Vertical Accuracy Assessment of 20-metre SPOT DEM using Ground Control Points from Lagos and FCT, Nigeria

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Abstract
Digital Elevation Models (DEMs) are one of the most commonly used datasets for representing variations in terrain elevation. Technological advancements in satellite remote sensing have led to the proliferation of digital elevation datasets with near-global coverage such as the SPOT (Satellites Pour L'Observation de la Terre) DEM. SPOT DEM, which has a spatial resolution of 20m, has a stated absolute vertical accuracy of 10-20m. In 2012, the Office of the Surveyor General of the Federation (OSGOF) in Nigeria acquired SPOT DEM version 1.0 for use in topographic mapping. As such, it is necessary to conduct localised assessments of the DEM to validate the stated accuracies. In line with this, the aim of this study is to conduct an accuracy assessment of the 20m SPOT DEM in Nigeria using Ground Control Points (GCPs) acquired from sites in Lagos State and the Federal Capital Territory (FCT). In addition, the DEM's suitability for topographic mapping is assessed in line with international standards. The DEM for both sites acquired from OSGoF and the GCPs were harmonised in WGS84 datum within ArcGIS software. Subsequently, heights were extracted from the DEMs with the GCP locations, for which the following accuracy parameters were computed – height differences, standard deviation (SD) and root mean square error (RMSE). In the results, the analysis of the height differences yielded the following – Lagos (SD: 3.367m; RMSE: 3.423m) and FCT (SD: 6.280m; RMSE: 6.285m). This assessment proves that the SPOT DEM for both sites surpasses the stated absolute vertical accuracy, and hence can be relied upon as a reliable elevation dataset. It was also shown that the DEM satisfies the Class 2 accuracy standard by the American Society for Photogrammetry and Remote Sensing, and is suitable for deployment in small and medium scale topographic maps. To fully exploit the advantages of the DEM, it is recommended that OSGoF should deploy it for use in other applications beyond topographic mapping.

Keywords: Digital Elevation Model, SPOT DEM, Ground Control Points, Accuracy Assessment, Root Mean Square Error.

1.0 INTRODUCTION

The availability of satellite-derived Digital Elevation Models (DEMs) has led to the increase in the use of satellite data for topographic mapping. A DEM is an ordered array of numbers that represents the spatial distribution of elevations above some arbitrary datum in a landscape. According to Al-Yami (2014), a DEM is referred to as one of the most basic methods of representing variations of heights or elevations of a region in an unambiguous manner for proper visualisation and interpretation by users and analysts. These elevation models can be derived from field data using manual methods like tacheometry, global positioning system surveys, total station surveys, etc. or through remote sensing methods (Onyegbula, 2019). DEMs are being actively incorporated into elevation models by researchers, governments and organizations for various forms of analysis. Recently, the use and availability of satellite-derived DEMs has proliferated the science community due to improved technology for data acquisition, recent launch of satellite missions, and the improved spatial and spectral resolution of space-borne sensors (Onyegbula, 2019). Consequently, satellite-derived DEMs have found applications in terrain modelling, earthworks, geomorphological modelling, urban planning and engineering by the research community, governments and organisations. DEMs are also important sources of topographical data for many scientific and engineering applications such as hydrological and geological studies, infrastructure planning and environmental management (Yu and Ge, 2010 in

Nwilo *et al.,* 2017a). In engineering, DEMs are useful for cut-and-fill volumetric calculations, large area drainage studies, long corridor route selection, and monitoring of ground movement related to seismic activity or hydrocarbon production (Harris Geospatial, 2020). Planning activities are often centered on parameters derived from DEMs such as slope and aspect which can help locate optimal agricultural areas, while river valley characteristics (e.g. reservoir capacity) is a critical factor for exploring hydrological power potential (EO4SD, 2020). In general, most civil engineering projects also require a thorough understanding of landscape topography.

Despite the rigorous process of DEM construction, the products are still known to contain attribute errors (Temme *et al.,* 2009). Certain discrepancies are bound to occur during the stages of acquisition to final processing of DEMs, leading to discrepancies between the DEM heights and the actual heights of the terrain (Olusina and Okolie, 2018). An example is the height offset caused by the shadowing effect of trees, buildings and other land obstructions which block the satellite pulses from reaching the ground. These features constitute noise on the DEMs by masking the actual height of the underlying terrain. Error is a measure of the discrepancy between observations/measurements and the true or most probable value (MPV). Accuracy is an offshoot of error. Hence, accuracy refers to the proximity in the value of an observation and the true value (Ayeni, 1981). Errors in DEMs are generally caused by discrepancies in the heights derived from them and the reference heights (Wechsler, 2007). A prevalent source of inaccuracy to the reliability of satellite-derived DEMs is the masking effect of obstructions such as buildings and elevations, yielding a false height of the terrain (Nwilo *et al.,* 2017a). This false height is due to the fact that the top of the obstructions reflects the incident electromagnetic radiation (E-M) to the sensors, which leads to an estimated height of the terrain at that point equal to the elevation of the obstruction or canopy reflecting the E-M pulses.

SPOT (Satellites Pour L'Observation de la Terre) is a commercial satellite mission acquiring high-resolution satellite imagery over the earth. It was launched to acquire high-resolution imagery of the earth's surface for applications in environmental and resource monitoring, climatology, human activities, cartographic purposes, geospatial analysis and other applications. There are various SPOT missions – SPOT 1 to SPOT 7, launched since the first in 1986, acquiring data at varying spatial resolutions. The SPOT 5 satellite included a High Resolution Geometric (HRG) instrument, a dedicated High Resolution Stereoscopic (HRS) instrument and a Vegetation large coverage instrument (CRISP, 2019) shown in Figure 1.

The HRS instrument allowed acquisition of stereoscopic pairs in a single pass in order to provide a worldwide database of Digital Elevation Models. SPOT DEM v1.0 is exclusively extracted from SPOT 5 HRS data, and comprises a raster layer as well as description data in XML format (SPOT Image, 2005). The DEM has been assessed to an absolute vertical accuracy of 10-20m (Baudoin *et al.,* 2004; Li and Gruen, 2004; Reinartz *et al.,* 2004; Massera *et al.,* 2012; GISAT, 2019). SPOT DEMs are referenced to the Earth Gravity Model 1996 (EGM 96), available at a spatial resolution of 20m. The vast spatial coverage and excellent geometric and spectral qualities of data acquired from SPOT missions (Rosengren and Willén, 2004) makes it a useful component for modelling diverse regions.

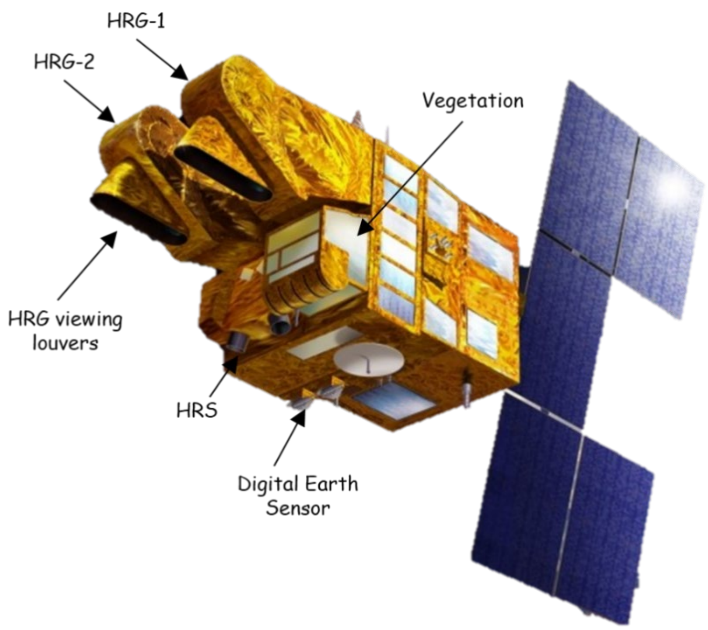

Figure 1: Instruments on-board SPOT 5 satellite (Modified after Satellite Imaging Corporation, 2015)

In 2012, the Office of the Surveyor General of the Federation (OSGOF) acquired the 20-metre SPOT DEM v1.0 from Astrium/Infoterra covering the full extent of Nigeria's land mass and has since been deployed for use in topographic mapping. The DEM has a stated absolute vertical accuracy of 10-20m. Previous studies have shown that DEMs have varying global vertical accuracies in different geomorphological contexts. Hence, localised studies are usually conducted to assess the vertical accuracy of these DEMs (Paul and Timothy, 1994). To inform the understanding of the users in Nigeria of this product's quality, this study assesses the vertical accuracy of the SPOT DEM with reference to highly accurate GPS Ground Control Points (GCPs) in Lagos and FCT, Nigeria. The suitability of the DEM for topographic mapping is also assessed in line with the American Society for Photogrammetry and Remote Sensing (ASPRS) and the U.S. National Map Accuracy Standards for topographical mapping. Vertical map accuracy is defined by the ASPRS Accuracy Standards as the Root Mean Square Error (RMSE) in terms of the earth's elevation datum for well-defined points only (Authority, 1998). The ASPRS Accuracy Standards are divided into Class 1, Class 2 and Class 3 accuracies with the first having an acceptable RMSE set at one-third of the contour interval. Class 2 accuracy applies to maps compiled within an acceptable RMSE twice those allowed for Class 1 maps. Class 3 accuracy applies to maps compiled within an acceptable RMSE three times those allowed for Class 1 maps (Authority, 1998). According to the U.S. National Map Accuracy Standards, the vertical accuracy standard requires that the elevation of 90% of all points tested must be correct within half of the contour interval (Johnson, 2016). For example, on a map with a contour interval of 30m, the map must correctly show 90% of all points tested within 15m of the actual elevation. This study is the first in a series of tests being conducted by the authors to assess the quality and reliability of the SPOT DEM. The variation in the DEM's accuracy over different landscapes and relationship with terrain derivatives is considered in another study.

1.1 Study Area

The study area is selected from two locations in Nigeria - Lagos State and the Federal Capital Territory (FCT) as shown in Figure 2. Lagos is located in the South-western part of Nigeria, with Ikeja as its capital. It is one of the 36 states of the Federal Republic of Nigeria and the smallest state in the country by land mass, with a total area of about 3,577.28km^2 – 2797.72km^2 of land and 779.56km^2 of water (BudgIT, 2018).

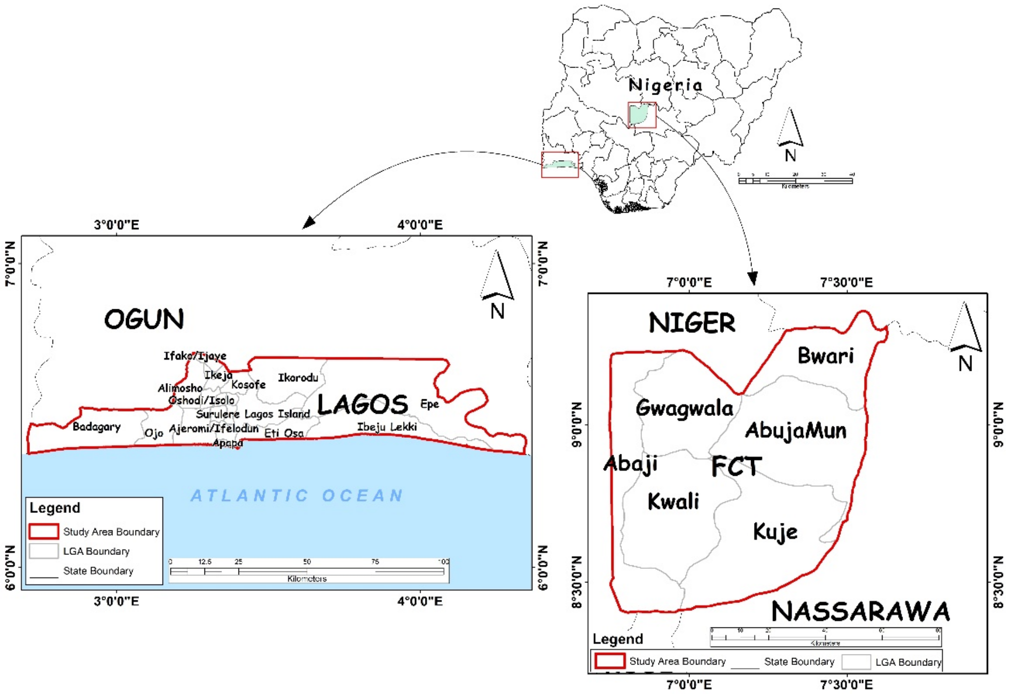

Figure 2: Study area – Lagos and FCT, Nigeria

Lagos is bounded in the south by the Atlantic Ocean, in the north and east by Ogun State, and in the west by the Republic of Benin. The land surface in Lagos State generally slopes gently downwards from north to south. FCT is the capital of Nigeria located in the centre of the country. The geography is defined by Aso Rock, a 400-metre monolith left by water erosion. The presidential complex, National Assembly, Supreme Court and much of the city extend to the south of the rock. Zuma Rock, a 792-meter monolith, lies just north of the city of the expressway to Kaduna. The terrain of FCT is generally of a high altitude and undulating terrain, with some areas as high as 700m. The disparity in the terrain of these two locations provide suitable case studies for the assessment of the SPOT DEM in variable terrain.

2.0 MATERIALS AND METHOD

The following datasets were acquired:

1. 20m SPOT DEM v1.0 covering Lagos State and FCT. The DEM has a spatial resolution of 20m, and was acquired from OSGOF.
2. GPS Ground Control Points (GCPs) coordinates for Lagos State and FCT. Figure 3 shows the spatial distribution of the GCPs. First and second order accuracy GCPs for Lagos State were acquired from the Lagos State Surveyor General's Office while second order GCPs for FCT were acquired from the Department of Survey and Mapping, Federal Capital Development Authority and field observations to densify the second order controls. A total number of 780 GCPs were acquired (Lagos – 556 GCPs, FCT – 224 GCPs).

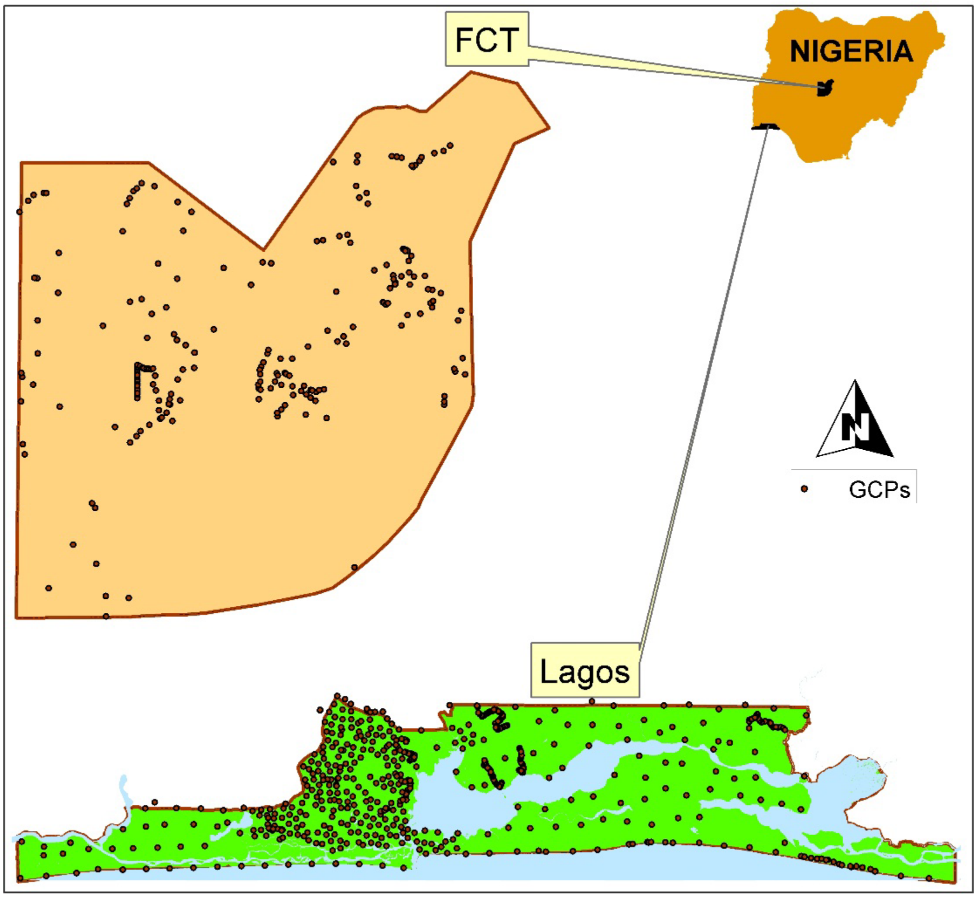

Figure 3: Map showing spatial distribution of GCPs in Lagos and FCT

The data (DEM and GCPs) were harmonised in an orthometric height system in the WGS84 Universal Transverse Mercator (UTM) system using ArcGIS 10.2 software. The data for Lagos was referenced to UTM Zone 31N while the data for FCT was referenced to UTM Zone 32N. Within the ArcMap environment, a 10km buffer was created around the Lagos and FCT administrative boundaries. Next, the SPOT DEM tiles provided were clipped to extract the portions within these boundaries. Afterwards, the GCP data in .xls format was imported into ArcMap and converted to shapefile format.

Steps were taken for the extraction of heights from the SPOT DEM at the GCP locations. This was necessary for a proper accuracy assessment of the heights extracted from the SPOT DEM relative to the GCPs, which for the purpose of this research, serve as the reference dataset. The extraction was done using the “extract values to points” tool in ArcGIS Spatial Analyst. The extraction appended the coincident DEM heights within the attribute tables of the GCP points. After extraction, the GCP and DEM heights were transferred from the .dbf attachment of the shapefiles to a Microsoft Excel worksheet. The differences between the DEM and GCP heights, referred to as height differences (ΔH) were calculated using equation 1:

$$\Delta H = H_{SPOT} - H_{GCP} \quad (1)$$

Where,
H_{GCP} = height from GCP
H_{SPOT} = height from SPOT DEM

After calculating ΔH, the worksheet was imported into the Statistical Package for the Social Sciences (SPSS) version 16 for further quantitative analysis. The following accuracy parameters were computed: standard deviation (SD) and root mean square error (RMSE). The equations for the SD and RMSE are given in equations 2 and 3 respectively.

$$SD = \sqrt{\sum_{i=1}^{n} \frac{(\Delta H_i - \overline{\Delta H})^2}{n-1}} \quad (2)$$

$$RMSE = \sqrt{\frac{1}{n} \sum_{i=1}^{n} \Delta H_i^2} \quad (3)$$

Where,
n = number of points
$\overline{\Delta H}$ = mean of the height differences
The correlation between the height differences and the heights from the DEM was also explored using Pearson's correlation analysis.

3.0 RESULTS AND DISCUSSION

Tables 1 and 2 present extracts of data points from the GCPs for Lagos and FCT showing height differences. Table 3 presents the descriptive statistics of the GCP heights (H_{GCP}), and SPOT DEM heights (H_{SPOT}) while Table 4 presents the descriptive statistics of the height differences (ΔH) for Lagos and FCT respectively. SPOT DEM records greater height levels in FCT than in Lagos. From the DEM, the following mean heights were obtained: Lagos (16.110m) and FCT (330.094m). The range shows that the height variations in Lagos are less pronounced with low-lying terrain than the terrain in FCT. Regarding the range of height differences between the DEM and the GCPs, the maximum range for Lagos State is 38.965mm, while FCT is 45.317m. This shows a higher variability in the height differences for FCT and suggests less reliability of the SPOT DEM in modelling its terrain compared to Lagos. It is however, important to note that the mean error (height difference) is less than 1m at both sites. Lagos State has a mean error of 0.634m, whereas that of FCT is 0.492m. Figures 4 and 5 show scatter plots of height differences (ΔH) against SPOT DEM heights (H_{SPOT}) for Lagos and FCT respectively while Figure 6 shows the histogram of height differences at Lagos and FCT respectively. A larger percentage of the height differences in both Lagos and FCT are within the range of +/-5m. While the height differences at Lagos have a tighter grouping, the dispersion is higher in FCT. There does not seem to be any discernable correlation between the height differences and the SPOT heights. One cannot say that height differences (error) increases or decreases with increase or decrease in height. This is corroborated by the weak correlation between both variables. A run of Pearson's correlation analysis between the height differences and SPOT DEM heights yielded coefficients of determination (r) of 0.170 and -0.029 at Lagos and FCT respectively. It also appears that most of the errors (height differences both –ve and +ve) cluster around the zero line, and are also equally distributed about same line. A key inference that can be drawn from the foregoing is that a data (error distribution) with such a pattern may be seen or said to be devoid of biases or systematic error (this is also seen in the nature of the histogram distribution shown in Figure 6). It is important to state that the above trait is a desirable quality a DEM should possess. The inference is also confirmed by the mean error values (in Table 4) tending toward zero.

Table 1. Extract of 25 points from 556 GCPs for Lagos State showing height differences

ID	GCP ID	Easting (mE)	Northing (mN)	H_{GCP} (m)	H_{SPOT} (m)	ΔH (m)
1	XST55	467678.0	705068.4	7.43	5	-2.43
2	XST230	644360.6	705170.5	4.08	1	-3.08
3	XST45	472714.3	705483.7	7.13	4	-3.13
4	XST229A	638918.3	705666.1	4.36	0	-4.36
5	XST49	478592.8	706032.8	5.11	0	-5.11
6	XST228	633892.3	706513.8	5.11	5	-0.11
7	ZTT35-28	633911.3	706599.4	4.72	5	0.28
8	XST56	487583.1	706684.8	5.21	0	-5.21
9	XST52	482777.1	706810.5	6.37	10	3.63
10	XST60	492147.8	706840.6	5.02	0	-5.02
11	ZTT35-26	633028.7	706928.2	4.94	3	-1.94
12	XST107	542214.8	707045.6	3.55	3	-0.55
13	XST68	501329.7	707068	5.10	0	-5.10
14	XST72	506015.8	707253.6	4.95	0	-4.95
15	ZTT35-23	631421.8	707290.5	4.99	6	1.01
16	XST227	629262.5	707380.9	4.39	5	0.61
17	XST76	510641.5	707392.9	4.93	0	-4.93
18	XST241	538110.2	707503.6	4.10	7	2.90
19	ZTT35-19	629057.3	707510.4	4.88	7	2.12
20	ZTT35-21	630251.1	707513.3	4.84	5	0.16
21	XST80	515232.4	707523.4	5.20	6	0.80
22	XST83	519767.7	707700.7	5.03	2	-3.03
23	ZTT35-16	627404	707756.5	5.14	5	-0.14
24	XST99A	533568.5	707799.1	3.75	5	1.25
25	XST84	524357.9	707817.9	4.96	2	-2.96

Table 2. Extract of 25 points from 224 GCPs for FCT showing height differences

ID	GCP ID	Easting (mE)	Northing (mN)	H_{GCP} (m)	H_{SPOT} (m)	ΔH (m)
1	GCP37	273087.8	935659.2	153.80	146	-7.80
2	FCT2909S	277589.7	939303.9	236.33	241	4.67
3	FCT2657S	273043.6	939677.9	170.20	170	-0.20
4	GCP35	261830.3	941265.4	65.25	74	8.75
5	FCT135P	321953.1	945075.8	204.48	205	0.52
6	FCT2661S	271225.8	946052.2	140.88	141	0.13
7	GCP34	266692.5	949865.4	86.54	79	-7.54
8	FCT2638S	271047.7	957112.8	134.61	142	7.39
9	GCP33	270431.5	958016.3	98.26	104	5.74
10	FCT10354T	257261.1	967737.7	86.99	85	-1.99
11	FCT10355T	256903.7	969739	79.59	80	0.41
12	FCT2617S	277983.9	969967.9	193.19	195	1.81
13	GCP32	279259.6	971196.9	181.26	181	-0.26
14	FCT2612S	280048.1	972208.9	177.88	180	2.13
15	GCP31	275017.3	973061.6	139.45	137	-2.45
16	FCT2608S	281819	973446.3	184.76	186	1.24
17	FCT10321T	286331.1	974182.1	208.39	210	1.61
18	FCT 3648S	316604	974588.4	391.27	380	-11.27
19	FCT2328S	283964.5	974635.2	189.03	193	3.97
20	FCT2605S	284218.9	974887	193.81	193	-0.81
21	FCT 3654S	306952.7	974993	325.43	321	-4.43
22	FCT 3650S	312530.4	975280.5	385.59	377	-8.59
23	FCT 3667S	306932.5	975666.2	358.79	345	-13.79
24	FCT2603S	285180.4	975791.8	195.26	197	1.74
25	FCT2324S	283657.6	976289.7	179.45	182	2.55

Table 3. Descriptive statistics of H_{GCP} and H_{SPOT}

Statistics	Lagos		FCT	
	H_{GCP} (m)	H_{SPOT} (m)	H_{GCP} (m)	H_{SPOT} (m)
Count	556		224	
Range	63.701	65.000	683.081	663.000
Min.	0.171	-2.000	65.254	74.000
Max.	63.871	63.000	748.335	737.000
Mean	15.473	16.110	329.602	330.094

Table 4. Descriptive statistics, SD and RMSE of height differences

Statistics	ΔH (m)	
	Lagos	FCT
Count	556	
Range	38.965	45.317
Max. (-ve)	-19.605	-27.843
Max. (+ve)	19.36	17.474
Mean	0.634	0.492
SD	3.367	6.280
RMSE	3.423	6.285

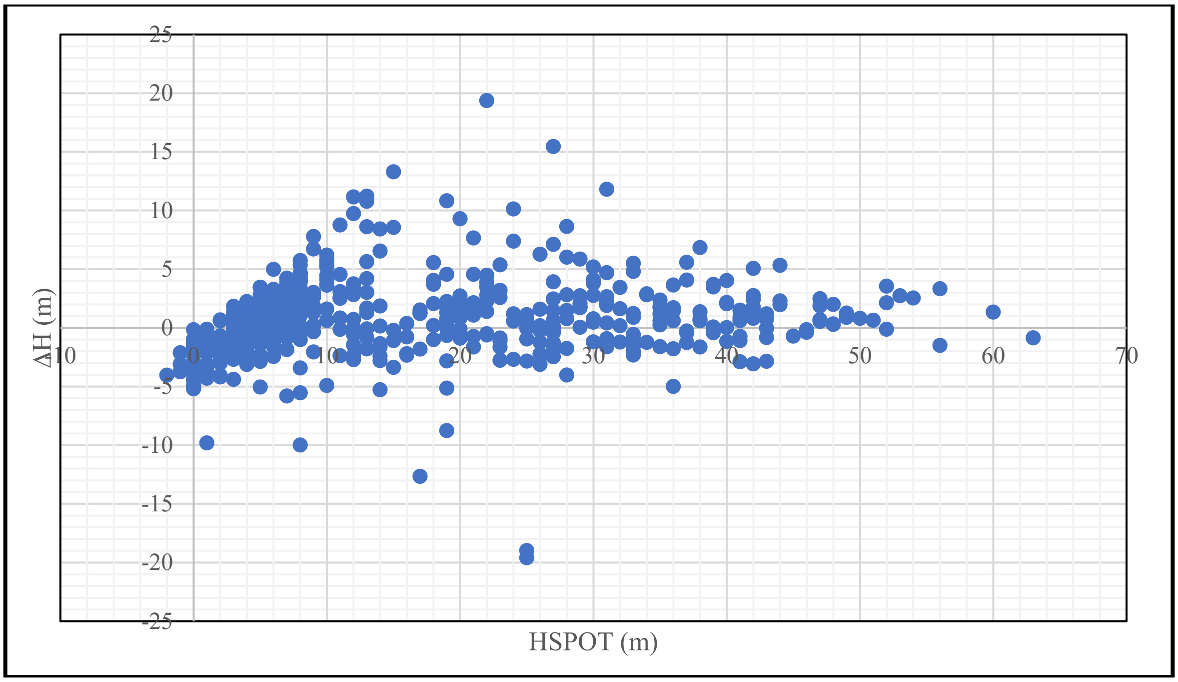

Figure 4: Scatter plot of ΔH against H_{SPOT} – Lagos State

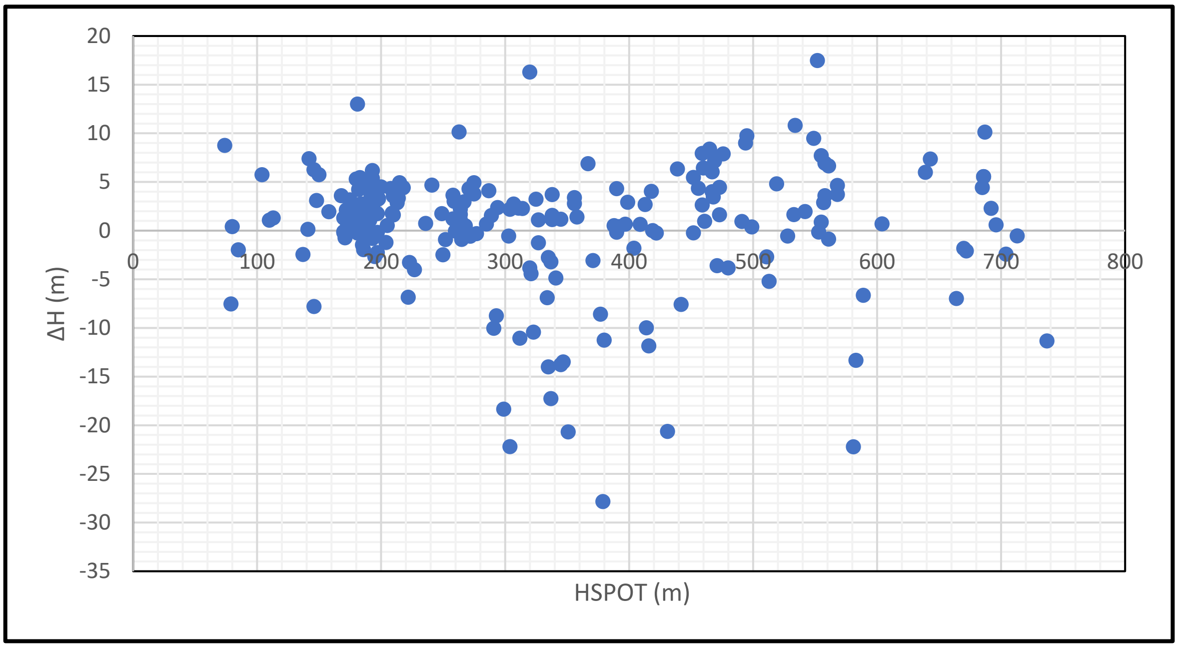

Figure 5: Scatter plot of ΔH against H_{SPOT} – FCT

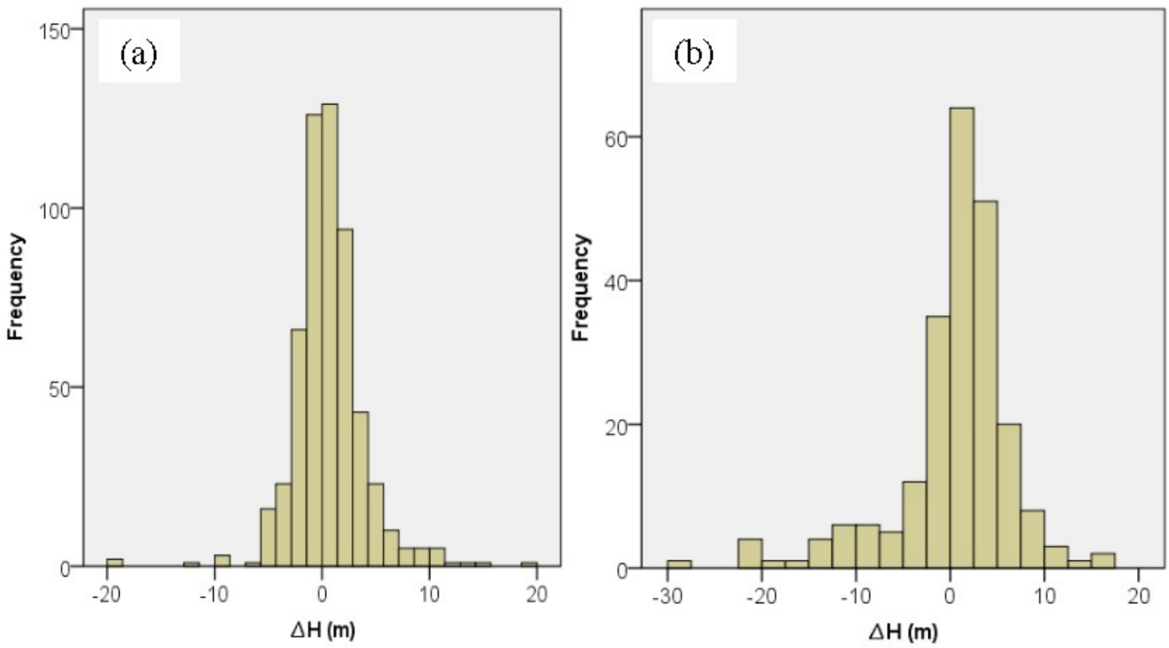

Figure 6: Histogram of height differences between SPOT DEM and GCPs – (a) Lagos (b) FCT

The SD and RMSE of the height differences are as follows: Lagos (SD: 3.367m, RMSE: 3.423m), and FCT (SD: 6.280m, RMSE: 6.285m). The results for both sites surpass the stated vertical accuracy of the DEM given as 10-20m. Hence, the 20m SPOT DEM v1.0 can be viewed as a reliable dataset within the areas tested as the RMSE values of height difference are well below the stated vertical accuracy. The significantly higher RMSE value of FCT compared to Lagos can be attributed to the hilly and undulating terrain of FCT. This is in agreement with the findings of earlier authors (e.g. Nwilo *et al.,* 2017b; Olusina et al., 2018; Arungwa *et al.*, 2018) that DEMs suffer a degradation in accuracy in hilly and mountainous areas. The vertical accuracy obtained from SPOT DEM has indicated that they can be used to develop a topographic map with contour interval not less than 7m for Lagos and 13m for FCT since the USGS map vertical accuracy standard requires that the elevation of 90% of all points tested must be correct within half of the contour interval. Based on the foregoing, it is also evident that the DEM satisfies the ASPRS Class 2 accuracy standard.

4.0 CONCLUSIONS

The accuracy performance of the SPOT DEM in this study surpassed the stated vertical accuracy of 10-20m. The results of this study have also shown that the SPOT DEM is sufficient for mapping vertical features to a specific uncertainty of ±3.423m in Lagos and ±6.285m in the Federal Capital Territory, and to such extent suffices for small and medium scale topographic mapping. However, further insight into the quality of the DEM in terms of its terrain derivatives (e.g. slope, aspect and curvature) and their relationship with the SPOT DEM elevations can be investigated. Since some previous studies have shown that DEM accuracy varies in different landscape and geomorphological contexts, it is also recommended that future studies on SPOT DEM accuracy assessment be conducted to test the quality in variable and complex landscapes especially in the northern highlands of Nigeria. OSGOF is encouraged to make the product freely available to researchers for further studies into its quality and applications.

5.0 ACKNOWLEDGMENT

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