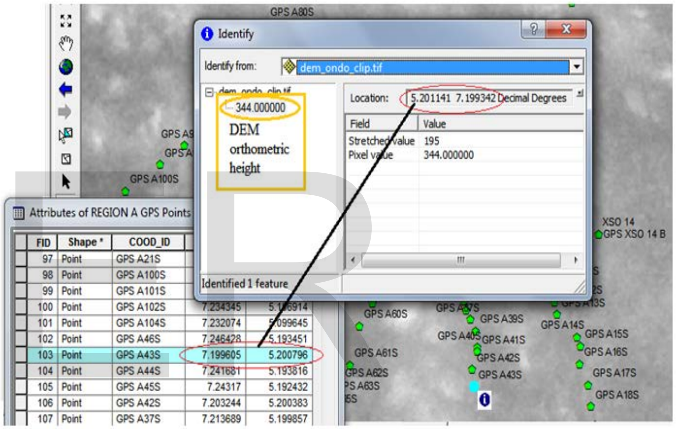
Where;

v_{ri} = The reference GPS elevation at the *i*th point

v_{mi} = The DEM elevation at the *i*th point

n = The number of points [22]

Extracting the DEM height requires overlaying the GPS points on them, and then the height value from the two data at their position of coincidence gives the DEMs orthometric height for computing the accuracy statistic. The identification tool in ArcGIS was used for the DEM height extraction as shown below in figure 6. The extracted heights from the two DEM are orthometric height



Identify from: dem_ondo_clip.tif

dem_ondo_clip.tif
344.000000

Location: 5.201141 7.199342 Decimal Degrees

Field	Value
Stretched value	195
Pixel value	344.000000

Attributes of REGION A GPS Points

FID	Shape *	COOD_ID		
97	Point	GPS A21S		
98	Point	GPS A100S		
99	Point	GPS A101S		
100	Point	GPS A102S	7.234345	[illegible]
101	Point	GPS A104S	7.232074	5.099645
102	Point	GPS A46S	7.246428	5.193451
103	Point	GPS A43S	7.199605	5.200796
104	Point	GPS A44S	7.241681	5.193816
105	Point	GPS A45S	7.24317	5.192432
106	Point	GPS A42S	7.203244	5.200383
107	Point	GPS A37S	7.213689	5.199857

Figure 6: DEM height extraction

The following relationship was used to calculate the DEM ellipsoidal height before comparing with the GPS heights to get their difference:

$$h = H + N \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Where,

h = WGS84 Ellipsoid heig

H = Orthometric or Mean Sea Level height

N = EGM96 Geoid undulation or Geoid separation

In this research context, the position of equation 2 and 3 parameters in computing the RMSE for each of the DEM can be well understood in table 1 below.

Table1: Positions of Equation 2 and 3 Parameters in the Vertical Accuracy Computation

	v_{ri}			v_{mi}	
POINTS ID	GPS **h** (m)	EGM96 GEIOD HEIGHT N(m)	DEM ORTHOMETRIC HEIGHT **H** (m)	DEM ELLIPSOIDAL HEIGHT **h (m)**	GPS **h** (m) - DEM **h** (m)

The DEM geoidal height information was computed using the NIMA EGM96 calculator after imputing the GPS latitude, longitude and geodetic height data, before calculating the DEM ellipsoidal height with equation (3). The derived DEM ellipsoidal height was subtracted from the GPS ellipsoidal height to compute the vertical accuracy for both regions. Below is a flow chart of the entire process;

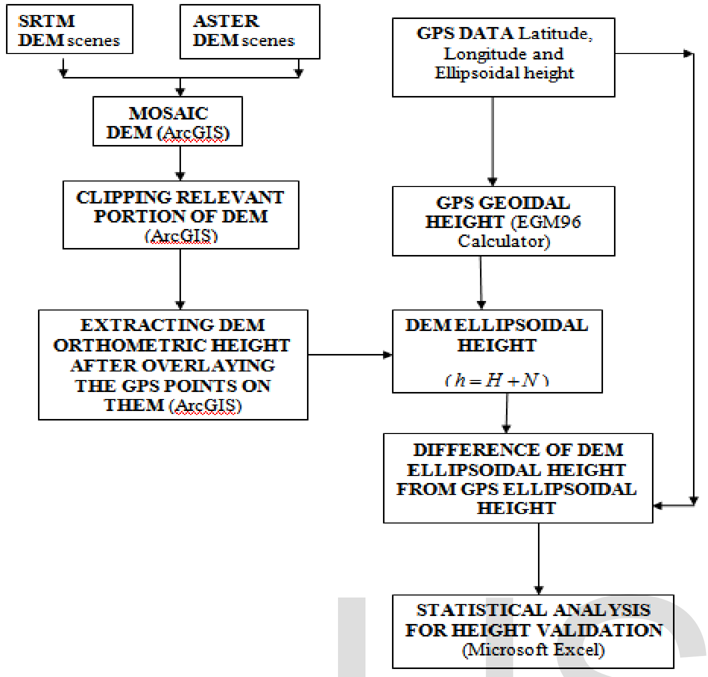


Figure 7: Flow Chart Methodology

The statistical analysis for the entire process of the height validation for both regions is summarized in tables 2 to 5. In statistical computation of positional accuracy, the expected error is usually estimated by the root-mean-square error, or RMSE, while the standard deviation σ is the square root of the population (data) variance which measures how much the variables of a population (data) deviate from the population (data) mean. The standard error σ_{μ} measures how estimates of the population (data) mean deviated from the true mean [22]. The results show that the absolute vertical accuracy of ASTER and SRTM for region A is ±12.72 and ±7.75, while that of region B is ±13.25 and ±14.48.

Table 2: ASTER vs GPS Statistical Analysis for Region A

Region A ASTER vs GPS Statistical Analysis			
Parameter	*ASTER Elevation (m)*	*GPS Elevation (m)*	*Δh (GPS-ASTER)(m)*
Count	119	119	119
Maximum	407.5	413.2	35.26
Minimum	284.36	288.82	-22.15
Mean	355.9	366.04	10.14
S.E.M	1.93	1.93	1.1
Std Dev	19.18	21.11	8.71
			RMSE ±12.72

Table 3: SRTM vs GPS Statistical Analysis for Region A.

Region A SRTM vs GPS Statistical Analysis			
Parameter	*SRTM Elevation (m)*	*GPS Elevation (m)*	*Δh (GPS-SRTM)(m)*
Count	119	119	119
Maximum	420.48	413.2	10.27
Minimum	299.36	288.82	-23.84
Mean	372.99	366.04	-6.95
S.E.M	1.85	1.93	0.32
Std Dev	20.24	21.11	3.44
			RMSE ±7.75

Table 4: ASTER vs GPS Statistical Analysis for Region B.

Region B ASTER vs GPS Statistical Analysis			
Parameter	*ASTER Elevation (m)*	*GPS Elevation (m)*	*Δh (GPS-ASTER)(m)*
Count	118	118	118
Maximum	82.2	117.25	42.09
Minimum	28.26	9.27	-38.87
Mean	63.67	60.6	-3.07
S.E.M	1.12	1.86	1.19
Std Dev	12.21	20.24	12.94
			RMSE ±13.25

Table 5: SRTM vs GPS Statistical Analysis for Region B.

Region B SRTM vs GPS Statistical Analysis			
Parameter	*SRTM Elevation (m)*	*GPS Elevation (m)*	*Δh (GPS-SRTM)(m)*
Count	118	118	118
Maximum	104.16	117.25	25.66
Minimum	31.26	9.27	-39.04
Mean	63.23	60.6	-2.63
S.E.M	1.12	1.86	1.32
Std Dev	12.18	20.24	14.3
			RMSE ±14.48

A further analysis to test the relationship of both DEM and the referenced GPS elevation was carried out using linear regression. Figure 8 below show the measure of association through their goodness of fit, R^2 and correlation coefficient (r) values.

REGION A

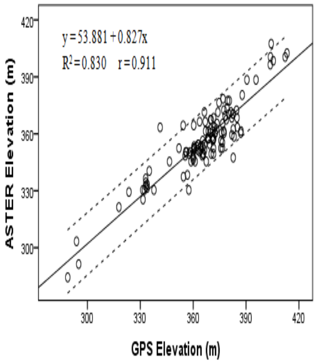


Figure (a) : A graph of Aster Elevation (m) against GPS Elevation (m)

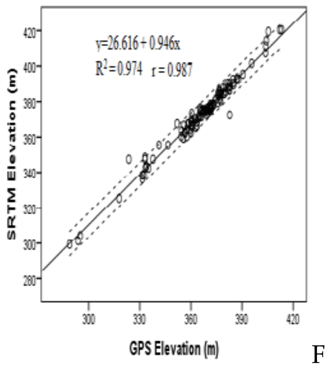


Figure (b) : A graph of SRTM Elevation (m) against GPS Elevation (m)

REGION B

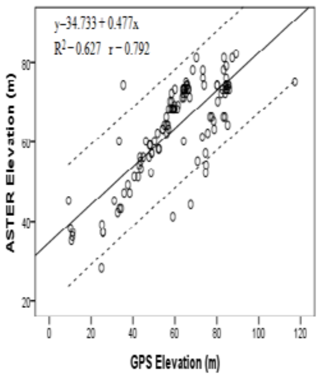


Figure (c) : A graph of Aster Elevation (m) against GPS Elevation (m)

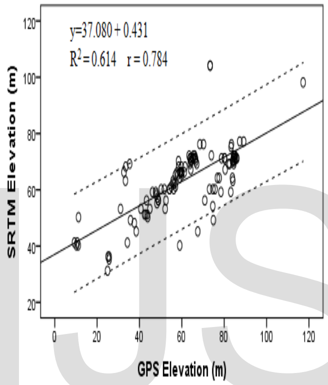


Figure (d) : A graph of SRTM Elevation (m) against GPS Elevation (m)

Figure 8: Scatter Plot depicting DEM elevation as a function of GPS elevation for both regions.

The graphs in figures 8a, 8b, 8c, 8d above reveal a linear and positive slope between both DEMs (Aster and SRTM) and GPS elevation for the two regions. The existence of this positive relationship (slope) between the two variables (DEMs and GPS elevation) points out that both variables are moving in the same direction. Also, the graphs (figure 8 above) also show the 95% confidence limits for the regression analysis revealing the out layers of points that fell outside the 95% prediction region for the regression. The deterministic model (R^2) and the correlation coefficients (r) between the variables were calculated and the results are shown in Table 6 below respectively.

Table 6: R^2 and r Statistic computed values.

REGION A		
SCATTER PLOTS	**R^2**	**r**
Aster Elevation (m) against GPS Elevation (m)	0.8301	0.911
SRTM Elevation (m) against GPS Elevation (m)	0.974	0.987
REGION B		
SCATTER PLOTS	**R^2**	**r**
Aster Elevation (m) against GPS Elevation (m)	0.627	0.792
SRTM Elevation (m) against GPS Elevation (m)	0.614	0.784

The values of R^2 (table 6 above) help to interpret the relationships exiting between the variables (DEMs and GPS elevation) in terms of variations. That is, from table 6 above, Region A and Region B in the graph of ASTER elevation against GPS elevation had 0.8301 and 0.627. These R^2 values indicate that 83.01% and 62.7% of the changes in Aster elevation are explained by the change of GPS elevation. In the case of SRTM elevation against GPS elevation data, 97.4% and 61.4% of the changes in the SRTM elevation and GPS elevation could be explained for Regions A and B respectively. The closer R^2 is to 1, then there is an indication that the data points lie close to the least square line. This can be seen in Figure 8 above. With reference to Table 6 above, it can be seen that the R^2 value for Region A are relatively closer to 1. This means that the linear regression analysis performed to estimate the R^2, comparatively, describe the variation in the data with reliable accuracy for Region A than Region B. The coefficient of correlation (r) further corroborated this high strength of linear dependence between the variables.

In this study, the correlation coefficient (r) was used as a criterion to determine the strength and nature of the linear relationship between the two DEMs (aster and SRTM) and the referenced GPS elevation. The results in table 6 above revealed a very high positive correlation between both DEMs and GPS elevation for regions A and B respectively. Comparatively, it was also noticed that the strength of the relationship for Region A in the linear regression analysis carried out were stronger than that of Region B. This shows that a stronger relationship exist between the DEMs and GPS elevation in Region A than in Region B. Furthermore, this strong correlation is backed up with the observation that vertical accuracy of DEMs are better predicted in mountainous regions compared to less mountainous regions as in the case of Ondo State, Nigeria.

7.0 The Correlation Confirmatory Test

To further confirm the degree of linearity (correlation) between the two DEMs and GPS elevation for both regions, a test of hypotheses (t-test statistic) at 5% significance level was conducted on the correlation coefficients determined.

Testing of Hypothesis: Both DEMs (Aster and SRTM) do not have any correlation with GPS elevation,

Null Hypothesis: $H_0 : \rho = 0$

Alternative Hypothesis: $H_1 : \rho \neq 0$

Significance Level: $\alpha = 0.05$

Test Statistic: $t = r\dfrac{\sqrt{n-2}}{\sqrt{1-r^2}}$

Where;

r = correlation coefficient (refer to table 2 above)

n = number of observations; n= 119 for region A and 118 for region B

Decision Rule: Reject H_0 if $|t| > t_{(\alpha/2, n-2)}$

Conclusion: If the calculated $|t|$ is greater than $t_{(\alpha/2, n-2)}$, reject the null hypothesis and vice versa.

From the student t- distribution tables the following critical values were obtained: $t_{(0.025,117)}$ = 1.9805 and $t_{(0.025,116)}$ = 1.9806.

Table 7: Computed t-test ($|t|$) value for correlation coefficient.

REGION A	
Aster Elevation (m) vs.GPS Elevation (m)	23.90642
SRTM Elevation (m) vs.GPS Elevation (m)	66.20997
REGION B	
Aster Elevation (m) vs.GPS Elevation (m)	13.96689
SRTM Elevation (m) vs.GPS Elevation (m)	13.59099

The calculated $|t|$ values obtained (table 7 above), exceeds the appropriate critical values $t_{(0.025,117)}$ = 1.9805 and $t_{(0.025,116)}$ = 1.9806. Judging from the t-test values, it can be concluded that the data provides convincing evidence that there is a relationship between DEMs (Aster and SRTM) and GPS elevation. These results further confirm that the correlation coefficients values obtained are statistically significant. Hence, $H_0 : \rho = 0$ is rejected and $H_1 : \rho \neq 0$ is accepted.

Figures 9 and 10 represent an elevation profile developed from the various sources of data. Both plots show harmonious trend among the three dataset and also indicate level of DEM profile line relative to the referenced GPS data. A visual inspection from region A reveals that SRTM deviation from the referenced GPS is less compare to ASTER; confirming its vertical accuracy value. It is also clear that SRTM over estimated the referenced GPS while ASTER underestimated it. In region B, there is a striking observation. The two DEM tends to agree more with each other showing the same approximate extent of deviation from the referenced GPS. Both DEM under estimated the referenced GPS to a particular point as shown on figure 10, and from that point to the end of the trend, over estimated the GPS point, and also show the same approximate extent of deviation from the referenced points.

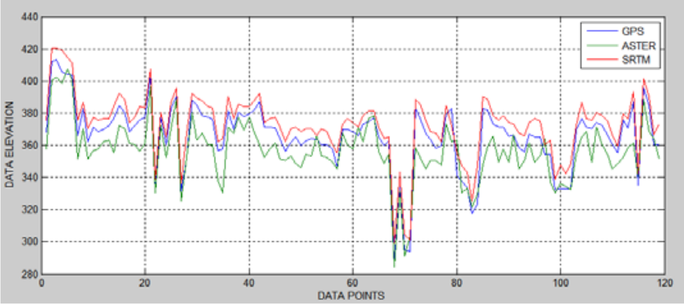


Figure 9: Datasets Elevation Profile for Region A

Figure 10: Datasets Elevation profile for region B

A 3D analysis was also carried out to know how both DEM represents the concerned regions relative to the referenced GPS. Although the three dataset used for the research were not obtained exactly the same period of time. But from clear observation from region A, ASTER reveals features of terrain better than SRTM and even the referenced GPS data, showing its affinity for mountainous region. But in region B, the referenced GPS represents the terrain better compare to both DEM.

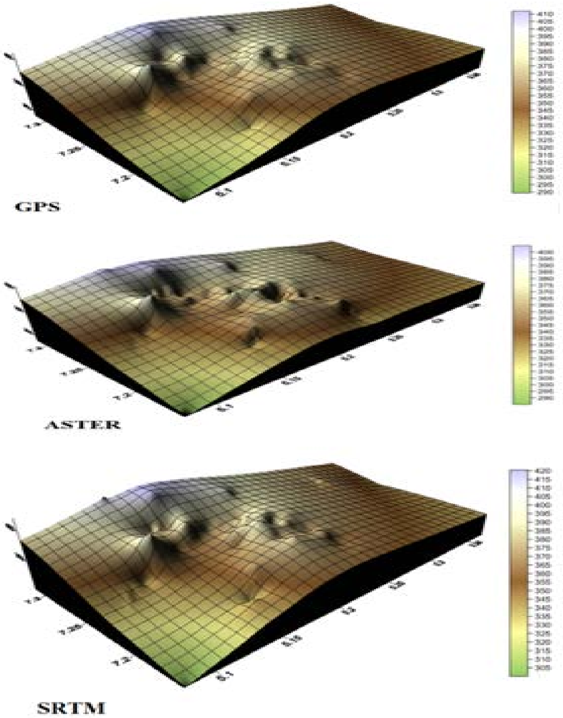


Figure 11: Region A 3DView of the referenced GPS data and the two DEM

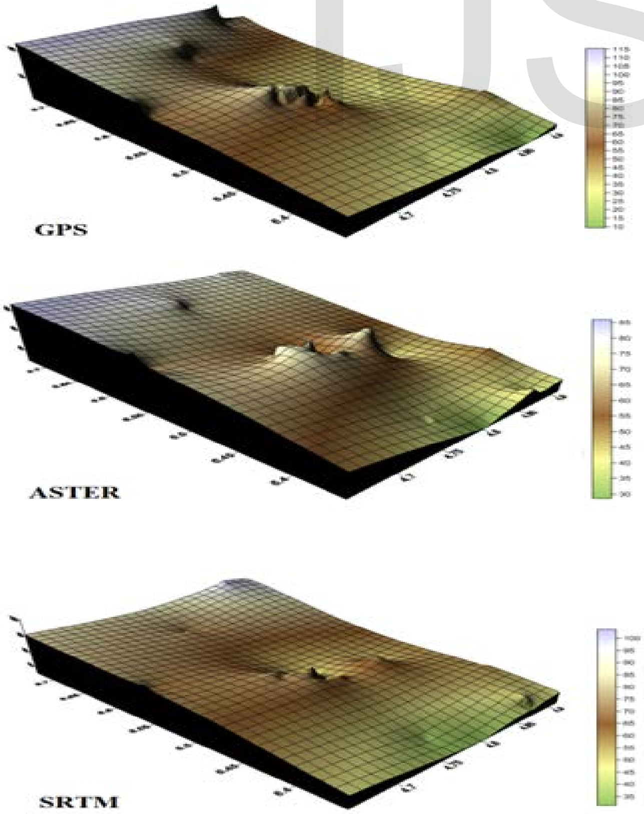


Figure 12: Region B 3DView of the referenced GPS data and the two DEM

8.0 Conclusion

The height quality of current DEM datasets of two space missions, ASTER and SRTM, has been investigated on Ondo State terrain. The DEM qualities which are considered appropriate for geomatics application were compared in mountainous and less mountainous region of the state. Their vertical accuracy in comparison with differential GPS ground control points for mountainous region A is **±12.72** for ASTER and **±7.75** for SRTM in terms of their RMSE. While for less mountainous region B is **±13.25** for ASTER and **±14.48** for SRTM. The good accuracy in region A is possibly ascribed to the fact that the GPS ground control points are located on less vegetated hills as compared to region B. Although the vertical accuracy of SRTM is better than ASTER in region A, the 3D model of the latter shows that it brings out terrain features better than the former.

The vertical accuracy obtained from these DEM in the concerned study area has indicated that SRTM can be used to develop topographic map with contour interval not less than 25m interval in region A, since vertical accuracy standard requires that the elevation of 90% of all points tested must be correct within half of the contour interval as stated in scientific findings. Based on the values of the obtained vertical, these DEM can be used for other geomatic applications for both regions depending on the accuracy demanded.

9.0 Acknowledgement

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