Comparative Analysis of SRTM and ASTER GDEMs in Topographic and Hydrological Modeling of Onitsha and Environs, Anambra State, Nigeria.

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Abstract
The aim of this study is to compare and analyze the three most freely available global elevation data set (SRTM and ASTER version 1 and version 2) for topographic and hydrologic modeling of Onitsha and environs using 1:50000 topographic map of the study area as the reference DEM. The contour lines of the topographic map were digitized and their equivalent values used to generate the topographic DEM. The topographic DEM was reclassified and used to determine the impact of terrain configurations on the DEMs. LandSat-7ETM+ was classified and used to determine the influence of landuse/ landcover on the DEMs. Hypothesis testing was used to determine the most suitable datasets for topographic and hydrological modeling in the study area using the z-test statistical analysis. SRTM was tested against ASTER ver1, and ASTER ver2. ASTER ver2 was tested against ASTER ver1. The study revealed that there is enough evidence to support the claim that elevation values obtained from SRTM is a better representation of the earth surface than ASTER ver1. Also, the hypothesis testing between SRTM and ASTER ver2 revealed that there is enough evidence to support the claim that elevation values obtained from SRTM is a better representation of the earth surface than ASTER ver2 dataset. For hypothesis testing between ASTER ver2 and ASTER ver1, the study shows that there is not enough evidence to support the claim that elevation values obtained from ASTER ver2 dataset is a better representation of the earth surface than ASTER ver1. The result of the hypothesis testing revealed that SRTM is most suitable for topographic and hydrological modeling in Onitsha and Environs. The study recommends the use of SRTM for topographic and hydrologic modeling of Onitsha and Environs and other areas of similar topography representation.

Keywords *- SRTM, ASTER GDEMs, Topographic, Hydrological, Modeling.*

I. INTRODUCTION

Since its original release, SRTM has been revised several times in order to remove erroneous pixel values (spikes and wells), better delineate water body boundaries, and represent the topography better. The SRTM DEM does not represent channels except where they are quite large. Farr *et al* (2007) attributed this partly to the SRTM radar's inherent resolution of around 50 m and partly due to the prevalence of trees on drainage lines that obscure, and effectively raise, the channel. Drainage enforcement using independently mapped stream lines is therefore required to produce a DEM that properly represents flow paths through the landscape.

The ASTER instrument were designed and built by Ministry of Economy, Trade and Industry (METI) of Japan and launched onboard of US National Aeronautics and Space Administration (NASA) TERRA Spacecraft in 1999 (Czubski*et al*, 2013). ASTER DEM data provided the first high-resolution near-global elevation source. Despite the relative advantage offered by its high resolution, it still suffers from some drawbacks, such as the lack of coverage in several areas due to the weather condition during the stereo-imagery acquisition, like the SRTM DEM. It obtains data in 14 channels from the visible through the therma+l infrared regions of the electromagnetic spectrum (Jensen, 2007).

The first version of ASTER GDEM was made available to the public in 2009 at no cost as a contribution to the Global Earth Observing System of Systems (GEOSS) (ASTER GDEM Validation Team, 2011) and it covers land surface between 83^{o}N and 83^{o}S latitudes. There have been some refinements in the original data from ASTER GDEM1 to ASTER GDEM2 with the view of decreasing the incidence of data artifacts and improving the spatial resolution and accuracy of water body delineation.

Despite these improvements in SRTM and ASTER GDEMs, studies (Ouerghi, *et al*., 2015; Gupta et al., 2014; Su and Guo, 2014) have shown that there still exist some artifacts which could affect its usage in certain applications such as topographic and hydrological modeling. Several studies have been carried out to investigate the vertical accuracy of SRTM and ASTER elevation measurements by comparing them to elevation from various sources; stereopairs (Ejikeme, *et al.*, 2017; Isioye*et al*, 2012; Czubski*et al.*, 2013 quoting Nikolakopoulos *et al.*, 2006), field measurements (Ebaid, 2014; Gesch*et al.*, 2012; Gorokhovich and Vostianiouk, 2006). This accuracy depends on the terrain characteristics and land cover types. Ejikeme *et al*. (2018) further assessed the impact of terrain configuration and landuse/landcover on the performance of these DEMs and found out that DEMs performed differently on varied topography and landuse/landcover types. There is still the need to compare the topographic and hydrological attributes that are derived from SRTM and ASTER GDEMs for better environmental applications. Topographic attributes, which are defined as numerical descriptions of terrain, may be classified as primary and secondary attributes (Moore *et al.*, 1991). Primary topographic attributes are those geomorphometric parameters that may be directly calculated from digital terrain such as elevation, aspect, hillshade and slope while secondary attributes, also referred to as compound attributes, are formed by combining the primary attributes with other environmental indices that characterize the spatial variability of specific processes occurring in the landscape.

Other terrain attributes which can be derived from DEM include: topographic wetness index (TWI) which describes the spatial distribution and extent of zones prone to saturation; stream power index (SPI) which estimates the erosive power of flowing water; Compound Topographic Index (CTI) and sediment transport capacity index (STCI) which shows areas that are prone to deposition or erosion.

A. Study Area

The study area selected for this study (Onitsha and environs) is located within Anambra State in South-eastern Nigeria. The geographic location is approximately between Latitudes $06^{0}05^{1}20.89^{11}$N and $06^{0}13^{1}26.473^{11}$N and Longitude $06^{0}45^{1}20.604^{11}$E and $06^{0}52^{1}10.573^{11}$E and covers Onitsha North and South Local Government Area and part of Obosi, Nkpor and IyiowaOdekpe of Anambra State (See figure 1a, 1b &1c). It is bounded by Anambra West/East L.G.A. and Oyi in the North, Idemili-North/South in the East, Ogbaru L.G.A in the South and in the West by the River Niger.

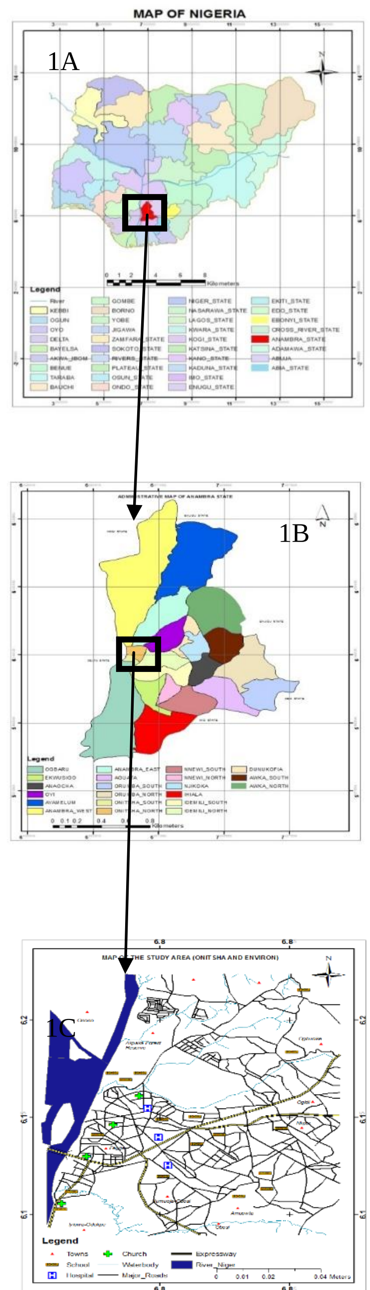


Figure 1a: Map of Nigeria showing Location of Anambra State; Figure 1b: Map of Anambra State showing the Location of the Study Area; Fig 1c: Map of Onitsha and Environs (Study Area)

Onitsha and environs was selected for this study because of the peculiar nature of its terrain and associated environmental problems. The South-east region of Nigeria lies within Awka-Orlu uplands and Enugu-Awgu-Okigwe escarpment where gully erosion is a general problem which reduces the land resource of the area. Onitsha and environs being located within the South-eastern Nigeria is found on the dip section of the east facing scarp slopes of the

Awka-Orlu landscape. It is underlain by flood plain deposits, and coarse to fine grained Nanka sands of the Bende-Ameki formation of the Eocene era (Orajaka, 1975). Onitsha stands at about 50 meters above sea level. Onitsha to Nsugbe is between 150-200 meters above mean sea level. There are east west trending hills from Nsugbe (near Onitsha) to Awka which constitutes the most prominent topographic feature. It provides a stretch of well drained, healthy site in the flood plains of River Niger. Thus, leaving a favorable site at the meeting point of two contrasting regions east and west of the Niger, and the Niger itself.

II. METHODOLOGY

The SRTM and ASTER GDEM1 and GDEM2 were resampled to a common resolution and coordinate system of 10m spatial resolution SPOT 5 Image. The 1/50,000 scale topographic map of the study area was used as reference data. The digitized contour lines elevation values from the topographic map were used to produce the topographic DEM. The resampled DEMs were filled to remove some spurious sinks. The coordinates (Northing, Easting and Height) of the DEMs were extracted and used for statistical and hypothesis testing.

The topographic DEM, SRTM and ASTER DEMs were used to derive the flow direction map. Using the 8 direction algorithm, the cells are coded as 2 to the power of 0, 1,2,3,4,5,6,7 that is 1, 2, 4, 8, 16, 32, 64, 128. 1 represents the water flow direction of the central cell to the east, 2 (southeast), 4 (south), 8 (southwest), 16 (west), 32 (northwest), 64 (north), and 128 (northeast). Every central cell's water flow direction is determined by one of the eight values. The flow direction map was used to derive the flow accumulation map. The accumulated flow is based on the number of cells flowing into each cell in the output raster. The threshold was set at 500 cells for topographic DEM. The minimum threshold of 500 was chosen in order to ensure that cells with high flow accumulation are used to delineate the stream. Threshold of 3000 cells which is equal to 1.2sqkm was set for the flow accumulation grids obtained for ASTER ver1, ASTER ver2, and SRTM. The 3000 cells represent the minimum number of cells that constitute stream. Also, threshold of 500 cells was set for the topographic DEM which also gave an area of 1.2sqkm. The threshold values of 3000 and 500 for ASTER and SRTM DEMs and Topographic DEM were chosen after series of trials and error. This was to ensure that cells with high accumulated flow were selected for subsequent delineation of the stream networks.

The results of Flow Accumulation were used to create a stream network by applying a threshold value to select cells with a high accumulated flow using symbology menu of the Flow accumulation layer properties menu. The Stream Definition function (Terrain Preprocessing menu) of the ArcHydro extension was used to delineate the stream networks. It takes the flow accumulation grid as input and creates a Stream Grid for a user-defined threshold. This threshold is defined either as a number of cells (default 1%) or as a drainage area in square kilometers.

This initial stream definition (and related Catchments definition) has no meaning for later basin processing (except for performance during the extraction stage), since all parameters can be changed. In general, the recommended size for stream threshold definition (which in turn defines the sub basin delineation during preprocessing) is 1% of the overall area (ArcHydro extension Manual). For increased performance on large DEMs (over 20,000,000 cells), the size of the threshold may be increased to reduce the stream network and the number of catchment polygons. This factor was considered while choosing the threshold of 3000 and 500 for the global DEMs and topographic DEM respectively. These thresholds were used to delineate the stream networks for the different DEMs.

Pour points shapefile was created and used to locate the junctions of the stream networks obtained from the flow accumulation. The Snap Pour Point tool is used to ensure the selection of points of high accumulated flow when delineating drainage basins using the Watershed tool. Snap Pour Point searches within a snap distance around the specified pour points for the cell of highest accumulated flow and move the pour point to that location. Sub catchments were delineated for the different DEMs. Areas that were delineated as sub catchments by the different global datasets were compared with sub catchments delineated from the reference topographic DEM. The common areas were merged together and vectorized as polygon.

Both primary and secondary topographic attributes were obtained from the different global DEMs and compared with the same products obtained from topographic DEM. The primary attributes include contour, slope, aspect, hillshade, and TIN while the secondary attributes include Stream Power Index (SPI) and Compound Topographic Index (CTI).

The slope was derived using the slope tool available at the Arc Toolbox extension of the ArcGIS 10.1. A flat surface is 0 percent, a 45-degree surface is 100 percent, and as the surface becomes more vertical, the percent rise becomes increasingly larger. The lower the slope value, the flatter the terrain; the higher the slope value, the steeper the terrain. Steeper slopes are shaded red on the output slope raster.The percent rise was used here because of its flexibility in computing the SPI and CTI. The contour of the topographic map was produced by digitizing the contour lines of the topographic map. The contour lines were assigned their equivalent metric values by multiplying the contour values in feet with the value of 0.3048. 0.3048 is the metric conversion factor for measurements in feet (Uzodinma and Ezenwere, 1993). The contour maps of the other DEMs were derived by exporting the coordinates (Northing, Easting and Height) of the DEMs to Surfer 10 software. The TIN were derived using the Raster to TIN tool of the ArcGIS 10.1 software.

The secondary topographic attributes derived are the SPI and CTI. Stream power index can be used to describe potential flow erosion at the given point of the topographic surface. As catchment area and slope gradient increase, the amount of water contributed by upslope areas and the velocity of water flow increase, hence stream power index and erosion risk increase.

The SPI was calculated using the raster calculator of the ArcGIS 10.1. This was calculated by multiplying the flow accumulation grid and the slope. Natural log (Ln) was clicked and the flow accumulation was added. Value of 0.001 was added to the flow accumulation in order to eliminate zero values in the flow accumulation calculation. This was multiplied with the slope. The slope was divided with the value of 100 since the slope were generated using percent rise option. Also value of 0.001 was added to the slope to eliminate zero values. Figure 4.5 shows the image window of the expression for deriving the SPI. Similarly, the CTI was generated using the flow accumulation and the slope. The difference is that the flow accumulation raster is divided by the slope to obtain the CTI.

The methodology used is summarized in the diagram represented in figure 2.1.

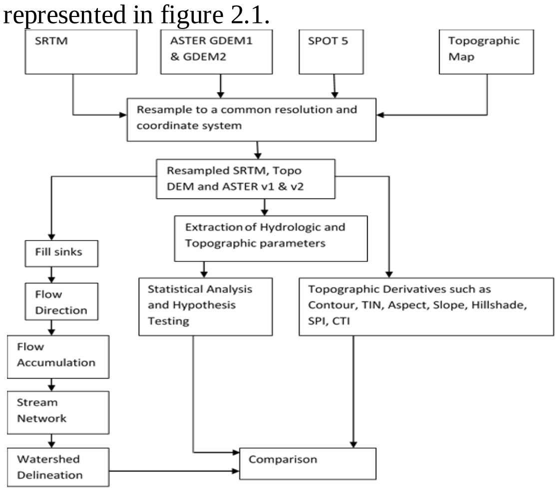


Fig. 2.1: Methodology Used

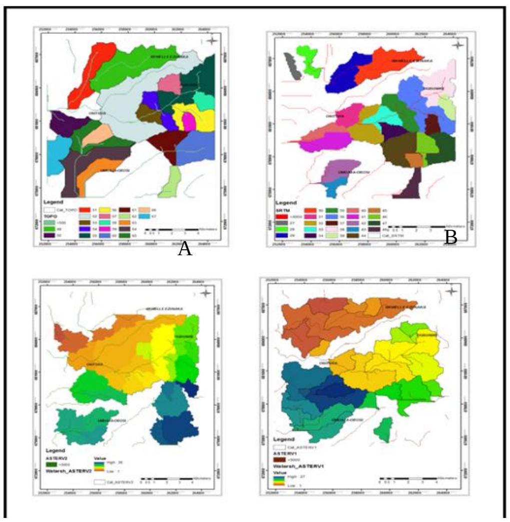
III. RESULTS AND ANALYSIS

In order to make objective statistical inferences in the data analyzed, three (3) hypotheses were carried out. Where a p-value obtained is less than the statistical level of significance (α =0.05), the null hypothesis (Ho) was rejected, otherwise, the alternative (H1) was accepted. The summary of the hypothesis testing and the decision taken is presented in table 1.1.

S/N	Hypothesis Testing	Summary of Decision
1	There is no significant difference in representation of topographic surfaces between SRTM and ASTER ver1 dataset.	*P-value* of 0.0001 was obtained. Since the P-value is less than α (That is 0.0001<0.01), the decision is to reject the null hypothesis. There is enough evidence to support the claim that elevation values obtained from SRTM dataset is a better representation of topographic surface than ASTER ver1 dataset.
2	There is no significant difference in representation of topographic surfaces between SRTM and ASTER ver1 dataset.	*P-value* of 0.0002 was obtained. Since the P-value is less than α (That is 0.0002<0.01), the decision is to reject the null hypothesis. There is enough evidence to support the claim that elevation values obtained from SRTM dataset is a better representation of topographic surface than ASTER ver2 dataset.
3	There is no significant difference in representation of topographic surfaces between ASTER ver2 and ASTER ver1 dataset.	*P-value* of 0.2206 was obtained. Since the P-value is greater than α (That is 0.2206>0.01), the decision is to not reject the null hypothesis. There is not enough evidence to support the claim that elevation values obtained from ASTER ver2 dataset is a better representation of topographic surface than ASTER ver1 dataset.

Table I: Summary of Decisions

The sub catchments were converted to polygon using the catchment polygon processing tool of ArcHydro tool extension. The results of the sub-catchments derived from the reference topographic DEM, SRTM, ASTER GDEM1 and ASTER GDEM2 are presented in figure 3.1.
The result of the output of the hydrological models obtained using the different elevation models were compared. The stream network delineated from the different elevation models were overlay together. The result is shown in fig. 3.2.



C D

Fig. 3.1: Sub-catchments derived from [A: Topographic DEM; B: SRTM; C: ASTER GDEM2 and D: ASTER GDEM1]

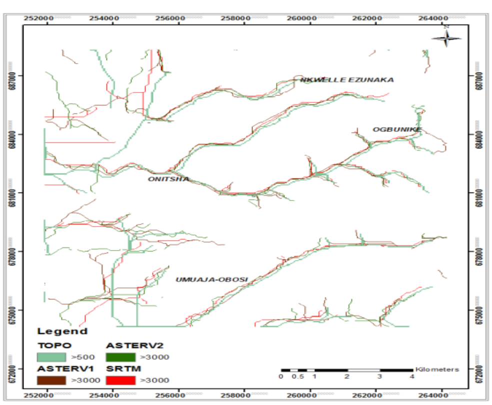


Fig. 3. 2. Overlay of stream network delineated from the different elevation models.

Also, the sub catchments obtained from the global elevation models were compared against that obtained from the topographic DEM using the Intersect tool of ArcToolbox extension. The Intersect tool extracts areas that are common among the datasets under comparison and merge them together. These areas were vectorized.Fig. 3.3 shows [A: the vectorized common area of the sub catchments obtained from SRTM and Topographic Map DEM merged together; B: the vectorized common area of sub catchments of ASTER ver1 and Topographic Map DEM merged together;C: shows the vectorized common area of sub catchments of ASTER VER2 and Topographic Map DEM merged together while D: shows the common area of all the elevation models sub catchments].

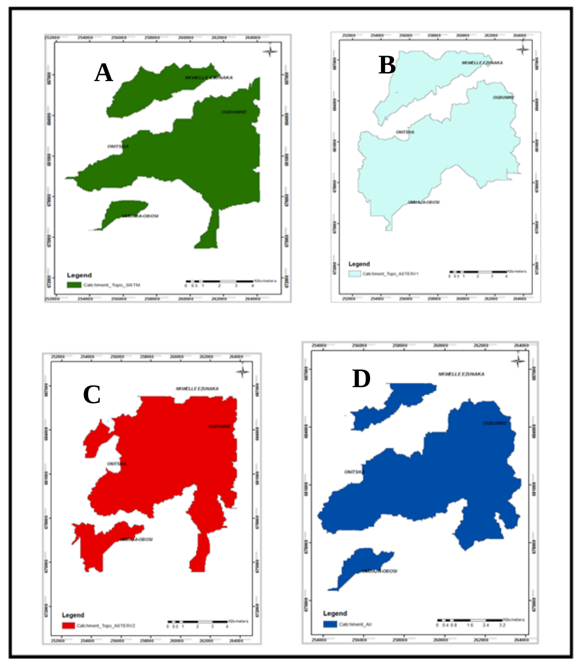


Fig 3.3: Common Area of sub catchments derived from topographic Map and SRTM DEM, ASTER GDEM1, ASTER GDEM 2 and composite catchment

Visual analysis of the merger of the sub catchments showed that there is a gap between the top sub catchment and the large sub catchment beneath it. This was noticed in all the overlay sub catchments except that of the ASTER ver2. Merged sub catchments obtained from combination of SRTM and topographic DEM proved to better represent the sub catchments when compared to the sub catchments derived from the combination of all the DEMs including the topographic DEM.

The different elevation datasets were used to derive both primary and secondary terrain attributes. The results obtained from the different elevation datasets were compared (See fig.3.4). The primary terrain attributes derived include slope and TIN while the secondary terrain attributes include Stream Power Index (SPI) and Compound Topographic Index (CTI). Slope and aspect are basic elements for analyzing and visualizing landform characteristics, and are important in studies of watershed units, landscape units, and morphometric measures. Chang (2002) stated that the accuracy of slope and aspect measures is probably influenced by the resolution and quality of DEM to a greater degree than the computing algorithm. It is on this basis that the slope, aspect and other terrain attributes were derived from the elevation datasets and compared with each other.

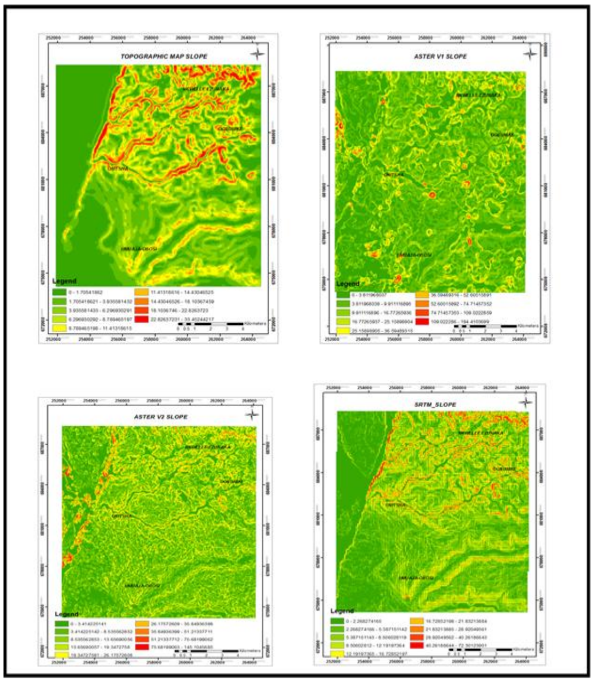


Fig 3.4: Slope derived from topographic DEM, SRTM DEM, ASTER GDEM1, and ASTER GDEM 2.

Steeper slopes are shaded red on the output slope raster. Field visits carried out revealed that the terrain covering NkwelleEzunaka towards Ogbunike (topmost part of the map) is steep while the down part of the slope map is of lower terrain variations. The left part of the map which is covered by River Niger was assigned a lower slope value. These are clearly represented in the slope map obtained from the topographic DEM.

TIN was also derived from the topographic Map DEM using the Raster to TIN conversion tool of the ArcGIS 10.1 software. The result is shown in fig (3.5).

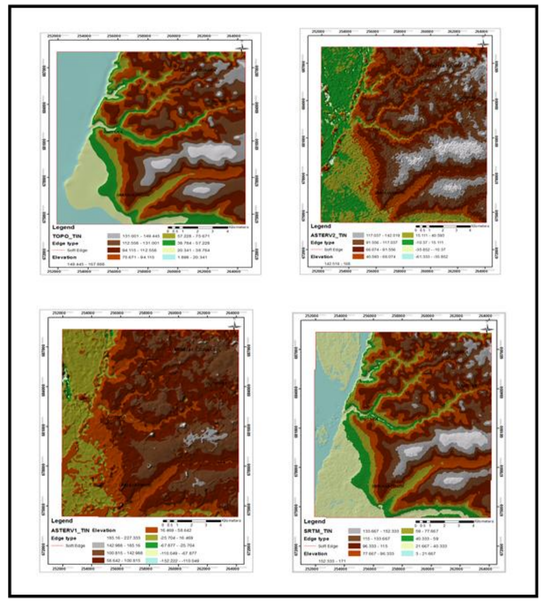


Fig 3.5: TIN derived from topographic DEM, SRTM DEM, ASTER GDEM1, and ASTER GDEM 2.

The SPI and CTI were equally derived and analyzed. The SPI and CTI derived from the flow accumulation and slope gradient obtained from the different DEMs are shown in fig (3.6) and (3.7) respectively. The high values are represented as white color while the low values are represented as dark color. Areas with white colors have large number of cells collecting water into them and have high erosion potential risk.

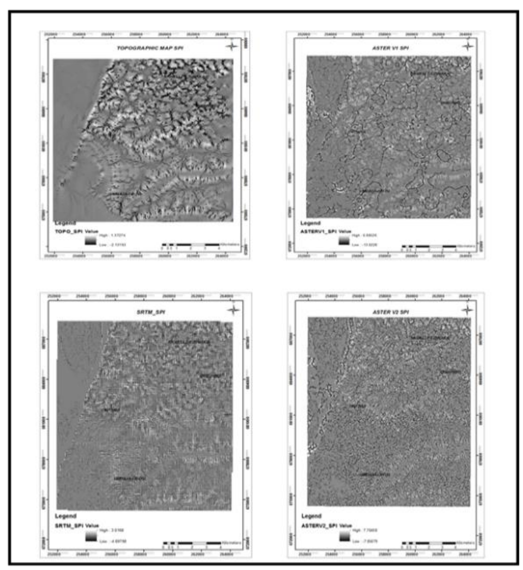


Fig 3.6: SPI derived from topographic DEM, SRTM DEM, ASTER GDEM1, and ASTER GDEM 2.

The high values represent as white color indicates wetness area. That is areas that have high water accumulations. The CTI can be said to be a wetness indicator.

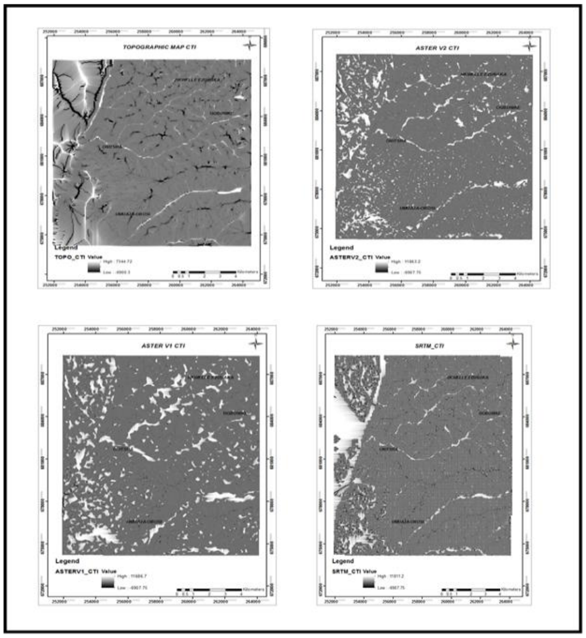


Fig 3.7: SPI derived from topographic DEM, SRTM DEM, ASTER GDEM1, and ASTER GDEM 2.

Comparing the results of the slope and TIN, SRTM have shown to have clearly distinguished the variation in the topography of the area. For example, comparing the result of slope obtained from the different DEMs, ASTER v1 and ASTER v2 falsely represents some areas of the River Niger as steep slopes. The River Niger at the left hand of the study area was clearly discernible in SRTM than the other DEMs.

The SPI derived from SRTM compares closely with that of the reference topographic DEM. It was observed from the results that the highest value recorded for the reference topographic DEM is 1.37274, SRTM- 3.0168, ASTER ver1- 6.88526 and ASTER ver2 is 7.70458. A close look at the results of the SPI derived from the SRTM also shows a close resemblance to that of the topographic DEM.

IV. CONCLUSION AND RECOMMENDATIONS

This study has clearly demonstrated that the results obtained from the different global available DEMs are not the same. In Onitsha and Environs, this study has shown that SRTM is better suited for modeling the topography of the study area than ASTER ver1 and ver2. Despite the fact that it has 90m spatial resolution when compared to the 30m resolution of the ASTER ver1 and ver2, it has clearly shown to clearly represent the topography better than ASTER ver1 and ver2. SRTM have shown to be a better DEM for hydrological modeling. The sub catchments delineated from SRTM compares favorably with that of the topographic map. The stream network delineated from SRTM is closely related to that obtained from the reference topographic map. With the non-availability of up-to-date topographic map of the study area, this research work has further demonstrated that global elevation datasets, particularly SRTM, have a good potential for topographical and hydrological modeling.

This study has been able to produce the sub catchment map of Onitsha and Environs. This was achieved through digitization of common areas of sub catchments obtained from the combination of sub catchments derived from each of the global elevation datasets and the topographic DEM.

Stream power index can be used to describe potential flow erosion at the given point of the topographic surface. As catchment area and slope gradient increase, the amount of water contributed by upslope areas and the velocity of water flow increase, hence stream power index and erosion risk increase. From this study, it was observed that SPI derived from SRTM has a close visual resemblance and elevation values with the reference topographic DEM. SRTM can be said to be more appropriate for modeling erosion problems in Onitsha and Environs

The use of these global elevation datasets in environmental modeling cannot be completely discouraged especially in a country like Nigeria that has no up-to-date topographic map. Based on the result of the findings from this study, the following recommendations were made:

1. Further studies should be carried out on the evaluation of these global elevation datasets as new version of them are released for public use.
2. SRTM should be used for topographic and hydrological modeling in Onitsha and environs or other areas that have similar topographic configuration like the study area. Also, SRTM should be used where higher accurate elevation data are not readily available since they can be obtained freely online.
3. Despite the fact that SRTM is recommended for topographic and hydrological modeling in Onitsha and Environs, care should be taken

when using this dataset in mountainous terrain.

4. SRTM should only be used in flat terrain while ASTER GDEMs should be used in hilly terrain. SRTM, ASTER ver1 and ASTER ver2 should not be used where there is dense vegetation.
5. SRTM and ASTER GDEM should be validated in other locations in Nigeria.
6. The result of this study should be adopted and used for accelerated action to provide the Country with accurate and up-to-date topographic Maps of scales 1:50000, 1:25000 and 1:10000. This will ensure that needed topographic data at various scales are available to serve the various needs of our National planning and development.

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