A COMPARATIVE ANALYSIS OF ASTER AND SRTM DIGITAL ELEVATION MODELS FOR TOPOGRAPHIC CHARACTERISATION OF IFE CENTRAL LOCAL GOVERNMENT AREA, OSUN STATE, NIGERIA

BY

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ABSTRACT

Understanding topographic surfaces and features is critical to providing ecological explanations for numerous consequences of human-environment interactions. However, there is a lack of regional information about the Nigerian environment, probably because topographic analysis often requires lengthy fieldwork. New advances in geographic information systems and remote sensing also point to the need to introduce publicly available open-access data and simplified procedures. This study is a simplified analysis of digital elevation models (DEM) from the open access records of the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER Global DEM) and the Shuttle Radar Topography Mission (SRTM). The main objective was to compare the slope, aspect, elevation, and topographic index of some selected topographic features in Ife Central Local Government Area of Osun State, Nigeria. Using ArcGIS software, the DEMs for the same period were extracted from the ASTER and SRTM data and were compared. The results showed comparative qualitative differences in the extracted forms of drainage properties, topographic index, and slope aspect, but did not show that the values were statistically different at the 95% confidence level. The study concluded that the DEMs, have differences that, if not thoroughly examined, can lead to inaccurate, erroneous, or incomplete results. Further research is recommended on quality control and comparative quality evaluation of widely used remote sensing products from missions whose ground controls are located outside of the nation.

Keywords: Digital elevation models, Medium-size settlements, Remote sensing, Topographic analysis

INTRODUCTION

Topography is described as a study or record of relief or terrain (Kane, 2017). The three-dimensional quality of the earth's surface and the identification of specific landforms is also known as geomorphometry. Topography can be described as the arrangement of features (natural and anthropogenic) on the Earth's surface (Lyle et al., 1987). It includes landforms and their characteristics, including mountains and valleys, but also rivers and anthropogenic features such as roads, built-up areas, and bridges. Previously, the term topography was synonymous with making measurements through direct or indirect surveying and mapping techniques (Zonneveld, 1989). The direct surveying method requires the use of basic surveying equipment, including tape measures, Günter chains, and theodolites, while the indirect method involves, among other things, the use of inclinometers, and requires a significant amount of mathematical calculations that can be difficult for non-experts (Venkatramaiah, 1996). Additionally, until recent advances in digital surveying equipment such as total stations, geodetic global positioning systems, and satellite remote sensing, some places were considered dangerous (e.g. habitats of certain animals - e.g. lions, tigers, etc.), war/crisis areas and epicenters of earth movements - including earthquakes, volcanoes, etc. – were considered unreachable (Awange & Kiema, 2013).

Until the advancement of 2.5 and 3D multidate satellite data, little information about changes in landforms was available in many parts of the world, particularly in developing countries, due to significant cost and labour implications. For example, the majority of Nigerian topographic maps were obtained as part of the 1961 area survey missions. This was the last time the country embarked on such a national area survey project on this scale (information from Nigeria Sat 1 and 2 did not reveal any such), and many parts of the southern part of the country were covered in noise (especially clouds). Poor mapping makes planning difficult and is likely a major challenge to security and resource planning in the country (Umble et al., 2013).

Topography or terrain representation is a major focus of DEMs for many applications including geology, hydrology, urban planning, and environmental modeling (Vadon, 2003; Menze et al., 2006; Evans & Hengl, 2009; Tsang et al., 2022). Sources of DEMs are mainly remote sensing - the technology of obtaining information from the earth's surface using a device that does not come into physical contact with the object (Jackman, 1962; O'Sullivan, 1983; Stoodley & Schmahmann, 2008). This technology includes LiDAR (light detection and ranging), photogrammetry (aerial imagery and optical satellites), and satellite-based radar systems (synthetic aperture radar satellites) (Whiting & Dietrich, 1993; Elden, 2010; Kane, 2017). The DEM is created from elevation data when the data is processed and converted into a digital format and is often stored as a grid or raster data set, where each cell or pixel represents a specific location on the Earth's surface and contains the elevation value for that location (Koehler et al., 2022).

Studies (e.g. Marcus & Fondsstat, 2010; Entwistle et al., 2019; Polidori & El Hage, 2020; Muthusamy et al., 2021) have argued that digital elevation models (DEMs) are suitable for various applications in areas such as hydrology and geology, urban planning and environmental modeling are crucial. They also provide a representation of the earth's surface in a digital format, enabling the analysis and visualization of terrain features. However, the accuracy and reliability of DEMs are critical to obtaining meaningful results and making informed decisions based on the data. Common questions related to DEM adoption include those focused on accuracy assessment and validation of DEMs, as well as determining appropriate data sources and collection techniques to generate high-quality DEMs. Addressing these concerns will help improve DEM accuracy, reliability, and usability in various applications.

This study focuses on extracting topographic information from freely available (open access) Digital Elevation Models (DEMs) resources for planning purposes. A DEM is a digital representation of the Earth's terrain, specifically the elevation or elevation information of the land surface. Burrough and McDonnell (1998) described DEM as a quantitative model of a portion of the Earth's surface in digital form that has evolved with advances in geographic information systems (GIS). A GIS is a computer-based system that includes a network of hardware, software, programs/algorithms, and people (users and expertise) for data collection, storage, processing, analysis and management, and information presentation to provide decision support an earth-related problem (Saba et al*.,* 2021).

In particular, the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) and the Shuttle Radar Topography Mission (SRTM) are the key USGS products that are the subject of this study. Because of their nearly global coverage, the two elevation datasets are the most widely used (of all USGS elevation products) for a variety of applications (Nikolakopoulos & Chrysoulakis, 2006). Recently, numerous regional and local evaluations of these products have been conducted by numerous researchers in developing countries, most likely because they are freely accessible. Therefore, this case study focuses on a medium-sized settlement in a predominantly residential local government area in southwestern Nigeria. Only the somewhat outdated topographic map with a resolution of 1:50,000 from 1962 to 1970 provides information about elevation datasets in the region. The specific objectives of this study are to evaluate the relevance of common digital elevation models in the determination of selected topographic and drainage characteristics and their spatial distribution across Ife Central local Government area, Osun State, Nigeria. A better understanding of DEMs for topographical features will be possible by being aware of the quality of the existing sources.

THE STUDY AREA

Ife Central Local Government of Osun State (Figure 1) is located between Latitudes 7°33′31.3″N and 7°24′13.32″N, and Longitude 4°28′45.46″ E and 4°39′17.78″E. The region which is found in the southwestern part of Nigeria lies at the intersection of roads from Ibadan (64 km west), Ilesha, and Ondo. Ife-central is divided into 11 wards; Ilare Ward 1-4, Iremo Ward 1-5, Moore-Ojaja, and Akarabata. Ife-Central local government area is situated on an elevation of about 375 meters above mean sea level. This city is in a bowl-like physical layout as a chain of seven hills surrounds it. But more than that, the city as observed today sits on a ‘cap-like’ structure with the center as the highest point in the town (Eluyemi, 1978).

Ife Central is underlain by a basement complex rock composed mostly of granitic rocks and schist. The granitic rocks consist of banded gneisses and pegmatite whilst the schist are composed mainly of mica schist and sillimanite-quartzites. A prominent feature of this geology is the occurrence of basic and ultrabasic rocks which are commonly found as amphibolite, meta pyroxenites, meta-ultimates, and talc-rich schists (Eludoyin et. al*.,* 2023*)*. The varieties of rocks may give rise to the sand of different compositions giving a potential glass maker access to several varieties of recipes. For example, the granitic rock is a source of alumina, and potassium whilst the quartz sillimanite schists are rich sources of alumina and silica. The manganese content could be derived from soils overlying weathered high magnesium, high iron mafic ultramafic rocks which are abundant in Ife and surrounding areas.

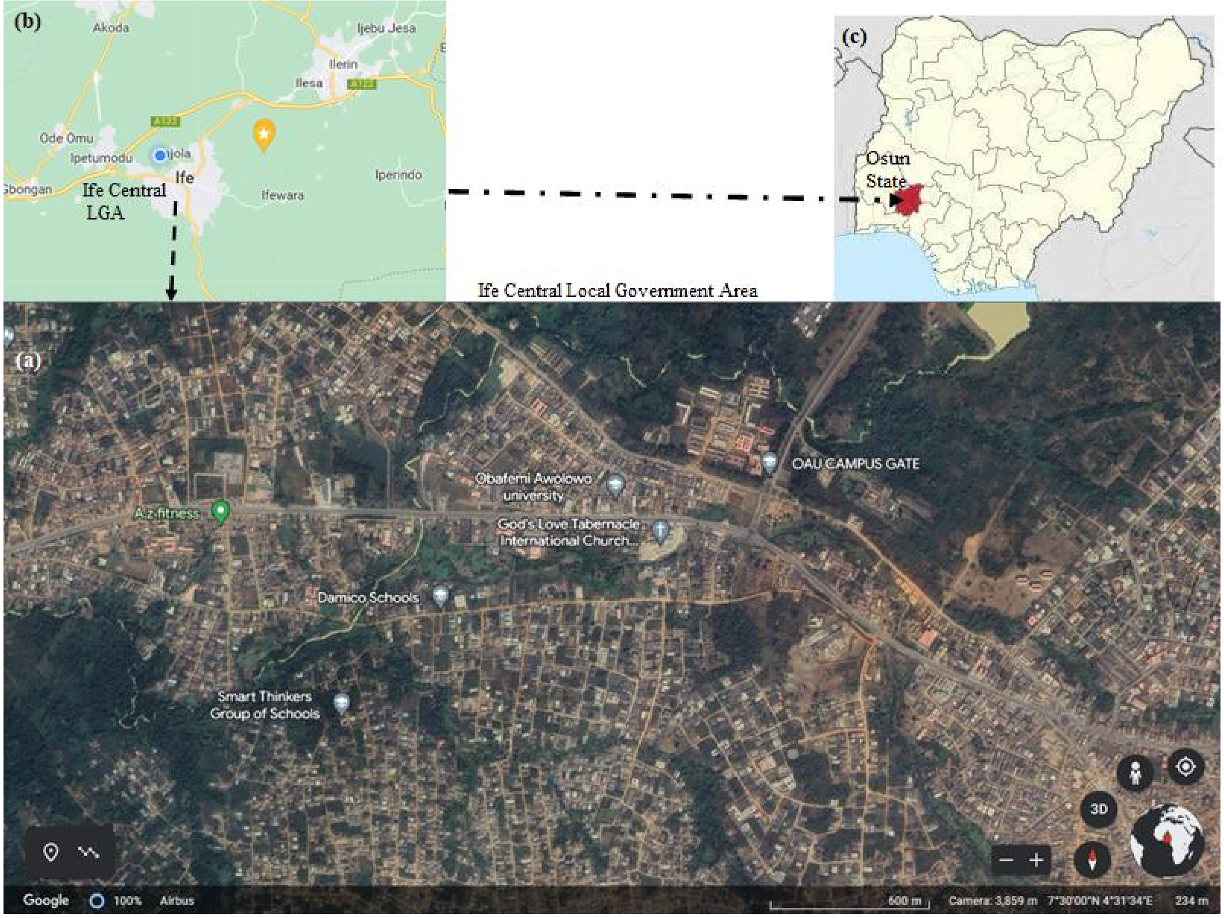

Figure 1. An aerial view of Ife Central Local Government Area (a) in Ile-Ife (b), Osun State, Nigeria (c)

These rocks are also extensively rich in base metals such as nickel, and cobalt (Ige et al., 2005) which could have been weathered and deposited as sand. Mixtures of such sand are still seen today in Alluvia sands in and around Ife Central. It has already been reported that iron masters in the Ile-Ife area have exploited a variant of such sand in making high-quality steels (Ige & Rehren, 2003). The study area is in the tropical humid climate zone (Eludoyin et al., 2014). The mean minimum temperature reported, ranges from 20^{o}C in January to 23^{o}C in February, whilst the mean maximum for the hottest month (August), is 27.6^{o}C. The average annual rainfall is 1250mm. The two prevailing seasons are the rainy season (April-October) followed by the dry season (November-March) (Eludoyin & Adewole, 2020).

In addition, the predominant kind of vegetation in Ile-Ife is the rainforest. The minimum normal annual rainfall is between 1750 and 2000 mm. The undergrowth in a rainforest is restricted in many areas because of the lack of sunlight at the ground level. This makes it possible to walk through the forest. If the leaf canopy is destroyed or thinned, the ground beneath is soon colonized by a dense, tangled growth of vines, shrubs, and small trees called a jungle. The soil is mainly derived from materials of the old basement complex, which is mainly made up of granitic metamorphosed sedimentary rock. An important category of soils in the Ife area is the

Itagunmodi series which is well known for its significance in cocoa cultivation. Soils belonging to this series are some of the best cocoa soils in Western Nigeria (Adewole, 2023)

MATERIALS AND METHODS

Data

Both primary and secondary data were used in the study. The primary data used in this study were the coordinates (x,y,z) of a few conspicuous locations on the earth that were located on the imageries acquired (secondary data). The coordinates were obtained using a Global Positioning System (Garmin (etrex 10) version ±5m accuracy level). The secondary data included the SRTM (Shuttle Radar Topographic Mission) DEM (Digital Elevation Model) and ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) DEM data of the study area.

A 30m SRTM data was downloaded from the United States of America's Geological Surveys' site (USGS Earth Explorer, http://earthexplorer.usgs.gov/), following the steps provided in a tutorial video (https://youtu.be/0YPFegTcL4w) The 30m SRTM DEM were used for creating auto photos, performing atmospheric and terrain corrections and for performing various topographic and elevation analysis. Following the tutorial, the image of the study area was downloaded from the USGS archive after observing the registration procedure. In doing this, *the SRTM* sub-folder (under the *Digital Elevation* folder) was selected and downloaded as *SRTM 1 Arc-second global*, with corresponding *GeoTIFF 1Arc-second*. In addition, ASTER DEM was downloaded from NASA's earth data site (Earthdata Search NASA, ‘http://search.earthdata.nasa.gov/search’), following the procedure explained in https://youtu.be/roryIl0EWlI. Both SRTM and ASTER data were processed and evaluated for selected topographic (slope, aspect, elevation, and topographic index) and drainage characteristics (number of streams, stream flow accumulation, stream order, and length), due to their relevance in hydrological studies (Beven et al*.,* 1995).

Data Analysis

The DEMs were first processed for geometric (through geo-referencing), and radiometric (through filtering) errors to correct for locational misplacement and noises, as advised in literature (e.g. Das & Ghosh, 2016). The DEMs were processed using ArcGIS (version 10.2) software, based on availability. The DEMs were introduced into the GIS environment by dragging the files from the folder (in which it was downloaded) into the *Layer* tab at the left side of the application. The file was thereafter clipped using the *clip tool* which first requires the needed shape file of the location to be extracted. The spatial distribution of the selected topographic characteristics was displayed using respective tools in the software application (Table 1).

Table 1: Information showing the process by which the selected topographic characteristics were derived

Topographic Characteristics	Process Of Derivation From ArcGIS (System Toolboxes >Spatial Analyst Tools)
Slope	> Surface > Slope (using ‘percent rise’ output measurement)
Elevation	The DEM clipped stood in for an elevation map.
Aspect	> Surface > Aspect

Topographic Index	>Map Algebra >Raster Calculator >input 'ln(flow acc./tan slope)' (overlaid on Elevation)

Selected procedures were linked to the *System Toolboxes* and *Spatial Analyst tools* tab options in ArcGIS (10.2 version) software. To extract the slope and aspect map, *the Surface* tool was selected and a list of surface-related tools was arranged with the DEM as input elevation map. Topographic Index (TI), a function of flow accumulation in an area (Beven et al., 1995) was extracted using *Raster Calculator*, within the *Map Algebra* tab option. The specific procedure for determining the investigated parameters is presented in Table 2.

Table 2: Information showing the process by which the selected drainage characteristics were derived

Drainage Characteristics	Process of Derivation (ArcGIS > System toolboxes > Spatial Analyst Tools)
Number of Streams	Addition of all the orders of the stream.
Flow Accumulation	>Hydrology >Fill Then, Hydrology > Flow Direction (using the 'fill' as 'input surface raster') Then, Hydrology >Flow accumulation
Stream Order	>Map Algebra >Raster Calculator (input 'Con (FlowAcc_flo >100, 1) > Stream Order (using the rastercalc result and flow direction).
Stream Length	>Hydrology >Flow length (flow direction is needed)

Flow Accumulation map was determined using the *Fill raster* file in the *Hydrology* tab option of the software. A DEM is expected to be *filled* as a means of improving the accuracy and precision of the DEM, followed by the determination of *Flow direction* as previously described in Table 2. Stream order was acquired with *Raster Calculator*, after which the corresponding stream order map was derived with flow accumulation map. The number of streams was determined by adding up all the values in each stage of the order while maximum and minimum stream lengths were generated using the *Flow Length* tab option of *the Hydrology* tab after the raster file had been reclassified to generate numeric values to the map created through viz:

ArcGIS v10.2 >System toolboxes >Spatial Analyst Tools >Reclass >Reclassify

Stream length was also obtained as *flow length* or *streamline*, while the difference in stream volume was determined based on the elevation records to relate topography with drainage in the area. The contrast in specific parameters of ASTER and SRTM DEMs was obtained with both visual comparison and Independent t-test (equation 1).

$$t = \frac{\bar{x}_1 - \bar{x}_2}{\sqrt{(S_1^2 / n_1) + (S_2^2 / n_2)}} \qquad (1)$$

where

t = t-value (difference in mean values relative to the variation in the sample data,

$\overline{X_1}, \overline{X_2}$ = sum of all the means derived from ASTER DEM, and SRTM DEM, respectively,

S_1^2, S_2^2 = the squared sum of all the standard deviations in ASTER and SRTM DEM, respectively

n_1, n_2 total number of data in ASTER and SRTM DEM, respectively.

Means and standard deviation were already derived from previously reclassified raster files

RESULTS AND DISCUSSION

Spatial distribution of the selected topographic characteristics

The slope of the study area varied from 2.64% to 40.14% in ASTER DEM and 2.67 % - 45.62 % in the SRTM DEM, indicating cumulative insignificant difference (Table 3), although the images project an obvious visually different pattern (Figure 2a-b). The pattern was similar for elevation and aspect, which depicted spatial angular variability (0 - 360°) (Figure 3a-b), albeit with significantly different values of the Topographic Index (TI). While the TI varied as - 48.33 - 100% in ASTER, it was -31.42 – 100% in SRTM (Figure 4a-b). In general, the results indicated that ASTER and SRTM DEMs produced spatially different results, despite that the values can be similar.

This observation is similar to that of Jing et al. (2014) in a subtropical landscape in Southeastern China. Jing et al. (2014) noted that ASTER and SRTM DEMS may not produce the same accuracy at the same topography and that ASTER could be a good alternative for areas where extensive voids exist in SRTM. Similarly, Pham et al. (2018) reported mean bias of 47% and 20% for mountainous sites and 16% and 58% for low-relief sites, with SRTM and ASTER DEMs, respectively. In general, the differences in the topographic explanations produced by the two commonly deployed (i.e. ASTER and SRTM) sources of DEMs as alternatives in many studies cannot therefore sufficiently be described as being explicitly homogenous – i.e. they do not perform each other's role.

Table 3: Range (minimum-maximum) of topographic characteristics derived from ASTER and SRTM DEMs

Topographic Characteristics	ASTER	SRTM
Slope (%)	<2.67 - 40.14	<2.67 - 45.62
Elevation (km)	15.9 - 35.3	17.3 - 35.3
Aspect (°)	0 - 359.51	0 - 359.19
Topographic Index (%)	-48.33 – 100	-31.42 – 100

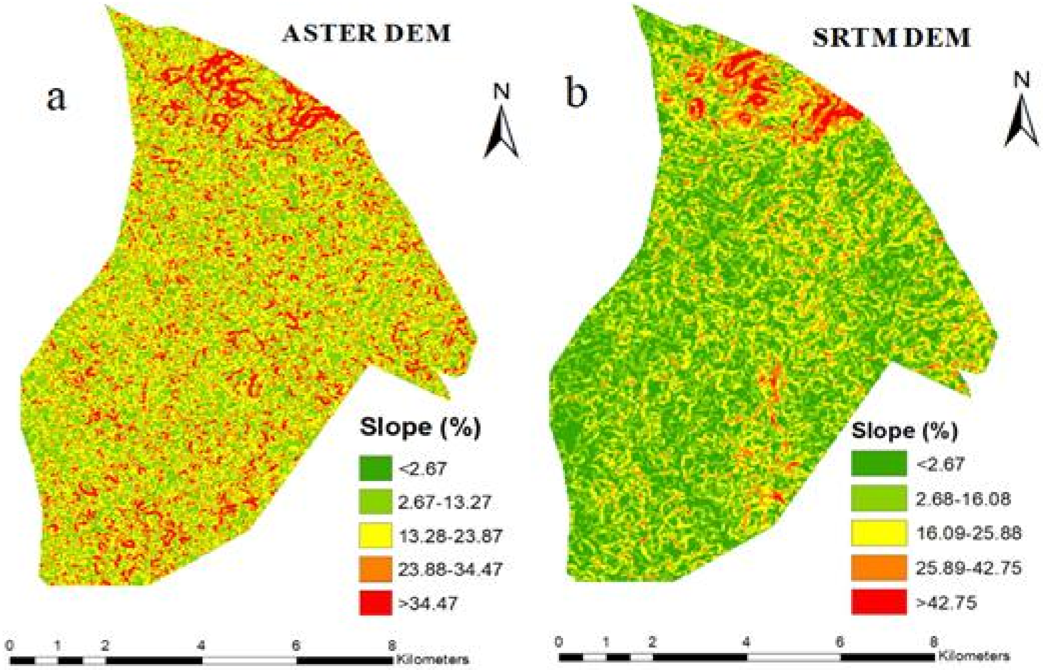

Figure 2a-b: Spatial distribution of the Slope (%)

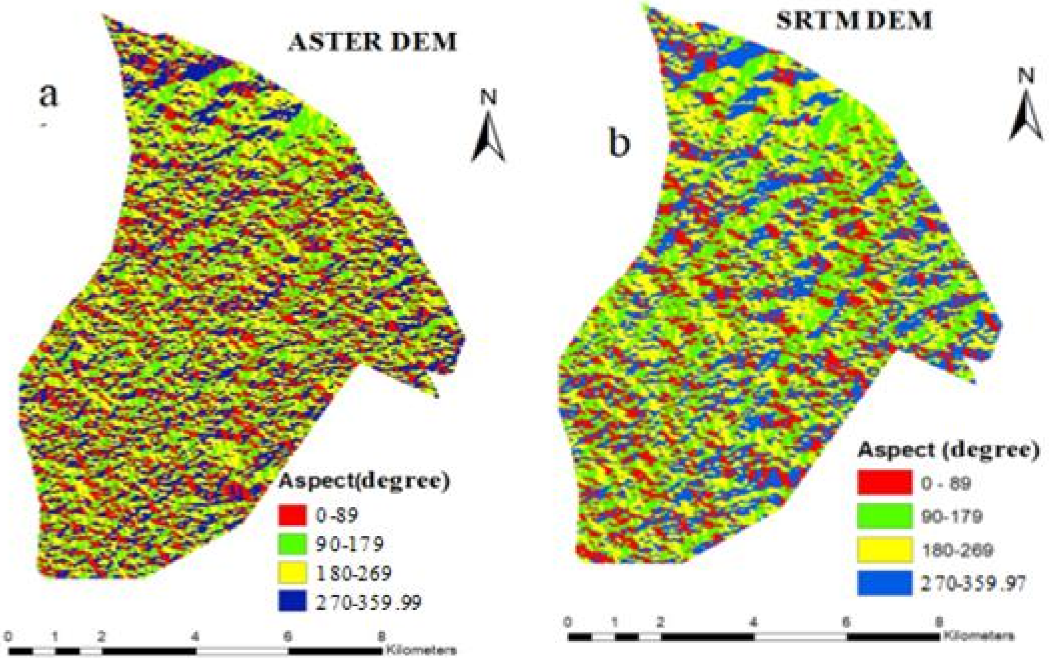

Figure 3a-b: The spatial distribution of the aspect

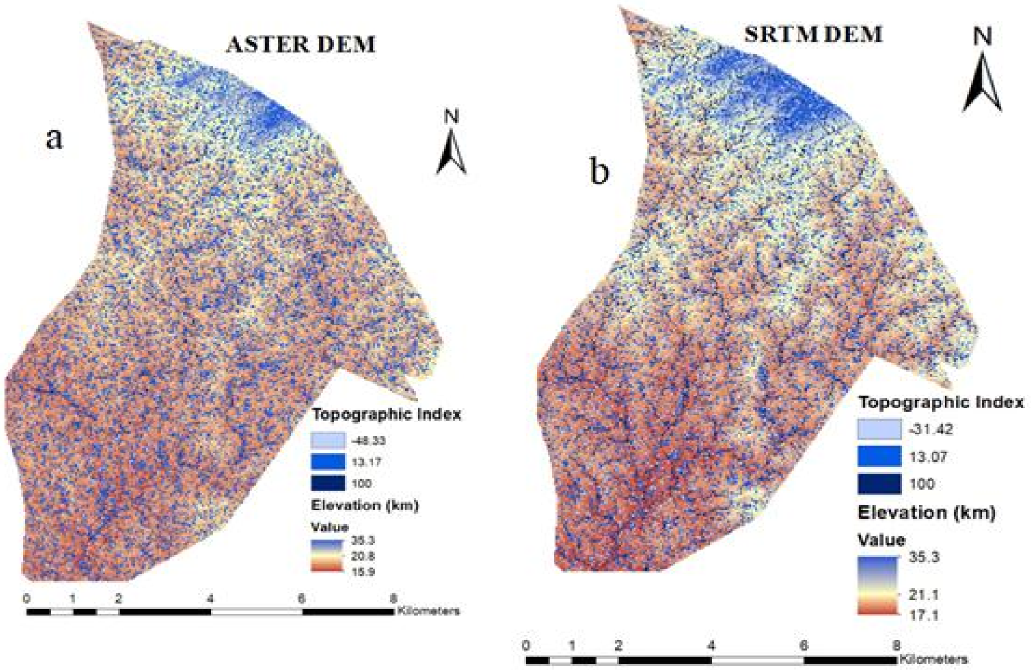

Figure 4 a-b: Result of overlay of elevation data aimed at revealing the area of higher hydrological activity

Drainage analysis

Results of the analysis of flow accumulation of the study area are presented in Table 4. Both DEMs showed that the flow accumulated in the south than in the northern part however, the number of streams, and the intensity of flow differed. Where there were five streams with three major and two headwaters in the ASTER GDEM, the SRTM displayed four streams; one major and three headwaters (Figure 5). Also, 204 streams were identified in the ASTER GDEM with more than three fourth-order streams, 11 third-order streams, 33 second-order streams, and about 157 first-order streams based on Strahler's stream ordering principle (Strahler, 1964). However, a different result was derived from the SRTM DEM with 195 streams in total, two fourth-order streams, 10 third-order streams, 31 second-order streams, and 152 first-order streams (Figure 6).

The results suggest the relative capacity of SRTM DEM to provide more information about the total number of streams than ASTER GDEM, and that of the latter to provide more explicit information for ordering (Sthraler) purposes. According to Hayakawa et al. (2008), ASTER GDEM appears to have fewer missing pixels than SRTM DEM, for steep terrain and may provide smoother and more realistic representations of drainage parameters, especially lowlands, valleys, and and mountain ridges, while SRTM DEM may tend to overestimate valley-floor elevation while it underestimates ridge elevation. The implication of this observation suggests that DEM-derived drainages may be better represented if the two DEM sources are combined.

Table 4. Information on selected drainage characteristics derived from this study

Drainage Characteristics		ASTER	SRTM
Number of streams		204	1925
Stream length (min-max) (km)		14 - 23	10 - 19
Stream order (Strahler's method)	Order 1	157	152
	Order 2	33	31
	Order 3	11	10
	Order 4	3	1
Flow Accumulation		5: (3 major outlets, 2 minor outlets)	4: (1 major outlet, 3 minor outlets)

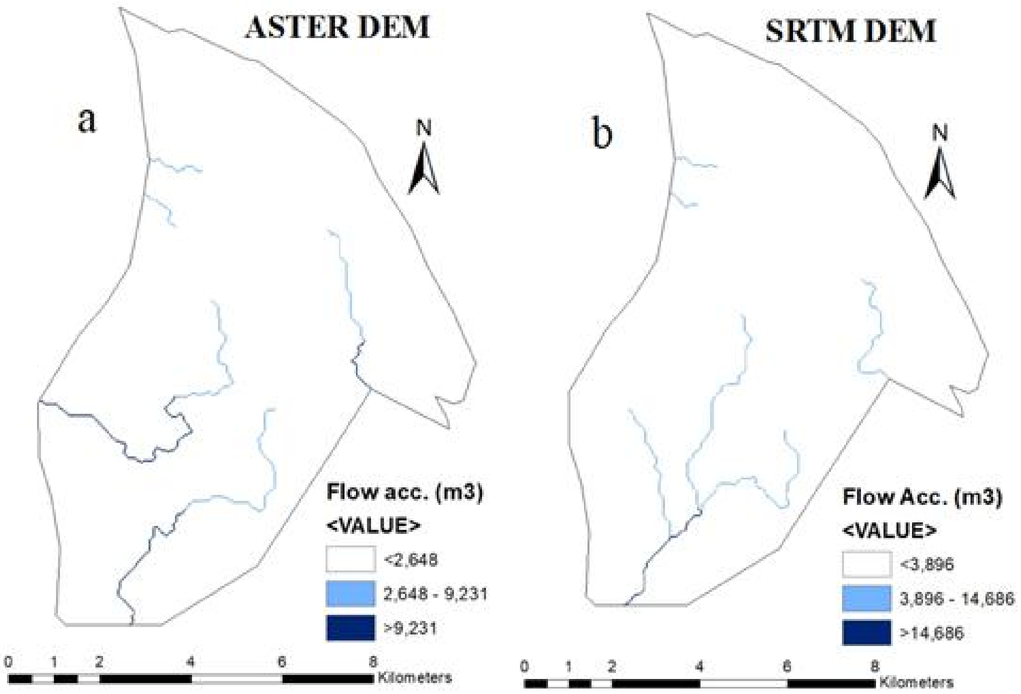

Figure 5: Difference in Flow accumulation in ASTER and SRTM DEMs.

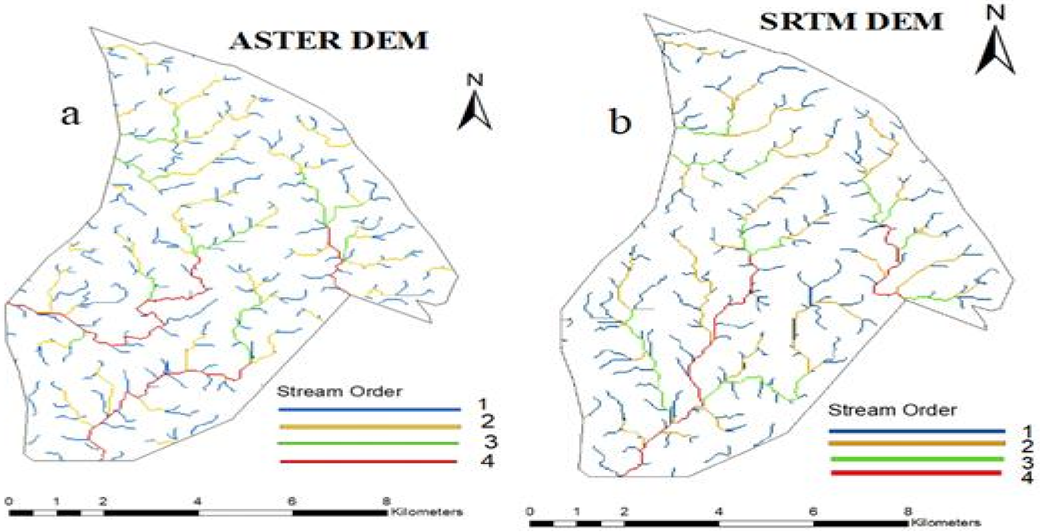

Figure 6: Stream ordering from both datasets

Stream volume – Elevation Relationship

Figure 7 shows the difference in stream volume concerning elevation in the ASTER and SRTM DEMs. The ASTER GDEM revealed an increase in elevation from 15. 9 km to 35.3 km in the south and northern part of the study area and the volume of the stream increases from about 1 m^3 in the north to 409 m^3 in the south. The SRTM DEM, on the other hand, showed a different result with an increase in elevation from 17.1 km to 35.3 km in the south and north respectively, and an increase in the stream volume from 1m^3 in the north to 380m^3 in the south; although the resulting trend remained similar for both DEM sources. When statistically compared, the result of the student t-test showed no significant difference between selected topographic characteristics (slope, aspect, elevation, and topographic index) of the study area with SRTM DEM and ASTER GDEM data despite their graphical dissimilarities ($t = 0.03 – 2.45$, $p > 0.05$).

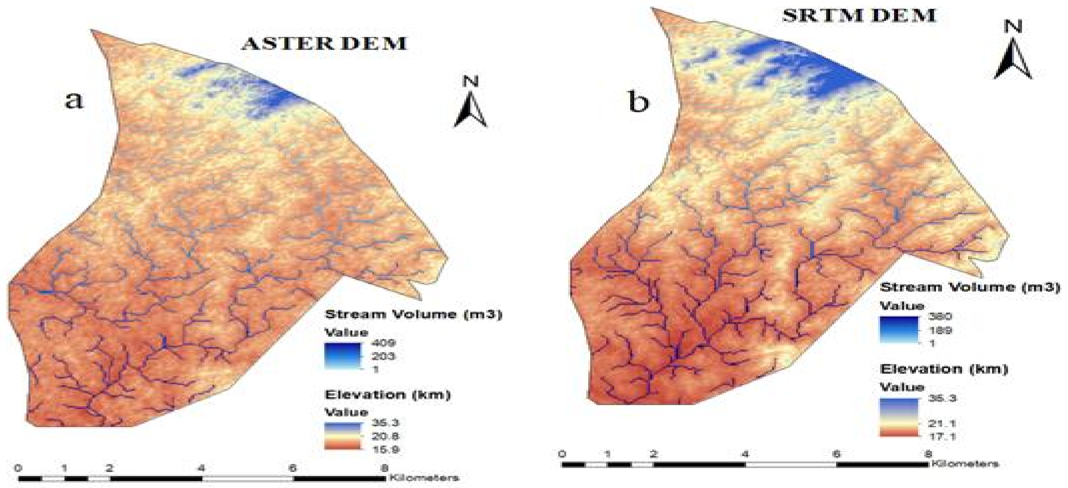

Figure 7: Difference in stream volume concerning elevation in ASTER and SRTM DEM

Elkhrachy (2018) found that SRTM DEM produced a comparatively much greater absolute vertical accuracy than ASTER GDEM in a study conducted in Saudi Arabia. While relative differences between the two DEMs' results occurred in this study, the differences are not displayed in the mean or aggregate values but rather in relatively smaller homogenous groups. This likely supports the finding of Nikolakopoulos et al. (2016) that comparing SRTM- and ASTER-derived DEMs allows for a qualitative rather than quantitative assessment of the effects of elevation differences between the two DEMs. However, in data-poor or ungauged environments, like those found in sub-Saharan Africa, particularly Nigeria, these differences can be significant. This supports the necessity of establishing stations at known geographic positions so that the DEMs can be actively calibrated. To put it broadly, Hayakawa et al. (2008) have argued that the ASTER GDEM record of many lowland areas, mostly below 100 m., has many missing data points compared to the SRTM record, which tends to overestimate the topography of valley floors and inaccurately represent complex topography. As a result, the latter is thought to provide a better topographic representation of low-altitude and mountainous areas.

CONCLUSION

The importance of relying on open-access remote sensing products has increased due to the challenges associated with securing field data in many environments, including Nigeria and many other developing countries, due to inadequate technology, security concerns, financial constraints, and other difficulties. Before being used by spatial scientists in the nation, the majority of these products—including the ASTER and SRTM DEMs datasets—are frequently not precisely calibrated or proven. They were captured by sensors of developed-country remote sensing missions. As per the study's findings, the majority of open-access data, including DEMs, have certain limitations that, if not thoroughly examined, may result in inaccurate, erroneous, or insufficient information that could influence the process of making decisions. The report suggests more research be done on comparative quality assessment and quality assurance of widely used remote sensing products from missions whose ground controls are located outside the nation.

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