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COMPARATIVE ANALYSIS BETWEEN GPS-BASED FIELD DIGITAL TERRAIN MODEL WITH TANDEM- X 90M, ASTER AND SRTM DIGITAL ELEVATION MODELS

Hosanna Attai [1*], Okon Ubom [2], Henry Okpo [3], Unwana Billy [1] and Anthony Jackson [3]

[1]Department of Surveying and Geoinformatics, Akwa Ibom State Polytechnic, Ikot Osurua, Ikot Ekpene
[2] Department of Surveying and Geoinformatics, University of Uyo, Uyo, Akwa Ibom State
[3] Department of Building Technology, Akwa Ibom State Polytechnic, Ikot Osurua, Ikot Ekpene

E-mail: * moseshosanna170@gmail.com

ABSTRACT

This study compared the vertical accuracy of existing satellite's Digital Elevation Model (STRM, ASTER) and the latest satellite remote sensing height data set TanDEM-90m. ASTER and STRM have vertical accuracies of ± 20m and ± 16m, respectively. TanDEMX-90m was processed before use, and the RMSE range of 19-20m was confirmed for TANDEM X 90m. The result of the study shows that ASTER DEM performed better than the rest of the global digital elevation models. The SRTM error of 4m between the first and second locations may be due to systematic error due to slightly different versions of SRTM used for processing. The TANDEM X 90m had the same resolution but performed poorer in positional fitness. The study found that digital elevation models have different resolutions and accuracy levels. Tandem-X90m has a resolution of up to 3 meters, while Aster and SRTM have 30 meters. GPS-based field digital terrain models provide higher accuracy, while Tandem-X90m has a 10 cm accuracy. The models cover a limited area, making them suitable for high-resolution elevation data. The data collection methods used by the models, such as SAR sensors, also affect their accuracy and resolution. Based on the above comparative analysis, it can be recommended that the GPS-based field digital terrain model is suitable for high-accuracy and high-resolution elevation data in a limited area. Tandem-X90m is suitable for high-resolution elevation data in a limited area but is expensive. Aster and SRTM are suitable for global-scale studies but have lower accuracy and resolution.

Keywords: Digital Elevation Model, ASTER, TanDEM-X, SRTM

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1. INTRODUCTION

The representation of an entity or a proposed structure, typically on a smaller scale than the original is called a model. A model is used to simulate reality in certain aspects. A model can be used to answer questions concerning what existed recently or long ago (Ndukwe, 2001). A model can come in many shapes sizes and styles. However, it is important to emphasise that a model is not the real world but just a human construct to help one understand real-world systems. They consist of three components, input, processor and output of expected results.

The earth's surface topography can be depicted by point elevations on the grid of squares which is in the form of a Digital Elevation Model (DEM). Digital Elevation Model (DEM) is a numerical representation of terrain features using different parameters such as elevation and planimetric data that is obtained by working on a topographic surface. It involves the representation of the earth's surface digitally with XYZ coordinates of points scattered all over the earth's surface. Digital Elevation Models are the main contributors to topographic analysis, and it is important for various aspects such as mapping of vegetation, volcanic eruption, flood modelling, balancing of glacial mass etc. In the same vein, Space-borne Global Digital Elevation Models are a useful source of terrain information for a variety of studies about the environment. The importance of the Digital Elevation Model cut across monitoring, curbing natural hazards and assisting in spatial decision-making.

Digital elevation models (DEMs) like SRTM, ASTER-GDEM, and TanDEM-X provide basic terrain information on Earth's surface. These models are suitable for global and regional studies but not for local studies (Chang, Li and Ge, 2010; Abrams, Bryan, Hiroji and Masami, 2010; Jing, Shortridge, Lin and Wu, 2013). The accuracy of these models depends on interpolation methods like Kriging, Inverse Distance Weighting, and Natural Neighbors. Researchers have validated and evaluated these models in various regions to test their accuracies (Chang, Li and Ge, 2010; Abrams, Bryan, Hiroji and Masami, 2010; Jing, Shortridge, Lin and Wu, 2013). TanDEM-X 90m is a new sensor from Germany. Therefore, this work was carried out in part of the University of Uyo Main campus along Nwaniba Road Use Offot, Uyo Akwa Ibom State to validate the recently released TanDEM-X 90m in comparison with the existing global Digital Elevation Model (DEM)-synthetic aperture radar data set(SAR): Shuttle Radar Topography Mission and Advanced Space-borne Thermal Emission Radiometer using Real Time Kinematic Global Positioning System receivers for primary horizontal and vertical control establishment, levelling for vertical control establishment and angular measurement for primary vertical and horizontal control extension and densification(trigonometric levelling and spot heightening).

Many environmental issues from flooding to disaster management, development and control require high-level-based data or rather consumed high-fidelity geoinformation data. There is a growing demand all over the world for readily large coverage and accurate based data for the purposes listed above, a recent addition to the family of existing global data is the TanDEM-X 90m. Previous studies and research have proved that global digital elevation model data such as Advanced Space-borne Thermal Emission Radiation (ASTER) and Shuttle Radar Topography Mission (SRTM) is suitable for a certain level of regional mapping from 1 in 100,000 given the currency of TanDEM-X 90m that was launched in September 2018. Therefore, this research is targeted at investigating the quality and geometric fidelity of the TanDEM x90m global-based data concerning existing field data and in comparison, to SRTM and ASTER.

The main objective is to compare and measure the discrepancies between the various existing satellite Digital Elevation Models (SRTM, ASTER), field data and the latest satellite remote sensing height data set -TanDEM-X 90m. For this to be realised, the topographic survey of the area must be carried out to determine field ground terrain configuration using level, total station and GPS receiver

2. LITERATURE REVIEW

Hui *et al*. (2022) evaluated the newly released Copernicus with NASA and AW3D30 to know the correction between accuracy and terrain slopes, and some relation with land curves. It was revealed that land cover has a greater impact on the accuracy than the terrain slope besides Copernicus DEM exhibits the greatest detail of terrain followed by AW3D30 and the NASADEM. Altunel (2019) evaluated TanDEM-X90m in four locations and found it better in flat to rough terrain. Bandura and Gallay (2018) validated the accuracy of TanDEM-X DEM product for landform densification in Karst, Slovakia, using LiDAR data. Hackel, Gisinger, Balss, Wermuth, and Montenbruk (2018) used LASER and RADAR measurements to validate Terra SAR-X and TanDEM-X. Chu and Erich (2017) examined different data sources and approaches to generate digital elevation models, using the Slave River delta in Canada. The TanDEM-X had the highest accuracy with an RMSE of 2.9m.

Grohmann (2017) assessed the TanDEM-X DEM in Brazilian Territory, comparing it with SRTM, ASTER GDEM, and ALOS AW3D30. They found that TanDEM-X had lower elevations in open vegetation, indicating powerful radar penetration. Pasuya et al. (2017) evaluated the Global Digital Elevation model and TanDEM-X in Peninsular Malaysia, finding that the global geoid model best fits the local geoid model. Blazter, Baade, and Rogers (2016) validated the TanDEM-X 12m at Kruger National Park, South Africa, revealing that DEM height data is affected by canopy height and landform features. Wessel et al. (2014) validated the DEM on moderate terrain, finding it had a better absolute height error. Kumani *et al*. (2022). compared the six DEMs using DGPS with estimation at ground control points. The application of DGPS data helped to eliminate systematic error. It was recommended that DEM be corrected by DGPS before being used for scientific studies.

Ardaens, Kahle, and Schulze (2014) validated TanDEM-X's in-flight performance using the German government. They found that 10m resolution improved relative control and autonomous formation control. Gruber, Wessel, Huber, and Roth (2012) used the least squares block adjustment method and found the TanDEM-X's absolute height error was better. Zama, Willem, and Adriaan (2014) compared land components from five different Digital Elevation Models, revealing that SRTM DEM was more suitable for delineating land components. Xiaoxiao *et al*. (2023) used three generated DEM GF-7 method 1, GF-7 method 2, and GF-7 method 3 to verify with LIDAR data in a section of Haiyan fault. The result indicated that the accuracy of GF-7 DEM method 1 was the worst and that GF-7 method 3 performed better than GF-7 DEM method 2. The following showed that vertical and horizontal offset could be accurately measured using the DEMs generated from GF-7 stereo images.

Mukul, Srivastava, and Mukul (2015) validated the vertical accuracy of X- and C-band SRTM data sets using data from the IGS Network. They found that different continents agreed on the STRM vertical accuracy of 16m and RMSE of 10m. Sridevi, Shrungeshwara, Kumar, Choudhury, Dumka, and Bhu (2017) tested SRTM data sets in the Indian, Himalaya, and Peninsula regions. They found that the data decreased with slope and elevation due to large outliers and voids. Olalekan and Castro (2013) assessed the quality of SRTM v.4.1 and ASTER-GDEM version 1 from NASA/METI, finding stronger correlations in flat terrain and better correlations in mountainous terrain. Antonios, Pierre, and Kostas (2010) found different slope inclinations among global DEMs, with SRTM smoothing out steep slopes due to coarser sampling. Rexter and Hirt (2014) found no significant disparity between SRTM DEMs, but ASTER GDEM had a Northeast to Southwest-aligned stripping error at the 10m level and an average height bias of 5m relative to SRTM models.

Guth (2006) compared twelve geomorphologic parameters from SRTM to NED for 500,000 sample regions in the United States. They found that STRM data had noise in flat areas and increased average slope, while SRTM had smooth topography and lowered slopes in high relief areas. Antonios, Pierre, and Kostas (2010) compared SRTM data sets in raster format to GPS data in vector format, ensuring proper blending with GPS measurements. Brown (2003) validated SRTM height data using passive targets and USGS DEM for calibration and validation. Hirt, Filmer, and Featherstone (2005) compared and validated ASTER GDEM ver1, SRTM ver4.1, and GEODATA DEM – 95 v.3, revealing vertical accuracy varying depending on terrain type and shape.

Arefi and Reinartz (2011) improved ASTER GDEM's accuracy using ICESat data, revealing high spatial resolution but height errors due to elevation accuracy and quality. TanDEM-X's absolute height accuracy was below 2m, moderate for terrain. Purinton and Bookhagen (2017) validated and compared satellite derived DEM's vertical accuracy, finding varying data sets' accuracies. Bildirici, Ustun, Selvi, Abbak, and Bugdayci (2009) evaluated height accuracy and 3D visualization in Turkey, finding SRTM DEM better than ASTER DEM. Nikolakopoulos, Kamaratakis, and Chrysoulakis (2006) compared SRTM DEM and ASTER DEM products in Crete, Greece, observing normal elevation distribution and misalignment. Kosman, Wessel, and Schwieger (2010) validated TanDEM-X with Kinematic GPS tracks, achieving height accuracy better than 0.5m and a 3m sampling on the ground. Thanh-Nhan *et al*. (2023) evaluated the six global DEMs products of MERIT, NASA, SRTM, ASTER GDEM2, AW3D3O and TANDEM X using the semi-distributed SWAT for the Lai Giang River basin, Vietnam. Criteria like statistical analysis were used it was revealed that NASA and STRM 30 DEM were most accurate while ASTER DEM 2 provided the worst MERIT, ASTER, GDEM 2 and STRM 90 provided inaccurate basin delineations.

3. METHODOLOGY

The diagram below summarises the general procedure for the research conducted in this study.

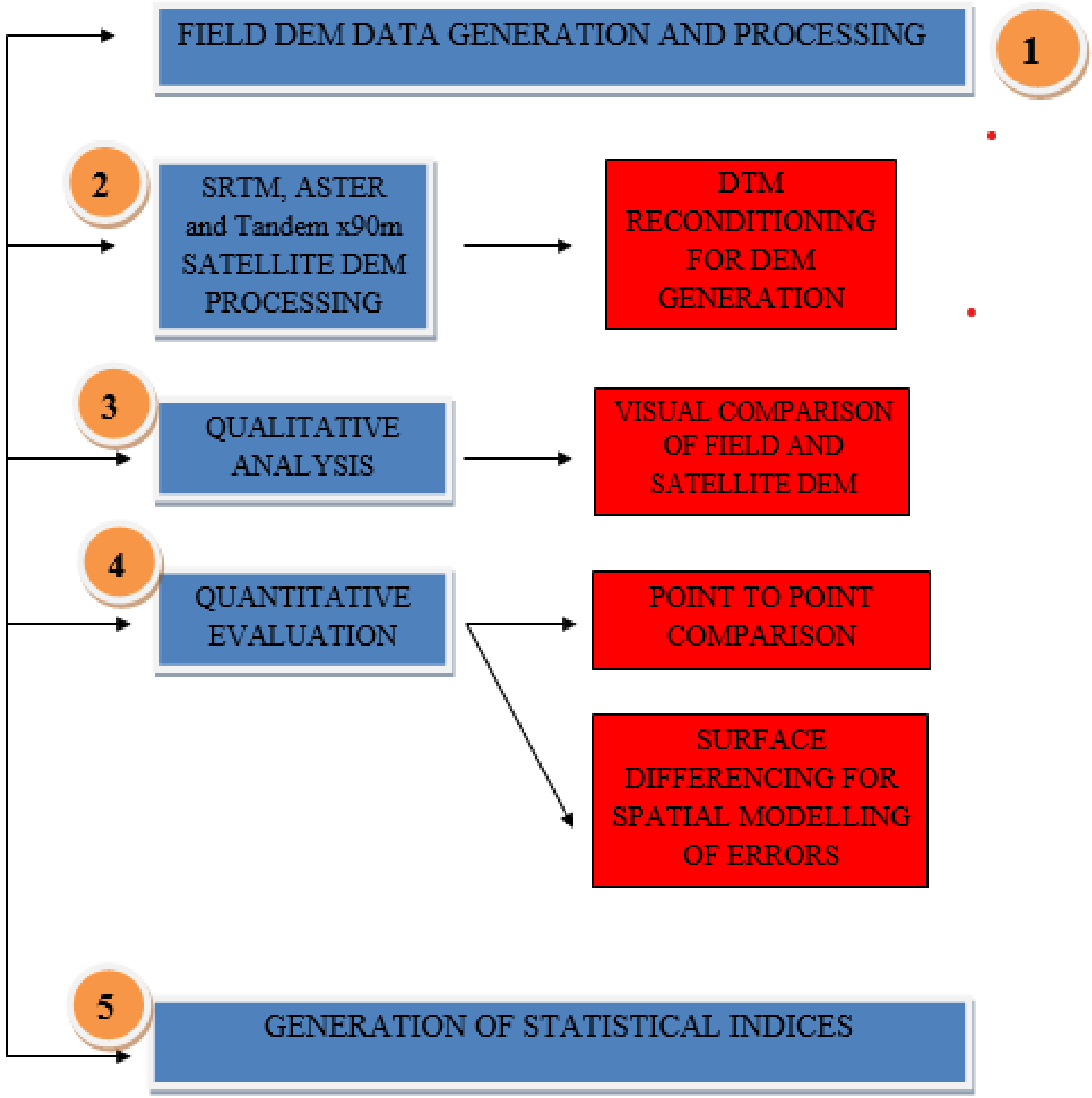

Figure 1: Flow chart showing summary of work conducted for the research.

The University of Uyo Main Campus was selected as a test site for this study because of the rolling terrain in the area with sparse vegetation (low grassland) A significant portion of this area has shape drops in landform being that it is still underdeveloped (a greater portion of it is virgin). It is located in Uyo. Uyo is the state capital of Akwa Ibom. It is located within the latitudes 05° 02’19’’N and 05°02’33’’N and longitudes 07°58’49’’E and 07°58’49’’E. The topography of the region varies from lowland to hilly regions. See Figure 1

The Main Campus of the University along Nwaniba Road, Nsukara Offot Uyo is about 1,443 hectares. The main campus accommodates some buildings like the Central Administration, Faculties of Engineering and Natural and Applied Sciences, International Centre for Energy and Environmental Sustainability Research and the Postgraduate School.

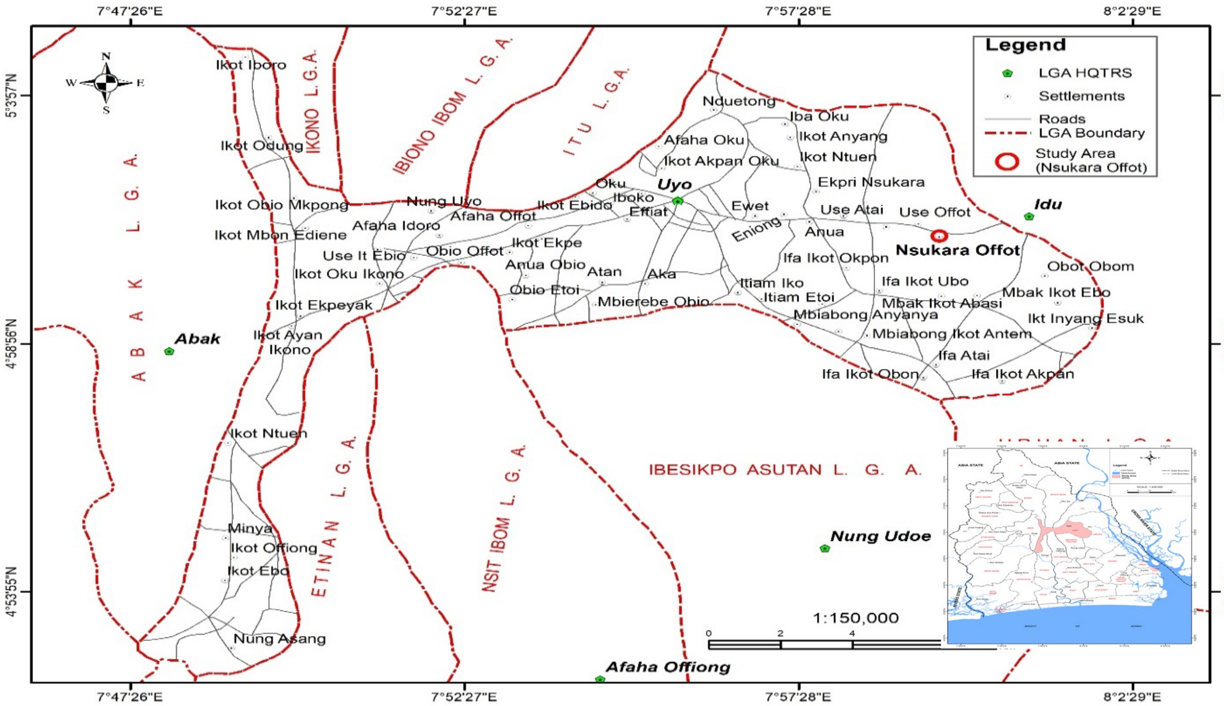

Figure 2: Map of Akwa Ibom State and the Study Area
Source: Physical Planning Directorate, University of Uyo, Akwa Ibom State.

The data requirement for this research includes elevation data from Advanced Space-borne Thermal Emission and Reflection (ASTER 30m DEM), Shuttle Radar Topography Mission (SRTM 90m DEM), TanDEM- X 90m and data from field survey using Total station, Spirit level and Real Time Kinematic (RTK) GPS receiver instrument for coordination of points on the field. Primary data obtained through direct field observation-ground survey method and Secondary Data Sources consisting of downloaded satellite Digital Elevation Models (DEM) from various hosted data portals by the operating nations of these satellites were generated and used for this research.

Other resources utilized in the study include a High Target V30 DGPS for the initial extension of GPS Controls to the site, a spirit level for perimeter levelling, and a Kolida Total station for spot heightening and detailing. To facilitate good data processing, the computer hardware used had a 2.16 Giga HZ Processor (Quad Core), Microsoft Windows 10 OS, 500GB HDD, 4 GB RAM and a 2GB VGA Graphic Card. The software employed for data processing includes Autodesk Civil 3D (for traverse data processing), ArcGIS 10.3 (DEM visualisation, manipulation and cartographic embellishment), SURFER 12 (verify the quality of elevation products in ArcGIS and for surface geo-visualisation), Ms Excel (statistical evaluation) and ArcGIS raster analyst module from the Spatial Analyst extension (for surface differencing).

The site was visited with the aim of inspecting, assessing and analysing the condition of the study area for reconnaissance. During the exercise, two existing controls were discovered at the University of Uyo Permanent Site. The coordinate information was obtained from the Department of Geo-informatics and Surveying University of Uyo. The coordinate of the controls (UUGS 5 and UUGS 6) served as the primary control used to extend control to the site. For the three instruments used for data capture, checks were performed thus; for the GPS, the distance between the two controls established was checked against tape measurements, a two-peg test to check for collimation error and a horizontal collimation test to check the consistency of vertical and horizontal angles. An Insitu check was also performed on the existing controls.

A high-target V30 GNSS receiver was utilised in the study for control establishment. The instrument has a range of ±2.5mm in the horizontal distance and ±5.0mm in the vertical distance when executing data acquisition in static or fast static mode. When carrying out Real Time Kinematic (RTK) data acquisition, it boosts 10mm in horizontal distance and ±20mm in vertical distance. UUGS5 was used as a base station as required in RTK systems acquisition. The base receiver was mounted over UUGS5 and the coordinate of the point enter into the equipment via the data logger. The height of the GPS receiver above the ground was also measured and recorded after setting up the instrument.

To coordinate a rover and in the process survey two new points (GPS001 and GPS002), the roving receiver was mounted on one of the new points and initialises to be able to see the same satellite as the base receiver and also receive subsequent correction from the base receiver. An icon on the system from the data logger indicates that the rover was ready to receive correction from the base with a cross with marks showing that the system was RTK enabled and in touch with the base station to get corrections. The rover was configured to log position at the rover for 10 minutes. This arrangement enabled rover surveying of the new stations (GPS001 and GPS002) which were the new controls established for further topographic data collection.

To systematically manage the accuracy and precision of point coordination in this research, a total station (Kolida KTS-440RC) was used to coordinate the traverse using the newly established GPS points as initial controls and later spirit levelling for vertical control coordination. To begin traversing, the orientation line was the baseline GPS 001 and GPS002. The instrument was mounted on GPS002 oriented to GPS001 and the coordination of the study area began with the point HA01. Traditional FL and FR (WCB) readings were taken at every station to ensure that at least two angle measurements were at every point.

The sequence of data capture was implemented in this manner from station to station enforcing angle readings by pointing to two stations from one station. This was how the traversing was carried out until all the points (HA01-HA021) were coordinated. A total area of 3.335 sq.m was achieved.

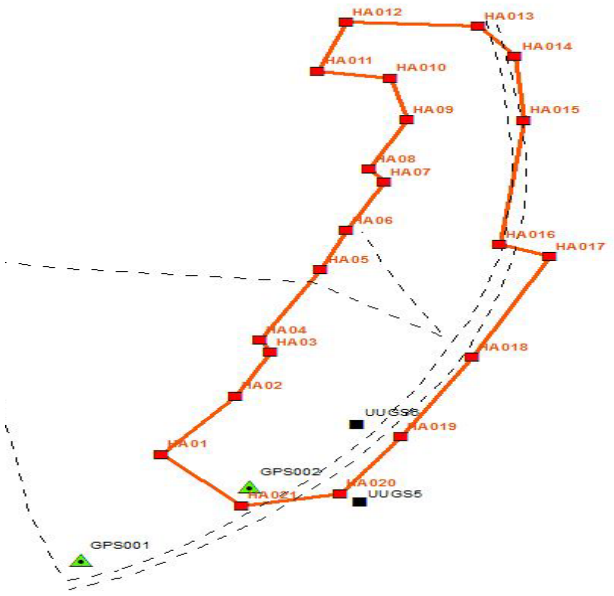

Figure 3: Schematic Diagram of the Study Area

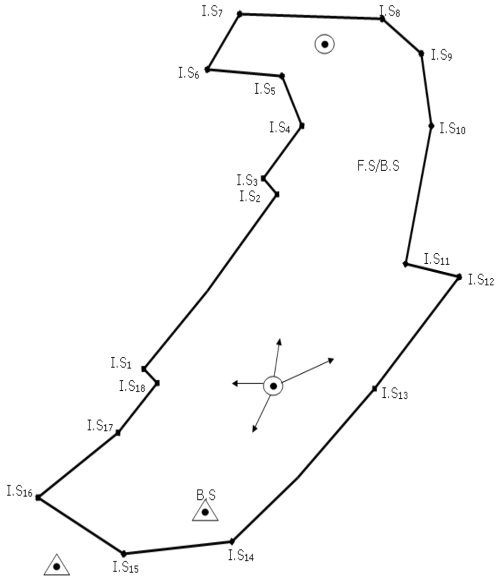

Figure 4: Schematic Diagram of Spirit Level

In furtherance of systematically improving the accuracy and precision of the coordination of points that formed the reference data for the validation of the satellite DEM. After the two-peg test, levelling was conducted around the boundary of the study area to describe the full configuration of vertical controls to be utilised for control densification (trigonometric spot heighting) describing a total distance of 995.150m.

The actual topographic survey was done using a total station for control densification of the study area using the earlier established x y z coordinates from Total Station traversing and Spirit levelling. At different locations of the study area and convenient sides of the boundary, orientation was carried on any two controls on the boundary before the extension and transfer of shots to new points to coordinate spot heights in the study area. In all, about five sides of the boundary were mounted for their baselines for orientation and coordination of spot heights by trigonometry levelling in the study area. The height of the instrument at each station during orientation was measured and inputted in the Total Station before the capture of any spot height. A total of 170 spot heights were coordinated in the study area including the boundary coordinates see Figure 5.

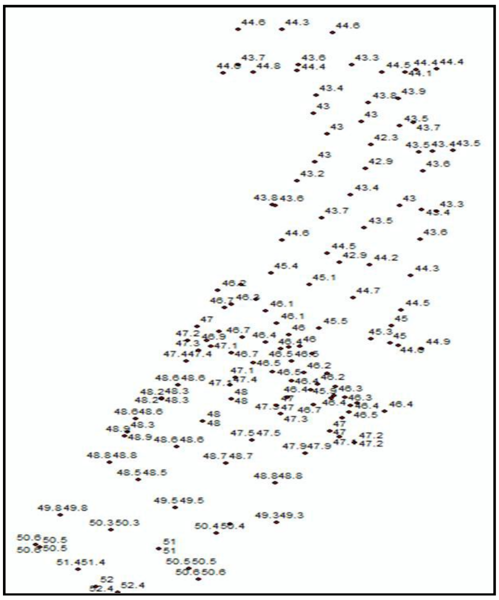

Figure 5: Sample of Spot Height by Trigonometric Levelling

These spot heights were captured in the field and were first processed in Excel and investigated for outliers. They were then ingested into Surfer, where a grid file was produced that was used for the generation of a digital terrain model to aid general visual interpretation of the terrain. The generated digital terrain model was tested for consistency by quickly applying different configurations of the Inverse Distance Weighing interpolation model (by varying the search radius, power and no of points used) and Ordinary Kriging with the geostatistical analyst in ArcGIS in a bid to make the "right choice" as regarding the better quality control reference surface (digital elevation model). These interpolators were chosen mostly because according to existing literature, they are known to handle very well abrupt changes in terrain and they are exact interpolators. Key indices used for the quality evaluation are the morphological appearance and the error indices taken in this case to be the root mean square error between the prediction surface and the original spot height points. The DEM reference surfaces were processed as ellipsoidal heights on the WGS84 datum as the focal DEM (Tandem-X 90m – see Figure 7) to which comparison would be made was processed and made available on the WGS84 datum.

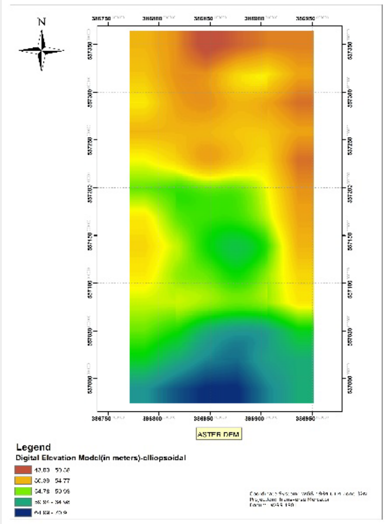

Figure 6: ASTER

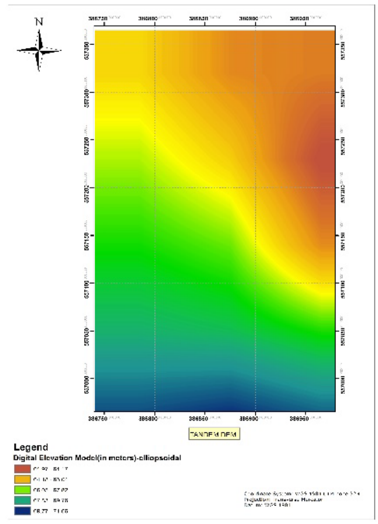

Figure 7: TANDEM

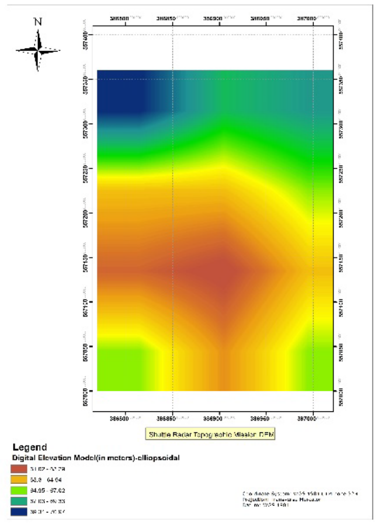

Figure 8: SRTM

The DEMs were collected from several types of research, public and commercial agreements downloaded from various platforms and were then subjected to clipping in ArcGIS to generate the needed common Area of Interest (AOI) for all of them. To support pixel-by-pixel comparison, vertical and horizontal referencing of these Digital Elevation Models (satellite DEM datasets) was done on the same datum of the WGS84 ellipsoid by re-projecting the DEMs from geographic coordinates (Lat/Long) on the WGS84 datum to UTM Zone 32 (AOI UTM Zone) by bilinear interpolation thereby allowing for metric analysis and interpretation and subsequent conversion of the ASTER (See Figure 6) and SRTM DEMs (Figure 8) to ellipsoidal height surfaces using the ArcGIS Raster Analyst tool with the appropriate geoid model.

4. RESULTS AND DISCUSSION

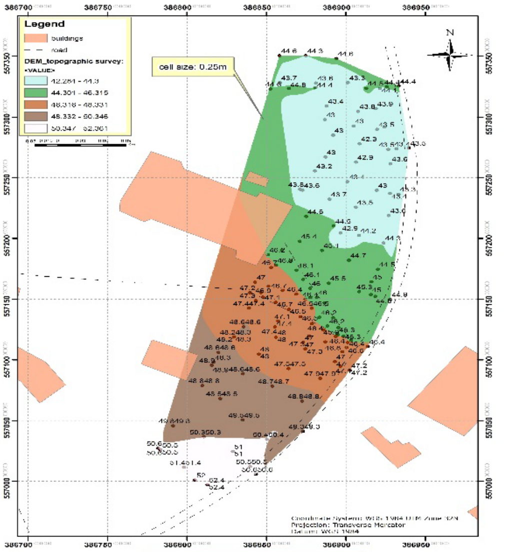

Figure 9: Topographic Survey of the Study Area

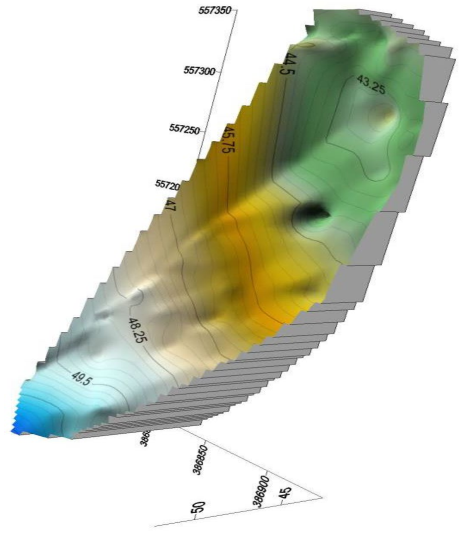

Figure 10: 3D Wire Frame of the Study Area

The Digital Elevation Model produced in Figure 9 has a cell size resolution of 2m and was produced from an inverse distance weighting interpolation method using over 170 spot heights coordinated in the field. The Digital Elevation Model shows a data range of 10m (42 – 52m) elevation. The elevation gradient here is the south-north direction as evident in the physical terrain from the researchers' observation. The terrain configuration shows decreasing from the south slope towards the centre and a rise on the right-hand side. Therefore, the character of gradient inclination indicates a terrain with a sagging outlook. The lowest point is 42.3 in elevation and is located on the right side of the study area when facing the administrative building (Science block-see Fig 11 below) which is almost at the centre of the area under investigation. The highest point in the study area is located on the left-hand side when facing the Science block at the extreme.

Figure 9 shows the Digital Elevation Model produced from the survey data as derived in the Surfer environment which shows a digital 3-D wireframe (surface) model of the study area which simulates very much the appearance of the terrain configuration of the study area. It should be noted that the direction of the gradient as indicated above (South-North) and the spread of numerical distribution in the data reflected on the surface. The model was developed in the Surfer environment.

To further affirm the value of the RMSE in our given geographical context. Evaluating the RMSE as it varies in a similar location became imperative. The site compared was highly undulating and about 5.174 hectares in area.

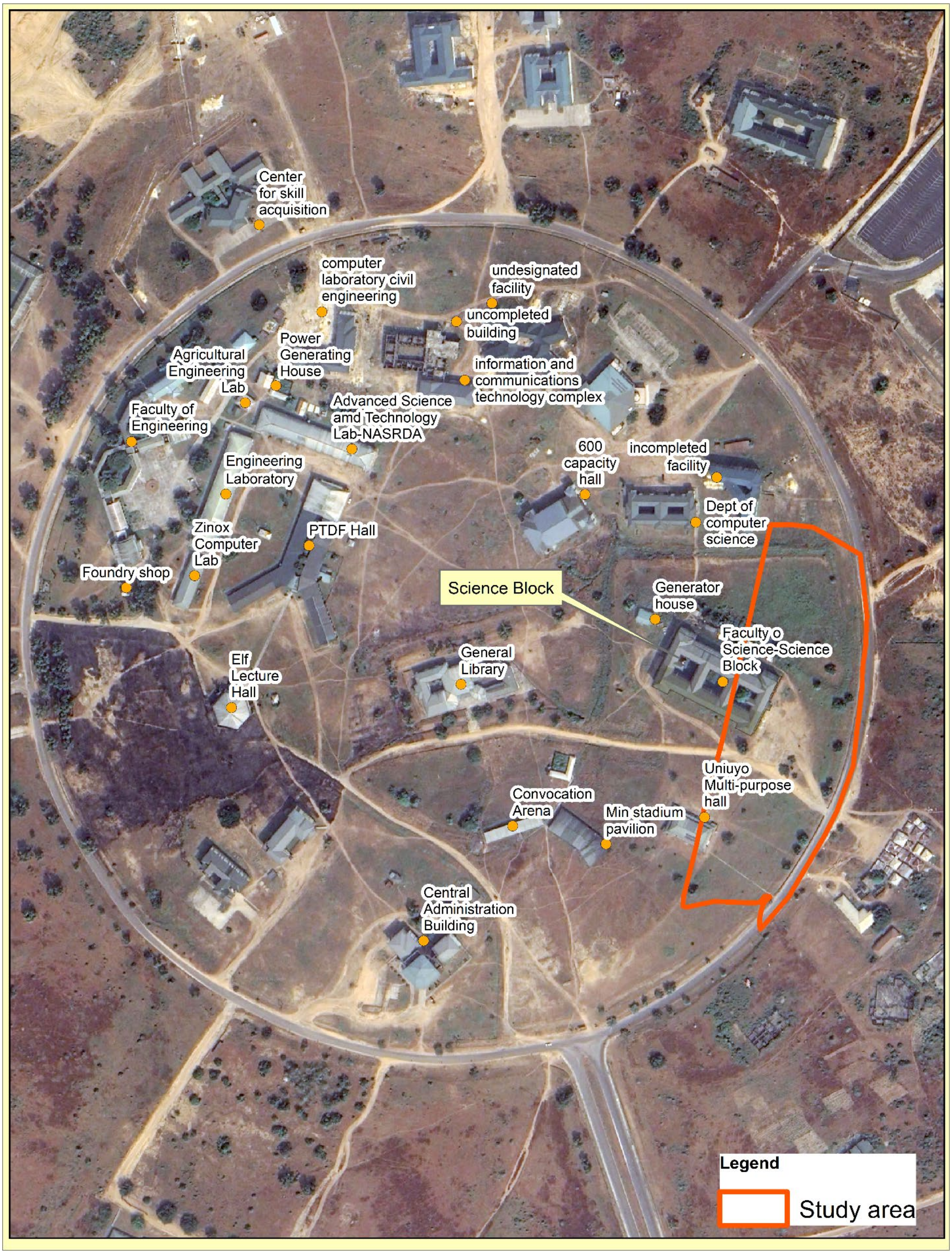

Figure 11: Map showing with Google Earth imagery background showing the study area and the Science block

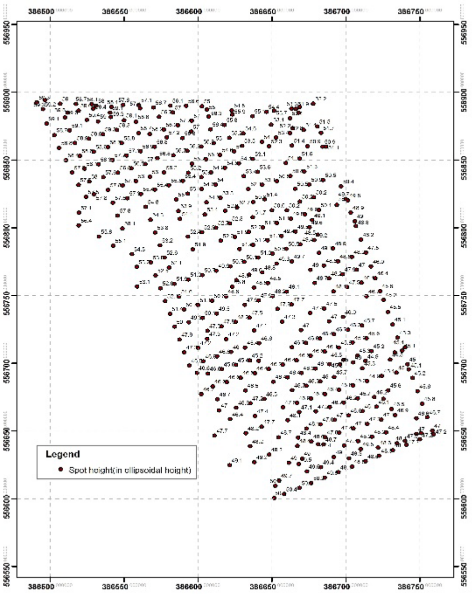

Figure 12: Spot Height Map of Site 2

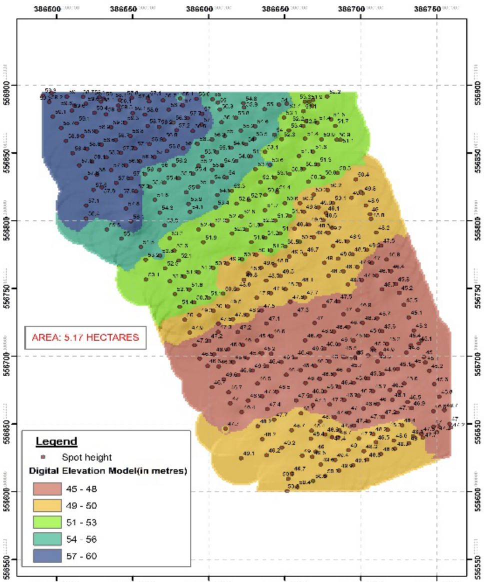

Figure 13: Spot Height Map of Site 2

The survey conducted on this site was carried out a year ago with a total station and the topographic survey by trigonometric levelling. The data was obtained from the University of Uyo Consult. The total number of spot heights captured in the field campaign was 403 spot heights. To develop the RMSE for the variation between the field data from this site and satellite DEM. Extraction was carried from the satellite DEMS for corresponding values of the Satellite DEMs for the corresponding values of the field-generated spot height data. As was the case earlier, Microsoft Excel was utilised in compiling the residuals between the field-generated spot height information and the extracted z-values from the various satellite-based DTM. The results are very significant as shown in the table, graph and bar chart below.

Table 1: Results of RMSE Comparison between ASTER, TanDEM and SRTM

LOCATION	RMSE_ASTER	RMSE_TANDEM	RMSE_SRTM
SITE 2	11.90	19.44	21.64
STUDY AREA	11.31	19.90	17.50

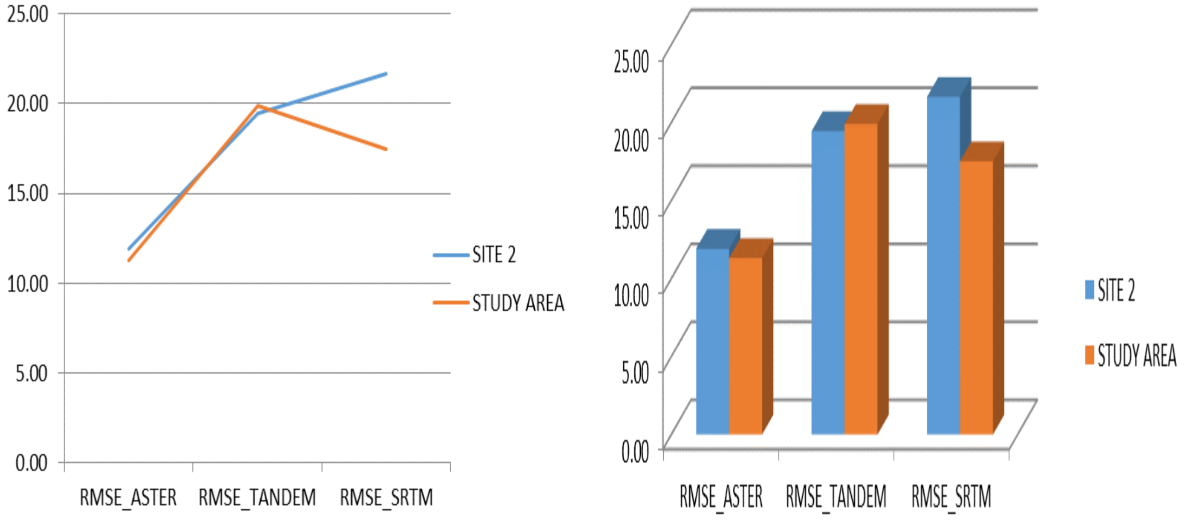

Figure 14: RMSE Comparison between ASTER, TanDEM X90m and SRTM

It is strikingly interesting to note that the ASTER and TanDEM X-90m have almost the same RMSE in the different locations while the RMSE for the SRTM DEM increased by 4m in the new location as shown in Figure 14. This may be unconnected by the fact the field data was captured in a time or the error incurred by SAR acquisition at the time of capture.

5. CONCLUSION

This study evaluated three global elevation datasets (SRTM-90m, ASTER-30m, and TANDEM X-90m) for vertical accuracy using field-generated Digital Elevation Models. ASTER DEM performed well in the study area, with a RMSE error difference of up to 9m and a 2% corresponding to ground locations. This is in line with the findings of Bandura and Gallay (2018), who opined that ASTER-30m has more accuracy among other tools. However, TANDEM X 90m showed the lowest standard deviation and standard error, indicating poorer variation in spatial changes. The DEM's overestimation of DEM compared to the original 12m posting confirms systematic error propagation from aggregation, re-interpolation, and classification. From a mapping perspective, we can safely conclude that the TANDEM X 90m can be used for making maps at contour intervals of 50m above (1:500,000 mapping) being that vertical accuracy standards require that the elevation of 90% of all points tested must be correct to within half of the contour interval, as indicated by analysis in this research. Also, this research has further established that the ASTER DEM overestimates elevation (from the known accuracy of ±20m) in the study area, while the SRTM datasets underestimate elevation in the study area (from the established specification ±16m) in the study area.

The study found that digital elevation models have different resolutions and accuracy levels. Tandem-X90m has a resolution of up to 3 meters, while Aster and SRTM have 30 meters. GPS-based field digital terrain models provide higher accuracy, while Tandem-X90m has a 10 cm accuracy. The models cover a limited area, making them suitable for high-resolution elevation data. The data collection methods used by the models, such as SAR sensors, also affect their accuracy and resolution. Based on the above comparative analysis, it can be recommended that the GPS-based field digital terrain model is suitable for high-accuracy and high-resolution elevation data in a limited area. Tandem-X90m is suitable for high-resolution elevation data in a limited area but is expensive. Aster and SRTM are suitable for global-scale studies but have lower accuracy and resolution.

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