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Investigation and Validation of SRTM v3 and ALOS PALSAR Accuracy Over Landcover/Landuse Types in Federal Capital Territory (FCT), Nigeria

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Abstract *- Digital elevation model (DEM) accuracy and spatial resolution are typically considered before a given DEM is used to assess any application. This is because the consequence of using unsuitable DEMs in environmental designs has a considerable and far-reaching effect on the resultant model. Hence this paper aimed to investigate and validate the accuracy of Shuttle Radar Topographic Mission (SRTMV3) and ALOS PALSAR DEM over Landcover/Landuse Types in Federal Capital Territory (FCT), Nigeria. The methodology involved data acquisition of ALOS PALSAR, SRTMV3, and Reference DEM, after which the ALOS PALSAR and SRTMV3 DEMs were resampled to 10m of the Reference DEM, image classification, and then an assessment of the impact of landcover/land-use types on DEM performance with horizontal profiles was carried out. The results revealed that Under landcover influence, SRTM performed better than ALOS PALSAR compared to the comparison with Reference DEM. The results indicated that the ALOS PALSAR overestimated the elevation under the influence of the built-up area, Vegetation, waterbody, and open space in the study area. It was recommended that SRTMV3 can be used as an alternative where high-resolution elevation data are not readily available for developmental activities in Abuja FCT, Nigeria.*

Keywords: *Landcover/Landuse, Digital Elevation Model, SRTM, ALOS PALSAR, Image Classification.*

I. Introduction

The use of Digital Elevation Models (DEM) in the study of the earth's topography is well documented (Zhang & Montgomery, 1994). DEMs are extensively used in issues relating to the terrain and its dynamics in a particular area. These include hydrological studies, urban planning and development, hazard prediction and relief studies, geomorphology, and vegetation cover (Sauber et al., 2005 & Gajalakshmi &Anantharama 2015). Furthermore, studies from (Ganas et al., 2005 & Chen, 2007) have buttressed the importance and use of the DEM in urban development, agricultural practices, and earthquake hazards respectively. With the advent of Space Satellite technology and the Geographical Information System (GIS), the presentation of the three-dimensional data (x, y, z) has been streamlined and made easy and could be better understood by the targeted audience.

According to (Jensen, 2009), there are four major methods used to acquire elevation information; and they are the traditional land survey methods (which include the use of Global Positioning System (GPS) and the Total Station), Photogrammetry, Interferometric Synthetic Aperture Radar (InSAR) and the Light Detection and Ranging (LIDAR). Okeke (2005), states that the pioneer DEM was generated by contours digitized from topographic maps and the elevations interpolated to form a regular grid. But Nigeria like most developing countries is faced with the non-availability of up-to-date topographic maps as the country was generally mapped last in 1963 at the scale of 1:50,000, and the most popular method of producing topographic information is the traditional ground survey method. Although (Hofton et al., 2005) state 'that the ground survey method yields accurate coordinates (x,y,z information), it is laborious, time-consuming, and expensive on a per point basis when a large expanse of land and thickly forested area are involved'.

Many attempts at a gathering of global elevation datasets have been made in the past few decades. However, in 1986, SPOT became the first satellite to make available stereoscopic images that allowed extraction of DEMs over large areas of the Earth's surface and for the first time, the scientific community was able to extract three dimensional data (x, y, z) over areas of interest that were unreachable before the SPOT launch. Since that time, various analog or digital sensors in the visible spectrum have been flown, providing users with spatial data for extracting and interpreting three-dimensional information on the Earth's surface. During the early years, the satellite stereo-pairs were acquired across-track on different days (SPOT, ERS, etc.). The automatic DEM generation has become an important part of international research in the last decade as a result of the existence of many satellite sensors that can provide stereo pairs. Technological advancement has made available new algorithms, the performances of which have been evaluated and documented in the literature (Toutin, 2001, 2004).

Another commonly used method for extracting relative or absolute elevation information is radar interferometry or InSAR. If a Synthetic Aperture Radar (SAR) is used. It presents the main advantages of radar systems and digital image processing: all-weather, night and day operation, and automated or semi-automated processing. The necessary data can be collected either by the same antenna during two different passes (Earth Resources Satellites 1 and 2), or by two antennas during the same pass (Shuttle Radar Topography Mission, SRTM). The phase difference information between the SAR images is used to measure precise changes in the range, on the subwavelength scale, for corresponding points in an image pair. Analysis of the differential phase and therefore change in distance, between the corresponding pixel centers and the observing antenna can lead to information on terrain elevation (Gabriel & Goldstein, 1988). If the SAR data are acquired from the same antenna during two different passes, the imaging geometry of the first pass must be repeated almost exactly in the second pass. The concept of the critical baseline was introduced (Gabriel & Goldstein 1988 & Massonnet & Rabaute 1993) to describe the maximum separation of the satellite orbits in the direction orthogonal to both the along-track direction and the radar range direction.

Following the importance of the DEM in several environmental applications, there is an increasing demand for higher accuracies in DEMs with wide area coverage; hence the Shuttle Radar Topography Mission (SRTM) and ALOS PALSAR was flown to cover the entire globe. The National Aeronautics and Space Administration (NASA) and the National Geospatial-Intelligence Agency (NGA) participated in an international project to acquire radar data which were used to create the first near-global set of land elevations. Although currently many applications use SRTM and ALOS PALSAR products around the world, there is limited scientific literature on their quality and application fitness, especially as it relates to Nigeria and the Federal Capital Territory in particular. SRTM and ALOS PALSAR like any other spatial data are subject to the induced error that could result from data collection, representation, or analysis (Rodrigues et al., 2006; Wechsler and Kroll, 2006). The combination of all these errors is modeled as data accuracy. When using a DEM on a regional or nationwide scale, a single product cannot have the same accuracy equally in all the various sub-region, due to the variation of the modeled terrain (Aguilar et al., 2005). To be able to use a given product more efficiently, each sub-region must be evaluated separately.

Because of the foregoing, it has become very necessary to investigate and validate SRTM Version 3 and ALOS PALSAR accuracy using over the landcover/land-use types in the Federal Capital Territory of Nigeria, to determine their suitability and accuracy of the elevation data derived per Landcover/land-use types.

II. Materials and Methods

A. Study Area

The study area for this study is Abuja, Federal Capital Territory. Abuja FCT is located in the heart of the country. The FCT stretches across approximately 8,000 square kilometers. With a geographic location of latitude $7^0$25'N and $9^0$20'North and longitude $5^0$45'E and $7^0$39'East, the FCT is bordered on the north by Kaduna, on the west by Niger, on the east by Plateau, and on the South-west by Kogi. The geographic location of Abuja is shown in figure 1. It comprises six Local councils, namely Abaji, Bwari, Kuje, Gwagwalada, Kwali, and Abuja Municipal Area Council (AMAC) which is the metropolitan city of Abuja (Olla et al., 2020).

The FCT experiences three weather conditions annually. This includes a warm, humid rainy season and a blistering dry season. In between the two, there is a brief interlude of harmattan occasioned by the northeast trade wind, with the main feature of dust haze, intensified coldness, and dryness. The FCT falls within the Guinean forest-savanna mosaic zone of the West African sub-region. Patches of the rain forest, however, occur in the Gwagwa plains (Omotosho and Ojo, 2015), especially in the rugged terrain to the south south-eastern parts of the territory, where a landscape of gullies and rough terrain is found. Thus the Federal Capital Territory (FCT) forms one of the few surviving occurrences of the mature forest vegetation in Nigeria. It has a landmass of approximately 7,315 km2, and it is situated within the Savannah region with moderate climatic conditions. The FCT has a total of 800,000 hectares of land, out of which some 274,000 hectares have been designated for agricultural activities and a further 270,000 hectares reserved for forestry. The land resources in the FCT can support the production of most kinds of the crop as well as livestock and fishery products consumed in the Territory.

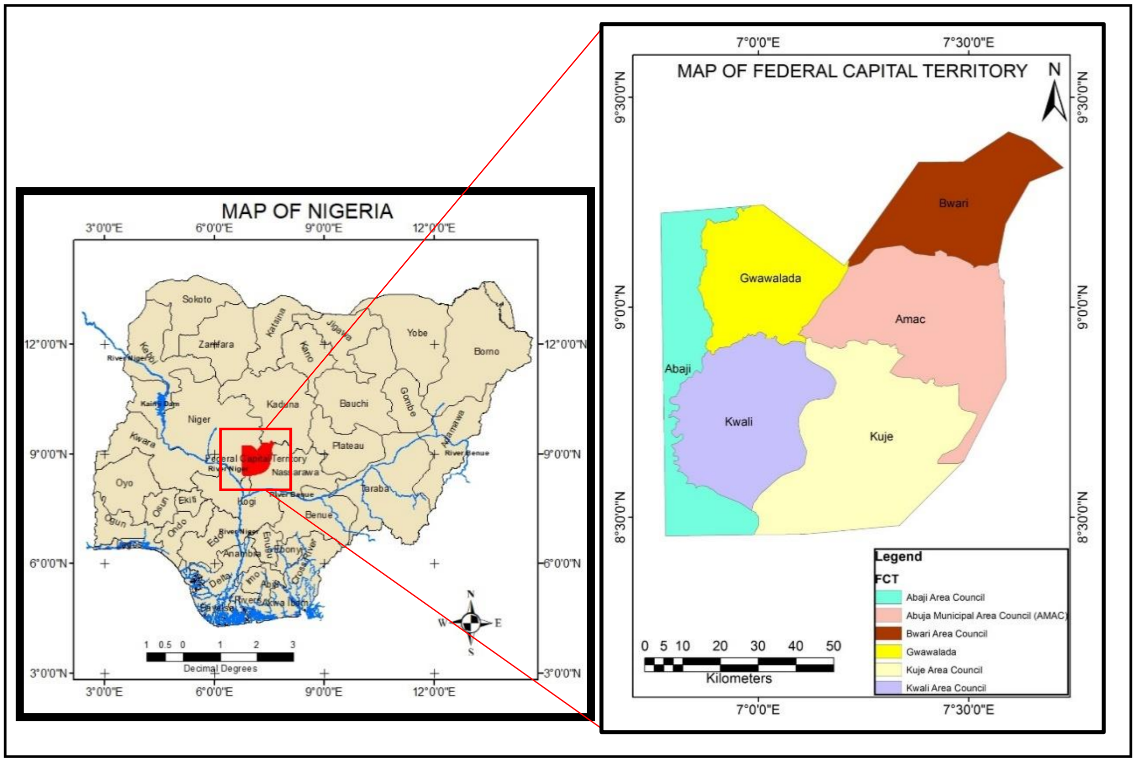

Fig 1.1: Map of Federal Capital Territory showing its position in Nigeria

B. Data collection and Sources

The data used in this study include:

1. 30m resolution Shuttle Radar Topography Mission version 3 (SRTM) image of the study
2. 30m ALOS PALSAR of the study area resampled to 10m
3. 10m spatial resolution Reference DEM dataset of the study area.
4. 10m resolution Sentinel-2 image of the area

SRTMV3 and Sentinel-2 Image was downloaded from http://earthexplorer.usgs.gov while ALOS PALSAR imagery was downloaded from https://vertex.daac.asf.alaska.edu/. The 10m spatial resolution Reference DEM produced from an aerial survey of FCT in 2010, was acquired from the Department of Survey and Mapping, Federal Capital Development Agency (FCDA) Abuja.

C. Data Processing and Analysis

The SRTM and ALOS PALSAR were resampled to a 10m resolution to achieve data conformity with that of the Reference DEM. After which image enhancement was performed to improve the quality of the image. This process was done to edit the original image data by increasing the amount of information for visual interpretation from the data to create a "new" image. Band combination was used for this study; this technique is most useful because many satellite images when examined on a band by band display give inadequate information for image interpretation. The appropriate RGB bands of the sentinel-2 image were merged to obtain a false-color composite, using band 12 (shortwave infrared), band 6 (near-infrared), and band 3 (green). After which a classification scheme was developed for the study area after Anderson *et al* (1998) followed by image classification (supervised classification) then subsequently accuracy assessment to assess the accuracy of the image classification using error matrix and kappa statistics.

To investigate and validate the accuracy of SRTM v3 and ALOS PALSAR over the landcover/land-use in Abuja FCT, the classified image was converted to polygons and each of the landcover/land use classes was extracted and overlaid on each of the individual DEMs and cross-sectioning was done to determine the profile of each of the landcover/land use classes on SRTM and ALOS PALSAR then subsequent comparison with the class profiles against that of the Reference DEM.

III. Results

A. Landcover/Landuse Distribution of Abuja FCT.

To examine the effect of land cover/land use types on the performance of SRTM and ALOS PALSAR, Sentinel-2 image was classified using level one classification scheme after Anderson *et al* (1998). This is shown in Figures 3.1a and 3.1b. In mapping land cover/land use, five different classes were identified to include Built-up areas, Rock, bare surfaces, Vegetation, and water bodies. The land cover/land use distribution of FCT indicated that Built-up area and

Vegetation, accounted for the largest land cover/use of about 31.17 % and 24.37% respectively, with areas of about 229,262 hectares and 179,268 hectares. While Bare Surfaces, Rocks, and water body had 19.82%, 17.91%, and 6.80% respectively with an area of 145,768 hectares, 130,987 hectares, and 50,030 hectares.

The accuracy of the classification process was assessed using the confusion matrix and kappa statistics (see table 3.1).

Kappa statistics was done to measure the level of agreement of the classification of the class categories, kappa is always less than or equal to 1. A value of 1 implies perfect agreement and values less than 1 implies less than perfect agreement. From the results (table 3.1) gotten from the Classification Accuracy Assessment Reports and Kappa (K^) statistics for all classes, the total reference points used was 256 and the total number of points classified was 256, the total number of correctly classified points was 230. This resulted in an overall accuracy of 89.84% and overall kappa of 0.9282. hence the landcover/land use result is adjudged to be accurate and accepted.

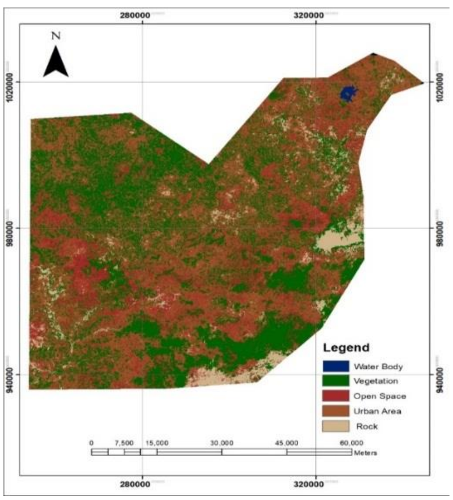

Figure 3.1a: FCT Landcover/Landuse

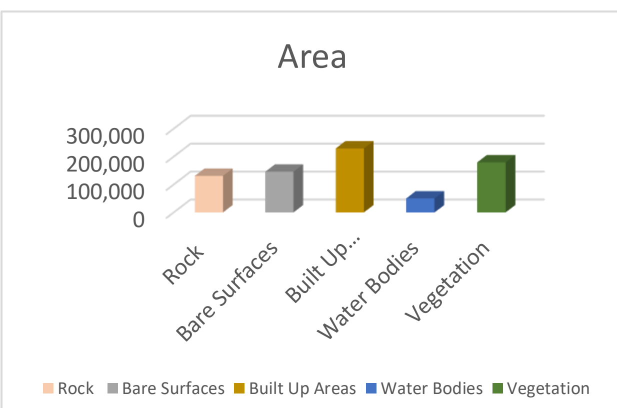

Figure 3.1b: FCT Landcover/Landuse distribution

Table 3.1: Accuracy Assessment Report

ACCURACY TOTALS			KAPPA (K^) STATISTICS
Class Name	Producers Accuracy	Users Accuracy	Kappa
Rock	97.56%	90.00%	0.9350
Bare Surface	98.46%	93.75%	0.9550
Built Up Areas	92.57%	93.46%	0.9249
Water Bodies	96.29%	84.61%	0.9012
Vegetation	93.22%	92.72%	0.9250
Totals			Overall K^ =
Overall Classification Accuracy = 89.84%			0.9282

B. Effect of landcover/land-use types on DEM performance in the study area

The landcover/land use classes were extracted then overlaid with the individual DEMs and cross-sectioning was done to determine the profile of each of the landcover/land use classes on SRTM and ALOS PALSAR then subsequent comparison with the class profiles against that of the Reference DEM. The results are displayed in figure 3.2 – figure 3.6 and table 3.2 – table 3.6.

The built-up area profile in fig 3.2 and table 3.2, indicated that SRTM had a mean elevation of 483m which had a close resemblance to the reference profile, while ALOS PALSAR had a mean elevation of 507m overestimated the profile under built-up area influence by 24m in comparison to the Reference DEM which had a mean elevation of 483m. The profile of SRTM compares favorably to the Reference DEM with a correlation coefficient of 0.967, which indicates a good relationship, while ALOS PALSAR compared relatively below SRTM in comparison to the Reference DEM with a correlation coefficient of 0.551.

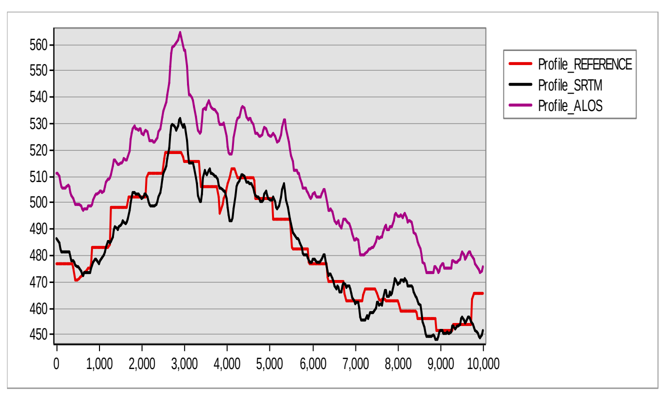

Figure 3.2: Built-up Area Profile

Table 3.2: Profile characteristics for Built-up Area

Built-up Area	Minimum Height (m)	Maximum Height (m)	Mean Height (m)
Reference DEM	451	518	483
SRTM	446	539	483
ALOS PALSAR	473	567	507

Similarly, the vegetation profile in fig 3.3 and table 3.3, indicated that SRTM had a mean elevation of 695m which was similar to the reference under vegetation influence while ALOS PALSAR vegetation profile had a mean elevation of 719m, overestimated the profile under vegetation influence by 21m in comparison to the Reference DEM with a mean elevation of 698m. The profile of SRTM compares favorably to the Reference DEM with a correlation coefficient of 0.802, which indicates a good relationship, while ALOS PALSAR compared relatively below SRTM in comparison to the Reference DEM with a correlation coefficient of 0.651.

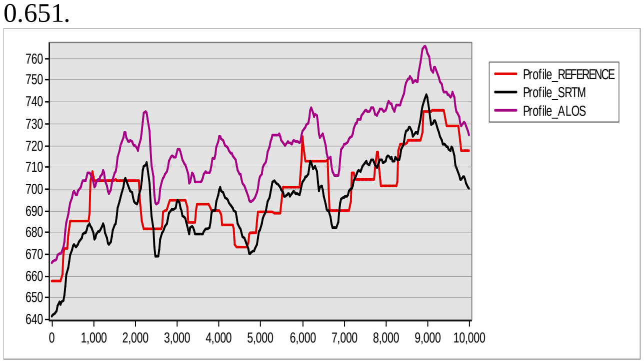

Figure 3.3: Vegetation Profile

Table 3.3: Profile characteristics for Vegetation

Vegetation	Minimum Height (m)	Maximum Height (m)	Mean Height (m)
Reference DEM	658	736	698
SRTM	641	744	695
ALOS PALSAR	664	768	719

The waterbody profile in fig 3.4 and table 3.4, indicated that SRTM had a mean elevation of 573m which underestimated the elevation under waterbody influence in comparison with the Reference DEM by 9m. while ALOS PALSAR with a mean elevation of 597m overestimated the profile under waterbody influence by 15m in comparison to the Reference DEM with a mean elevation of 583m. The profile of SRTM and that of ALOS PALSAR were not close to the Reference DEM as was confirmed with a correlation coefficient of 0.147 and 0.131 respectively. this indicates a weak relationship between SRTM and ALOS PALSAR against the Reference DEM.

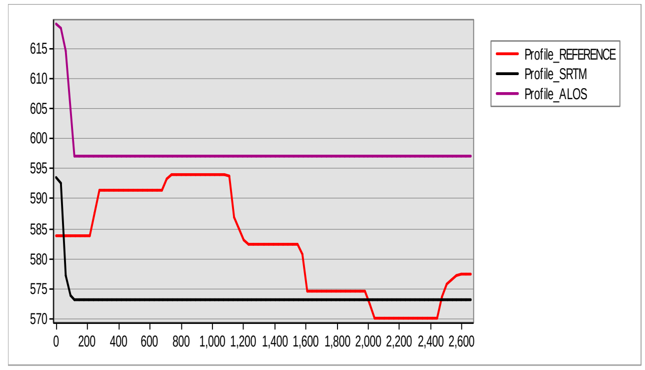

Figure 3.4: Waterbody Profile

Table 3.4: Profile characteristics for water body

Waterbody	Minimum Height (m)	Maximum Height (m)	Mean Height (m)
Reference DEM	570	593	582
SRTM	573	593	573
ALOS PALSAR	597	623	597

From the rock profile in fig 3.5 and table 3.5, it can be seen that SRTM with a mean elevation of 614m underestimated the elevation under rock influence by 4m when compared to the Reference DEM, while ALOS PALSAR with a mean elevation of 626m, overestimated the elevation under rock influence by 8m in comparison to the Reference DEM with a mean elevation of 618m. The profile of SRTM and ALOS PALSAR compared favorably to the Reference DEM as indicated with a correlation coefficient of 0.904 and 0.892 respectively which indicates a good relationship.

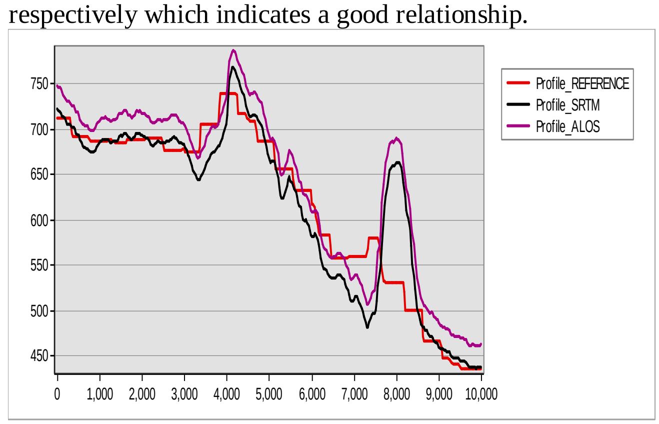

Figure 3.5: Rock Profile

Table 3.5: Profile characteristics for Rock

Rock	Minimum Height (m)	Maximum Height (m)	Mean Height (m)
Reference DEM	435	738	618
SRTM	436	769	614
ALOS PALSAR	460	784	626

From the open space profile in fig 3.6 and table 3.6, it can be seen that SRTM with a mean elevation of 145m had a close resemblance to the reference under open space influence, while ALOS PALSAR with a mean elevation of 164m overestimated the elevation under the influence of open space by 19m in comparison to the Reference DEM with a mean elevation of 145m. The profile of SRTM compares favorably to the Reference DEM as indicated with a correlation coefficient of 0.988, which indicates a good relationship, while ALOS PALSAR compared relatively below SRTM in comparison to the Reference DEM with a correlation coefficient of 0.789.

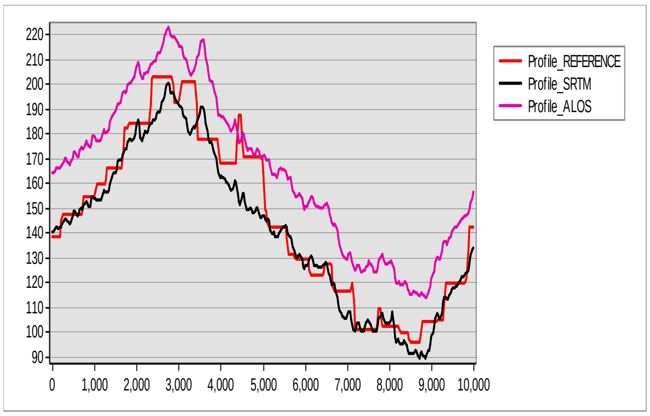

Figure 3.6: Open Space Profile

Table 3.6: Profile characteristics for open space

Open Space	Minimum Height (m)	Maximum Height (m)	Mean Height (m)
Reference DEM	95	202	145
SRTM	89	203	145
ALOS PALSAR	113	223	164

Landuse/ landcover types affect the elevation values obtained from DEMs and subsequently, on the performance of the DEM, this was evident in the results achieved. Under built-up area influence, SRTM v3 performed better than ALOS PALSAR when compared to the Reference DEM. SRTM v3 also performed better than ALOS PALSAR under vegetation influence when compared to the Reference DEM. Under waterbody influence, SRTM v3 and ALOS PALSAR performed poorly when compared to the Reference DEM. Under rock influence, SRTM v3 underestimated the elevation by 4m when compared to the Reference DEM, while ALOS PALSAR overestimated the elevation under rock influence by 8m in comparison to the Reference DEM. The elevation of SRTMv3 and ALOS PALSAR compared favorably under the influence of rock when compared to the Reference DEM with a correlation coefficient of 0.904 and 0.892. Under open space influence, SRTMv3 performed better than ALOS PALSAR when compared to the Reference DEM. These results indicate that the ALOS PALSAR overestimated the elevation under the influence of the built-up area, Vegetation, waterbody, and open space in the study area.

IV. Discussion and Conclusion

As indicated by (Ojigi & Dang 2010; Isioye & Obafaro 2016 & Olla et al., 2020), SRTMv3 and ALOS PALSAR DEM are alternative sources of elevation data needed for topographic and hydrologic applications in the study area. and thus, this study evaluated their performance and demonstrated that the performance obtained from SRTMv3 and ALOS PALSAR are not the same. Being that the DEMs and the extracted information the most important and fundamental variables to various streams of engineering and planning designs which are the hallmarks of development in Abuja FCT and all over the world. Thus, to provide alternatives when high-resolution DEMs are not available for the Planning framework of the Federal Capital City of Nigeria, the investigation and validation of the accuracy of Shuttle Radar Topographic Mission (SRTM) and ALOS PALSAR DEM data over landcover/land use was very crucial. Under landcover influence, SRTM performed better than ALOS PALSAR, the results indicated that the ALOS PALSAR overestimated the elevation under the influence of built-up area, Vegetation, waterbody, and open space in the study area an observation supported by (Ejikeme, et al, 2018; Olla et al., 2020), in terms of SRTM being the top choice in the freely available global Dems. It was therefore recommended that SRTM v3 can be used as an alternative DEM source in FCT, Nigeria where high-resolution elevation data are not readily available.

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