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# ASSESSING VERTICAL ACCURACIES OF SATELLITE-DEM FOR TERRAIN MODELLING IN AKURE, NIGERIA

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## Abstract

*This research conducts a comparative analysis of the vertical accuracies of satellite-derived Digital Elevation Models (DEMs) in the Akure South Local Government Area, Ondo State, Nigeria. The DEMs assessed were obtained from three open-source satellite missions: Sentinel-1A, ALOS PALSAR, and TanDEM-X. The reference Ground Control Points (GCPs) used in the evaluations comprised 133 GCPs of 2$^{nd}$ and 3$^{rd}$-order accuracy acquired from the Office of the Surveyor General, Ondo State, and through field surveys using the South Galaxy-1 Differential GPS. These obtained GCPs provided extensive coverage of the study area. The evaluation was undertaken based on the land cover, which was established by dividing the study area into open (built-up and bare land) and vegetation-covered (agricultural and forested) areas. The vertical accuracies of the satellite-based DEM collected within the study area were then compared and analyzed. The results revealed that Sentinel-1A and TanDEM-X were the most suitable in both open and vegetation-covered parts of the study area, with Sentinel-1A exhibiting the best performance. The effect of vegetation cover was mostly felt by ALOS PALSAR. Sentinel-1A and TanDEM-X displayed commendable vertical accuracies, deemed highly suitable for applications in topographic mapping, as shown by an RMS of less than 2m. This research recommends the open-source satellite DEMs Sentinel-1A and TanDEM-X for planning and engineering applications because they offer the highest accuracy among their counterparts within Akure and its environs.*

## 1.0 INTRODUCTION

The Digital Elevation Model (DEM) which represents the actual surface of the earth, aids in understanding terrain characteristics and is a potential tool for terrain analysis at various spatial and temporal scales [1]. In other words, DEM can be defined as a digital representation of the ground surface topography or terrain. A high-spatial-resolution DEM with high accuracy and precision in elevation has a wide range of applications, including natural resource management, engineering, infrastructure projects, crisis management and risk analysis, archaeology, security, aviation industry, forestry, energy management, surveying and topography, landslide monitoring, subsidence analysis, and spatial information systems [2]. Several techniques adopted in DEM creation are stereo satellite images, Light Detection And Ranging (LIDAR) and Interferometric Synthetic Aperture Radar (InSAR) technique [3]. This study examines the vertical accuracies of three (3) satellite Digital Elevation models (DEMs): Sentinel-

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1, ALOS PALSAR, and TanDEM-X. The potential of these DEMs was assessed as a possible alternative for terrain modelling in the city of Akure, Nigeria. This study was found to be of essence to the study area, considering the sporadic growth in urban development requiring terrain modelling within and around the city.

Sentinel-1 was the European Space Agency's first Copernicus program satellite constellation [4]. Sentinel-1 comprises two satellites, Sentinel-1A and Sentinel-1B, which share the same orbital plane. They are equipped with C-band synthetic-aperture radar equipment that collects data in any weather condition, day or night. This technology offers a spatial resolution of 5m × 20m along the latitude/longitude direction and a sweep of up to 400km. The constellation was in a near-polar (98.18°) sun-synchronous orbit. The orbit has a repeat period of 12 d and completes 175 orbits per cycle. Sentinel-1A, the first Sentinel satellite, was launched on 3 April 2014 and Sentinel-1B was launched on 25 April 2016. Both satellites took off Soyuz rockets from the Guiana Space Centre in Kourou, French Guiana [5]. The Advanced Land Observing Satellite (ALOS) is a Japanese satellite that has three (3) remote sensing instruments: the along-track 2.5m resolution Panchromatic Remote-sensing Instrument for Stereo Mapping (PRISM), the 10m resolution Advanced Visible and Near-Infrared Radiometer type 2 (AVNIR-2) and the polarimetric Phased Array L-band Synthetic Aperture Radar (PALSAR). ALOS, also known as "DIACHI"in Japan, was developed by the Japan Aerospace Exploration Agency (JAXA) to contribute to mapping, precise regional land coverage observation, disaster monitoring, and resource surveying. It was launched by the H-IIA launch vehicle from the Tanegashima Space Centre (TNSC) on 24 January 2006.

This technology provides a spatial resolution of 12.5m. TanDEM-X is an earth observation RADAR mission consisting of a SAR interferometer produced by almost twin satellites flying in close orbit. German Aerospace Center (Deutsches Zentrum für Lust- und Raumfahrt e.V.DLR) released a new GDEM known as TanDEM-X DEM with two spatial resolutions that are 0.4 arc second (~12m), 1 arc second (30m) and 3 arc seconds (~90m). However, only TanDEM-X DEM 90m is freely downloadable online for scientific use and is now available as a global dataset. One of the elements that makes TanDEM-X differ from other GDEMs is that it uses WGS84 for both horizontal and vertical datum heights [6].

## 2.0 MATERIALS AND METHOD

### 2.1 Study Area

The study area is the Akure South Local Government Area of Ondo State, Nigeria. It is situated between latitudes 07° 21' N and 07° 50' N and longitudes 05° 50' E and 07° 25' E. It lies approximately 250m above mean sea level, with a landmass covering an area of approximately 33,200 ha. The population of the Akure South Local Government Area (LGA) based on the 2006 population census was 360,268 [7], and the current metro area population of Akure in 2022 was 717,000, a 3.76% increase from 2021 [8]. The increasing annual growth of the population can be attributed of the administrative role of the town and its long-standing role as a centre of economic activities which keep attracting many immigrants into it [9]. The annual temperature typically ranges from 18 to 31°C, with temperatures rarely falling below 14°C or rising above 34°C. Akure and its surrounding areas experience frequent rainfall, with a mean annual rainfall of approximately 1500 mm. Rainfall occurs virtually every month, with heavy downpours during the rainy season and light downpours during the dry season [10]. The Akure south terrain consists of mountainous and forested areas [11] with topographic elevations between 260 and 470 m above the mean sea level. Considering the land cover classes, Akure is dominated by vegetation cover, with ~ 34% thick vegetation and ~ 24% light vegetation. Built-up and bare land cover ~ 23% and 12%, respectively, and rock outcrops are visible, covering ~ 7% of the total area of Akure South. Figure 1 shows a map of the study area, showing the land cover classes.

### 2.2 Data and Processing

The properties of the satellite missions evaluated in this study (ALOS PALSAR, and TanDEM-X DEMs) and evaluations performed by several authors in varying climes are briefly outlined in Table 1.

**Table 1:** Properties and validation of global satellite-DEM missions used in terrain modelling

| Satellites Mission | Release Year | Datum | County Location | Vertical Accuracy | Authors |
|---|---|---|---|---|---|
| **ALOS PALSAR (Open Source) Japanese Space Agency—JAXA** | 2006 | EGM 96 (Geoid) | Morocco | 1.718m | [12] |
| | | | Turkey. | RMS: Plain 0.4m<br>Mountainous 2.1m<br>Agricultural 8.8m | [3] |

| | | | | | |
|---|---|---|---|---|---|
| **Sentinel-1A (Open Source) European Space Agency—ESA** | 2014 | WGS 84 (Ellipsoid) | Malaysia<br>Iran<br>Turkey | Iran: 6.7m (RMS) Malaysia: 9.5m(RMS) (RMS)Turkey:1.0, 2.6, 9.0m for plain, Agric & mountainous | [13]<br>[3] |
| **TanDEM-X (Open Source)** | 2010 | WGS 84 (Ellipsoid) | Romania<br>USA<br>India<br>Argentina | 0.03461 (SE)<br>1.59m (RMS)<br>2.19 m (RMS)<br>1.97m (RMS) | [14]<br>[15]<br>[16]<br>[17] |

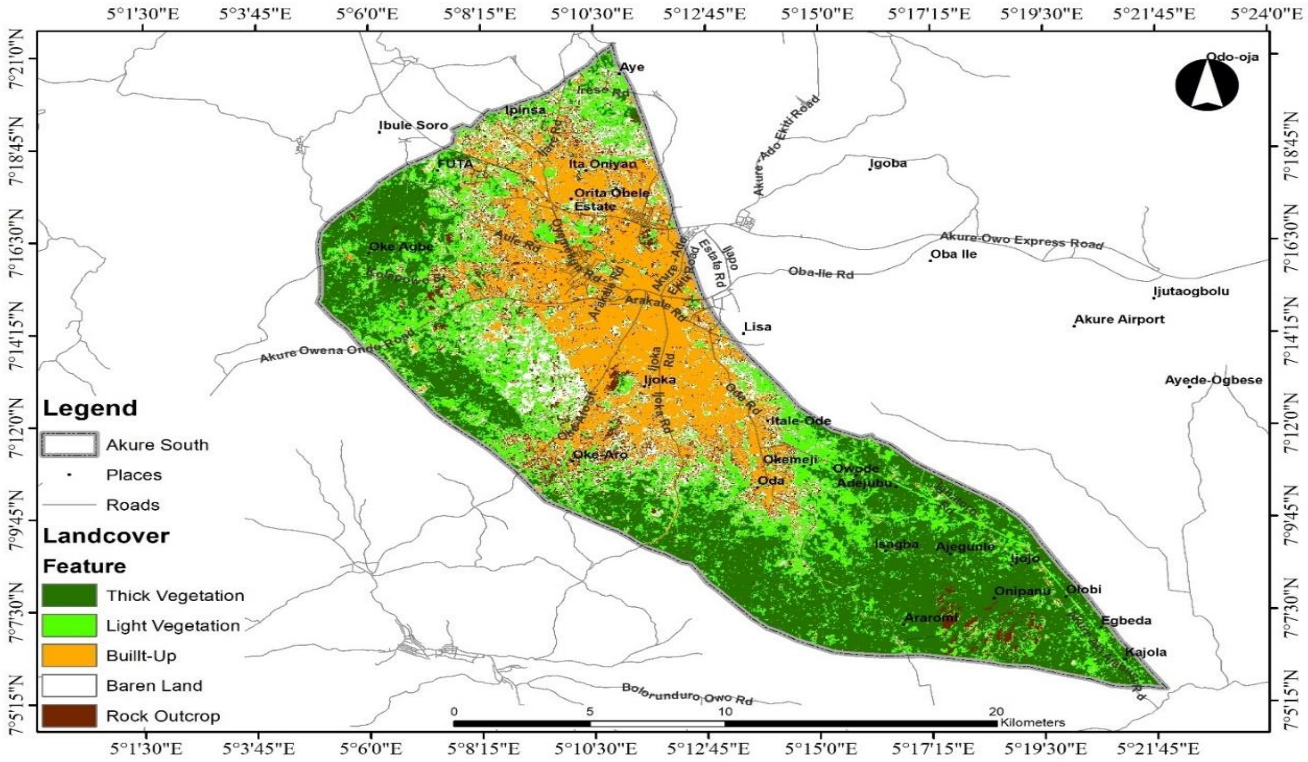



**Figure 1:** Map of the study area (Akure South LGA, Ondo State, Nigeria) indicating land cover classes

The data acquired are existing second- and third-order ground control points, extended ground controls acquired by field surveys using South Galaxy-1 Differential GPS, Sentinel-1A, ALOS PALSAR, TanDEM-X DEMs and Lansat 8 image. Details of these datasets, along with their sources, are presented in Table 2.

**Table 2:** Data collected for the study

| **Dataset** | **Description** | **Data Source** | **Resolution / Precision** | **Uses in study** |
|---|---|---|---|---|
| Existing Ground Controls | Latitude, longitude and height of 105 ground controls | Department of Survey and Mapping, Office of the Surveyor General of Ondo State | 2nd and 3rd order | Assessment of satellite DEM and Control extension |
| Extended Controls | Latitude, longitude and height of 28 ground controls | Ground Survey with Differential GPS | 3rd order | Assessment of satellite DEM |
| Raw Sentinel-1A data | Sentinel-1 Interferometric Wide (IW) swath data/product in Single Look Complex (SLC) format | Alaska Satellite Facility (ASF) official website https://search.asf.alaska.edu/ | 5 m x 20 m Lat / Lon | Input for DEM creation by processing with SNAP and subsequently for Height extraction from DEM |
| ALOS PALSAR DEM | Synthetic Aperture Radar (SAR) Raster DEM in TIF format | Japan Aerospace Exploration Agency (JAXA) https://search.asf.alaska.edu/ | 30 m | Height extraction from DEM. |
| TanDEM-X DEM | Synthetic Aperture Radar (SAR) Raster DEM in TIF format | German Aerospace Center (DLR) https://geoservice.dlr.de/web/maps/tdm:dem90 | 90 m | Height extraction from DEM. |
| Landsat 8 Satellite Imagery | 11 bands multispectral image Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS) | United States Geological Survey (USGS) | 30m | Land cover mapping |

Data processing includes DEM creation from Sentinel-1 raw data using Sentinel Applications Platform (SNAP) software tools, height extraction from DEM using ArcGIS, and Processing the GNSS observations using the South Geomatics Office (SGO). Unlike ALOS PALSAR and TanDEM-X, whose DEMs are provided directly in the TIF format, in the case of Sentinel-1, the initial challenge lies in the raw Single Look Complex (SLC) format, necessitating processing to transform it into a usable DEM. This intricate procedure was facilitated using the Sentinel Application Platform (SNAP) software. This software suite employs rigorous methodologies that require substantial amounts of time and computational resources. Through these efforts, raw Sentinel-1 data were transformed into processed DEM, putting in place the groundwork for further analysis.

In parallel to DEM processing, the control points essential for accuracy assessment underwent refinement. A total of 105 controls were secured from secondary sources specified in Table 2, comprising 93 number of 2nd order controls and 12 number of 3rd order controls. The spatial distribution of these controls in an ArcGIS-generated map revealed clustering within certain regions of the study area. To enhance the precision of the control points and address areas lacking adequate control coverage, a strategic approach was employed. A 2.5 km grid map was superimposed on the study area. Within the grids devoid of control points, 33 positions were designated for control densification. The field observation phase involved precise GPS positioning, base station occupation, and control densification using a South Galaxy-1 Differential GPS (DGPS). A quality assessment of instruments and existing controls used in the fieldwork involved instrument tests and in-situ checks, respectively.

In the field observation phase, the DGPS served as the base for this endeavour, anchored to an existing control point. Static mode (observation) was employed, dedicated 30 min to each of the 33 targeted points. Navigational assistance was provided by the Garmin 76CSx handheld GPS, which guided the observer to designated positions. Despite the challenges posed by the dense forest environment, data capture for 29 of the intended 33 points was achieved. The acquired data were processed using South Geomatics Office (SGO) software. The net adjustment report yielded positive outcomes of 28 points, reflecting the effectiveness of the applied methodology. Unfortunately, the unprocessed points were due to signal interruptions caused by the natural canopy within the forest area. This limitation underscores the impact of external factors on data collection.

Height extraction at the locations of the reference stations was performed on the DEM using the *Elevation Point From DEM* tool of ArcGIS to extract points from the raster DEM. The heights were extracted at points located based on the horizontal (Easting and Northing) coordinates of the reference controls, as both satellite DEM and GCPs were all on a uniform horizontal datum of WGS 84. However, the vertical data of the satellite DEM differ, which necessitates vertical datum harmonisation.

### 2.3 Vertical Datum Harmonisation

In this study, the satellite DEM used was based on different vertical data. Table 1 provides details of the satellite altimetry missions. ALOS PALSAR provides orthometric height based on the EGM96 datum, whereas Sentinel-1A and TanDEM-X provide ellipsoidal heights based on the WGS 84 ellipsoidal vertical data. For a compatible correlation between the DEMs and GCPs elevations, the elevations were transformed to a unified reference surface and the EGM96 vertical datum was adopted. This transformation was performed using the relationship shown in Equation 1.

$$H = h_{GCP} - N \quad (1)$$

Where, $H$: Orthometric height; $h_{GCP}$: Ellipsoidal height derived from Sentinel-1A and TanDEM-X; and N: Geoid height / Geoidal undulation.

### 3.4 Vertical Accuracy Assessment

To enhance the accuracy of the generated Global Digital Elevation Models (GDEMs), a vertical accuracy assessment was undertaken. The assessment process involved the calculation of vertical differences between the GDEMs (Sentinel-1A, ALOS, and TanDEM-X) and the corresponding data obtained from conventional survey reference GCPs. This comparison was conducted on a point-by-point basis, allowing for a comprehensive evaluation of the vertical discrepancies across the study area. The calculated elevation differences were subsequently employed to derive the error metrics for the analysis. These metrics include the Mean Error (ME) given in Equation 2 and Root Mean Square (RMS) errors given in Equation 3. The ME quantifies the average difference between the GDEMs and the reference data, whereas the RMS provides an overall measure of the dispersion of these differences.

$$ME = \frac{1}{n} \sum_{i=1}^{n} (\bar{x}_i - x_i) = \frac{1}{n \sum_{i=1}^{n} E} \quad (2)$$

$$\text{RMS}= \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(\bar{x}_i - x_i)^2} \quad (3)$$

Where, $x_i$ is the number of points; $x_i$ is the elevation value from Satellite DEM; and $\bar{x}_i$ is the elevation value of the reference surface.

This assessment is vital to ensure that these GDEMs align with the standards required for scientific applications and research purposes. The evaluations were performed based on land cover classes which were broadly divided into two categories: light/thick vegetation and built-up and bare areas. A concise flowchart illustrating the workflow of methodology is provided in Figure 2.

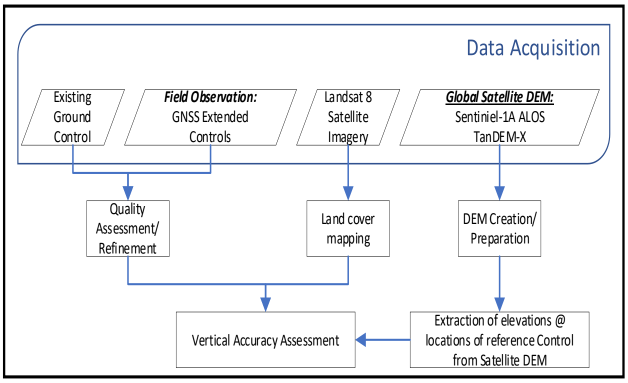



**Figure 2:** Workflow of methodology

## 3.0 RESULTS AND DISCUSSION

### 3.1 Results

This section presents the results of this study. These results are DEMs derived from the satellite products evaluated in the study, point elevations extracted from satellite DEMs, their respective differences relative to the reference elevations of the GCPs, and results on vertical accuracy assessments. The DEMs derived from the ALOS, TanDEM-X, and Sentinel-1A satellite missions are shown in Figures 3a, 3b, and 3c, respectively. The results of point elevations extracted from satellite DEMs, along with their respective differences, are presented as a sample of 20 out of 133 points in Table 3. In this table, it is noteworthy that the data of the elevations from GCPs ($H_{GCP}$), Sentinel-1A ($H_{SENT}$), ALOS ($H_{ALOS}$), and TanDEM-X ($H_{TDX}$) have all been harmonised with the EGM96 datum. $\Delta H_{SENT}$, $\Delta H_{ALOS}$, and $\Delta H_{TDM}$ represent the differences in point elevations between $H_{GCP}$ and {$H_{SENT}$, $H_{ALOS}$, and $H_{TDM}$}. The results of the vertical accuracy assessments are presented as descriptive statistics in Tables 4 and 5, respectively. Table 4 describes the statistics of the elevations $H_{GCP}$, $H_{SENT}$, $H_{ALOS}$, and $H_{TDX}$, while Table 5 shows the differences in elevation $\Delta H_{SENT}$, $\Delta H_{ALOS}$, and $\Delta H_{TDX}$. The results in Tables 4 and 5 are presented based on all the areas and then further separated into land cover classes which are broadly divided into two areas: vegetation cover (light/thick) and open (built-up/bare) areas. A thematic map of the land cover classes overlaid with the reference GCPs is presented in Figure 3d.

**Table 3:** Extract of 20 points from 133 GCPs for the study area showing elevation differences

| ID | GCP ID | $H_{GCP}$ (m) | $H_{SENT}$ (m) | $H_{ALOS}$ (m) | $H_{TDX}$ (m) | $\Delta H_{SENT}$ (m) | $\Delta H_{ALOS}$ | $\Delta H_{TDX}$ |
|---|---|---|---|---|---|---|---|---|
| 1 | GPS A1S | 345.45 | 345.485 | 347.874 | 346.072 | 0.035 | 2.424 | 0.622 |
| 2 | GPS A2S | 347.073 | 346.016 | 349.724 | 346.446 | -1.057 | 2.651 | -0.627 |
| 3 | GPS A72S | 359.913 | 359.014 | 363.824 | 359.405 | -0.899 | 3.911 | -0.508 |
| 4 | GPS A73S | 359.15 | 358.571 | 360.712 | 358.913 | -0.579 | 1.562 | -0.237 |
| 5 | GPS A74S | 377.414 | 374.625 | 376.695 | 374.976 | -2.789 | -0.719 | -2.438 |
| 6 | GPS A76S | 350.698 | 349.229 | 352.216 | 349.502 | -1.469 | 1.518 | -1.196 |
| 7 | GPS A77S | 348.65 | 346.961 | 348.120 | 347.345 | -1.689 | -0.530 | -1.305 |
| 8 | GPS A78S | 351.389 | 351.103 | 349.083 | 351.569 | -0.286 | -2.306 | 0.180 |
| 9 | GPS A79S | 356.336 | 356.094 | 357.316 | 356.760 | -0.242 | 0.980 | 0.424 |
| 10 | GPS A80S | 359.905 | 358.786 | 363.800 | 358.557 | -1.119 | 3.895 | -1.348 |
| 11 | GPS A81S | 375.736 | 374.937 | 375.391 | 375.323 | -0.799 | -0.345 | -0.413 |
| 12 | GPS A82S | 370.966 | 370.345 | 369.000 | 370.047 | -0.621 | -1.966 | -0.919 |
| 13 | GPS A83S | 387.116 | 386.129 | 384.368 | 383.880 | -0.987 | -2.748 | -3.236 |
| 14 | GPS A84S | 383.17 | 382.623 | 380.015 | 380.344 | -0.547 | -3.155 | -2.826 |
| 15 | GPS A85S | 376.571 | 378.052 | 378.518 | 381.159 | 1.481 | 1.947 | 4.588 |
| 16 | CP2 | 338.949 | 338.229 | 347.110 | 338.244 | -0.720 | 8.161 | -0.705 |
| 17 | CP4 | 365.260 | 366.343 | 374.436 | 366.693 | 1.083 | 9.176 | 1.433 |
| 18 | CP5 | 342.763 | 343.165 | 342.948 | 343.833 | 0.402 | 0.185 | 1.070 |
| 19 | CP6 | 382.097 | 382.486 | 383.005 | 382.131 | 0.389 | 0.908 | 0.0341 |
| 20 | CP7 | 358.766 | 359.404 | 369.980 | 360.385 | 0.638 | 11.214 | 1.619 |

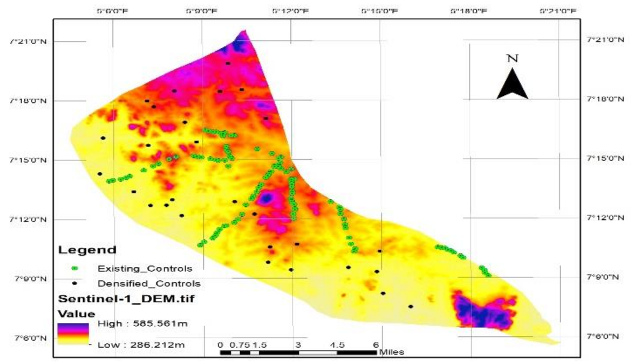
**Table 4:** Descriptive statistics of $H_{GCP}$ and $H_{SENTINEL-1}$, $H_{ALOS}$, and $H_{TANDEM-X}$

| STATISTICS | Land Cover | $H_{GCP}$ (m) | $H_{SENTINEL-1}$ (m) | $H_{ALOS}$ (m) | $H_{TANDEM-X}$ (m) |
|---|---|---|---|---|---|
| | Open | 96 | 96 | 96 | 96 |
| **Count** | Vegetation | 37 | 37 | 37 | 37 |
| | **Overall** | **133** | **133** | **133** | **133** |
| | Open | 95.387 | 95.657 | 89.139 | 95.515 |
| **Range** | Vegetation | 141.890 | 141.675 | 140.734 | 142.974 |
| | **Overall** | **141.890** | **141.675** | **140.734** | **142.974** |

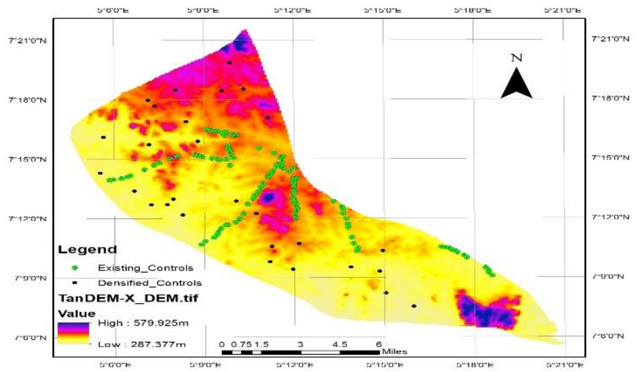
| | | | | | |
|---|---|---|---|---|---|
| | Open | 295.090 | 295.273 | 302.721 | 296.026 |
| **Min** | Vegetation | 261.877 | 261.758 | 262.943 | 262.408 |
| | **Overall** | **261.877** | **261.758** | **262.943** | **262.408** |
| | Open | 390.477 | 390.930 | 391.860 | 391.541 |
| **Max** | Vegetation | 403.767 | 403.433 | 403.677 | 405.382 |
| | **Overall** | **403.767** | **403.433** | **403.677** | **405.382** |
| | Open | 352.373 | 352.106 | 354.779 | 352.445 |
| **Mean** | Vegetation | 326.022 | 326.303 | 330.074 | 326.758 |
| | **Overall** | **345.042** | **344.928** | **347.906** | **345.299** |

**Table 5:** Accuracy assessment metrics of Satellite-DEMs with respect to reference GCPs

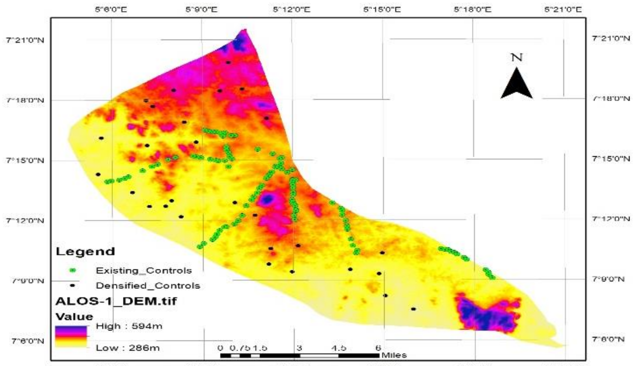
| STATISTICS | Land Cover | ΔH (m) SENTINEL-1 | ΔH (m) ALOS | ΔH (m) TANDEM-X |
|---|---|---|---|---|
| | Open | 96 | 96 | 96 |
| **Count** | Vegetation | 37 | 37 | 37 |
| | **Overall** | **133** | **133** | **133** |
| | Open | 6.777 | 28.165 | 7.824 |
| **Range** | Vegetation | 8.481 | 27.955 | 8.250 |
| | **Overall** | **9.704** | **29.805** | **9.893** |
| | Open | -3.154 | -12.986 | -3.236 |
| **Max. (-ve)** | Vegetation | -6.081 | -14.626 | -5.305 |
| | **Overall** | **-6.081** | **-14.636** | **-5.305** |
| | Open | 3.623 | 15.179 | 4.588 |
| **Max. (+ve)** | Vegetation | 2.400 | 13.329 | 2.945 |
| | **Overall** | **3.623** | **15.179** | **4.588** |
| | Open | -0.267 | 2.405 | 0.072 |
| **Mean** | Vegetation | 0.281 | 4.052 | 0.736 |
| | **Overall** | **-0.114** | **2.863** | **0.257** |
| | Open | 1.188 | 3.513 | 1.371 |
| **SD** | Vegetation | 1.479 | 5.302 | 1.517 |
| | **Overall** | **1.299** | **4.156** | **1.444** |
| | Open | 1.217 | 4.257 | 1.372 |
| **RMS** | Vegetation | 1.506 | 6.673 | 1.686 |
| | **Overall** | **1.304** | **5.047** | **1.467** |
| | Open | 0.933 | 3.055 | 1.009 |
| **MAE** | Vegetation | 1.063 | 5.520 | 1.298 |
| | **Overall** | **0.969** | **3.741** | **1.089** |
| | Open | 0.998 | 0.985 | 0.997 |
| **r** | Vegetation | 0.998 | 0.978 | 0.998 |
| | **Overall** | **0.999** | **0.986** | **0.998** |



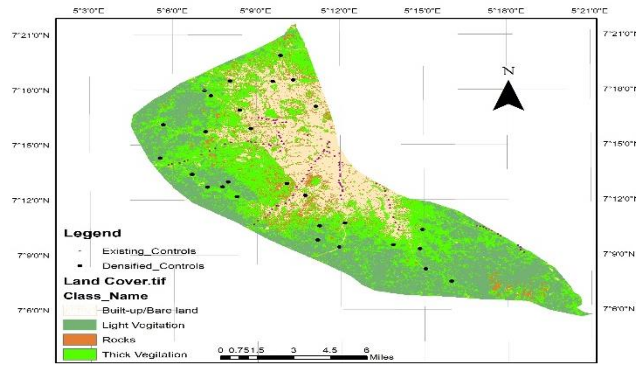
**3(a):** Sentiniel-1A DEM



**3(c):** TanDEM-X DEM



**3(b):** ALOS PALSAR DEM



**3(d):** Land cover classes of the study area

**Figure 3:** Map of the study area depicting Satellite DEM, Land Cover maps overlaid with Reference GCPs (a) Sentinel-1A DEM (b) ALOS PALSAR DEM (c) TanDEM-X DEM (d) Land Cover

### 3.2 Discussion

The results obtained in this study were analysed and compared. Considering the meticulous visual inspection of the thematic maps of the DEMs derived from the Sentinel-1A, ALOS and TanDEM-X satellite missions, presented in Figures 3a, 3b, and 3c, respectively, it may be difficult to discern the differences in the DEMs. However, further statistical evaluation revealed obvious differences. Overall, 133 reference GCPs were used for the evaluations, consisting of 93 number of 2$^{nd}$-order and 40 number of 3$^{rd}$-order GCPs. To ensure accuracy in the GCPs, the reference GCPs were assessed by in-situ check and error propagation analysis, the results confirmed that the accuracy did not fall short of a 3$^{rd}$-order accuracy. Therefore, the GCPs were affirmed to be fit for the purpose in terms of density and accuracy.

From the statistical analysis presented in Tables 4 and 5 of the elevation datasets whose sample is presented in Table 3, the evaluation statistics are carefully assessed. The differences in elevations between the satellite DEMs and the reference GCPs, and the maximum ranges for the overall study area were 9.704, 29.805, and 9.893 for Sentinel-1A, ALOS, and TanDEM-X, respectively. This shows a higher variability in the height differences for ALOS and suggests less reliability of the ALOS PALSAR DEM in modelling the study area terrain compared to Sentinel-1A and TanDEM-X DEMs. In the aspect of land cover classes, similar trends were observed, however, the vegetation cover had higher variabilities in their elevation values compared to open areas However, it is important to note that the overall Mean Absolute Error MAE (height difference) is less than 3.8m for ALOS, less than 1.1m for TanDEM-X and less than 1m for Sentinel-1. While the elevation differences for Sentinel-1A and TanDEM-X had a tighter grouping, the dispersion was higher for the ALOS DEM. A measure of association by Pearson's correlation analysis between the elevations from the GCPs and satellite DEM elevations yielded correlation coefficients (r) of 0.999, 0.986 and 0.998 for Sentinel-1A, ALOS and TanDEM-X respectively. This reflects a strong association between GCPs and satellite DEMs in all cases. Also the errors (height differences) appear to be normally distributed having larger errors cluster around the zero line and are symmetrically distributed along the same line. This indicates that data (error distribution) with such a pattern may be seen or said to be devoid of biases or systematic errors. It is important to note that this trait is a desirable quality that a DEM should possess. The overall RMSE of the height differences of the DEMs for this study were as follows: Sentinel-1 (1.304m), ALOS (5.047m), and TanDEM-X (1.467). Again, comparing the RMS in land cover, the open areas performed better than the vegetation cover, still maintaining the trend in the overall accuracies of the satellite DEM.

Sentinel-1A (5×20m resolution) demonstrated remarkable accuracy with the lowest RMS in the open area, vegetation cover, and overall study area of 1.217m, 1.506m, and 1.304m, respectively. This could be associated with the comparatively high resolution. Compared to the findings in Turkey where Sentiniel-1A recorded an RMS of 1.0, 2.6, and 9.0m for plain, agric and mountainous [3]; and in Iran and Malaysia where an RMS of 6.7m and 9.5m were also recorded [13]. This proves that geomorphology plays a critical role in the accuracy of satellite-derived DEM. However, Sentinel was found to be suitable for various land covers in the study area. ALOS PALSAR (30m resolution), recorded an RMS in the open area, vegetation cover and overall the study area of 4.257m, 6.673m and 5.047m respectively were obtained in the study area. Compared to the study of Morocco, where an RMS of 1.718m was recorded [12], in Turkey, an RMS was recorded for plain (0.4m), mountainous (2.1 m), and agricultural (8.8m) areas [3]. This emphasises the effects of the vegetation cover occasioned by agricultural and forest areas on the accuracy of the ALOS PALSAR satellite-derived DEM. It was also observed that Morocco is an open flat terrain, whereas the Akure South terrain consists of mountainous and forested areas [11]. TanDEM-X (90m resolution), demonstrated better accuracy with a lower RMSE in open areas, vegetation cover and overall study area 1.372m, 1.686 m and 1.467m respectively, compared to RMS at various global studies, such as those at Argentina (1.59m) [17]; USA (1.59m) [15]; and India (2.19 m) [16]. This demonstrates the suitability of the TanDEM-X satellite DEM for various land-cover types in the study area.

Considering previous study in Ondo state, where the study area (Akure south) is situated, the accuracy of satellite DEMs (SRTM and ASTER), an RMS of 7.75 m and 12.72 m SRTM and ASTER respectively, in the mountainous region and an RMS of 14.48m and 13.25m for SRTM and ASTER respectively, in plane region respectively [18]. Considering that the satellite DEM used in their study were older products, an improvement was anticipated with the relatively

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newer products used in this study which can be seen in the study with the least accurate DEM in the study outperformed ASTER and SRTM used in the study of [18]. This implies that there has been an improvement in the DEM of relatively newly released satellites.

## 4.0 CONCLUSION AND RECOMMENDATIONS

In recent times, satellite missions have increasingly been adopted as a viable alternative for topographic applications. However, the need to ascertain the accuracies of the satellite-derived DEMs in varying terrain characteristics remains an issue. In a bid to address the aforementioned, a comparative assessment of vertical accuracies of satellite-derived DEMs namely: Sentinel-1A, ALOS PALSAR, and TanDEM-X was conducted and accomplished in Akure, Nigeria. The assessment was considered by classifying the study areas into vegetative covered and open areas, to cater for the land cover variations in the DEM. The study employed 133 reference control points (2nd and 3rd order) alongside statistical techniques to evaluate these satellite-derived DEMs.

The key findings are as follows: Sentinel-1A demonstrated the highest vertical accuracy, ALOS PALSAR exhibited the lowest vertical accuracy, and TanDEM-X performed well, closer to the performance of Sentiniel-1A, positioning it as a reliable source of elevation data for the study area. The effects of vegetation cover on the vertical accuracies of the satellite DEMs were also evaluated, with ALOS PALSAR being the most affected by vegetation cover characteristics of the study area, while the effects were only slightly felt in Sentinel-1A and TanDEM-X DEM. The analysis revealed minimal bias or systematic error in height differences, which is a favourable trait for DEMs used in topographic mapping. The results therefore affirm the reliability of these datasets for a range of applications, particularly in fields such as surveying and remote sensing, urban planning, flood modelling, environmental management, agriculture, and disaster risk assessment.

These findings exceeded the specified vertical accuracy standards, suggesting that all three DEMs are suitable for topographic mapping purposes. Hence, all the DEMs evaluated in this study can be viewed as reliable datasets, as the RMS values of height differences are well below the stated vertical accuracy for deployment in small- and medium-scale topographic maps. In addition, The vertical accuracy obtained from these results indicates that they can be used to develop a topographic map because the United States Geological Survey (USGS) map vertical accuracy standard requires that an elevation of 90% of all points tested must be correct within half of the contour interval. Based on the results of this study, it is evident that the DEM satisfies the American Society for Photogrammetry and Remote Sensing (ASPRS) Class 2 accuracy standard. The findings of this study contribute significantly to the field of remote sensing and geospatial technology by providing empirical evidence of the vertical accuracy of specific satellite-derived DEMs in a real-world context. This knowledge enhances the reliability of the elevation data, ultimately improving the precision of decisions in urban planning, disaster management, and other applications that rely on accurate terrain information.

Based on the findings of this study, Sentinel-1 was recommended as the most preferred for applications requiring high vertical accuracy, such as urban planning and disaster risk assessment, the use of the Sentinel-1 DEM is recommended in the study area, considering its superior performance. TanDEM-X was considered, a suitable choice for applications like environmental management and agriculture based on its good vertical accuracy and moderate dispersion of height differences. Although ALOS can still be a valuable resource, its lower vertical accuracy necessitates careful consideration, especially in critical applications such as flood modelling and infrastructure development. Further research is recommended in regular monitoring and assessment of DEM accuracy to ensure the continued reliability of elevation data for decision-making processes.

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