Shuttle Radar Topography Mission (SRTM) Elevation Data: A Contemporary Global Elevation Model for describing the topography in Zaria and its environs

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Abstract

Shuttle Radar Topographic Mission (SRTM) Digital Elevation Model (DEM) has created an unparallel data set of global elevations that is freely available for modeling and environmental applications. The global availability (almost 80% of the Earth surface) of SRTM data provides baseline information for many type of the worldwide researches. This product presents a great value in the production of topographic map, analysis in ecology, accuracy of precise gravimetric geoid, agriculture, climatology, geology, pedology, geomorphology, environmental modeling, rainfall-runoff studies, landslide hazard zonation, seismic source modeling and hydrological modeling. However, overall assessment of the accuracy of this product requires additional regional studies involving ground truth control and accuracy verification methods with higher level of precision, such as the Global Positioning System (GPS). The study presented in this report is based on two independent datasets collected with GPS system and Topographic map. Statistical analysis included estimation of absolute errors. Data from the various dataset were analyzed independently and in combination. Differences in terrain enabled a good interpretation of results. The results of this study showed that absolute average vertical errors of the SRTM dataset is 5.586 ± 1.001m in Zaria (mean ± S.E.M.). This is significantly better than a standard SRTM accuracy value indicated in its specification (i.e. 16 m). The error values have strong correlation with slope and certain aspect values. The result show good contour and terrain harmonization at contour interval greater than 15m. It was recommended that SRTM dataset and other global elevation datasets be evaluated before put to use. Also, it was further recommended that the application of SRTM dataset in providing terrain correction for the Nigerian Gravimetric Geoid Model will help improve the accuracy of the model which is for now being questioned.

Keywords: SRTM, GPS, Digital Elevation Model (DEM), Slope, Aspect.
Introduction

Digital Elevation Models (DEMs) are becoming more and more important in the production of topographic map, analysis in ecology, agriculture, climatology, geology, pedology, geomorphology, environmental modeling, rainfall-runoff studies, landslide hazard zonation, seismic source modeling, hydrological modeling and in water resources management (because they can provide many hydrological relevant parameters, such as drainage networks and catchment boundaries). Digital elevation models also play an important role in the accuracy of precise gravimetric geoid; they are used to compute terrain corrections, direct topographical effects on gravity and indirect effects on geoid, and also to generate mean gravity anomalies (Featherstone and Kirby, 2000). Most of the disciplines of scientific research involving the Earth’s land surface require topographic data and derived slope, slope aspect, and ortho-image cartographic products (Hohle, 1996). Our capacity to understand and model earth surface processes depends on the quality of the topographic data that are available in a digital format called Digital Elevation Model (DEM). A DEM is a computerized representation of the Earth’s terrain (Burrough and McDonnell, 1998), and can be described by a wire frame model or an image matrix in which the value of each pixel is associated with a specific topographic height (Evans, 1980).

The Shuttle Radar Topography Mission (SRTM) 3-arc second DEM is the result of a collaborative effort by the National Aeronautics and Space Administration (NASA), the National Imagery and Mapping Agency (NIMA), the German space agency, and Italian space agency (Rabus et al., 2003; Foni and Seal, 2004; Van Zyl, 2001). The mission was launched on 11 February 2000 aboard the Space Shuttle Endeavour. Using radar interferometry, a 3-arc second (SRTM-3) and a 1-arc second (SRTM-1) DEM were produced for almost the entire globe. The Australian SRTM-3 data were publicly released in July 2004, although the SRTM-1 data are yet to be released. Data were collected using two interferometers, C-band (American) and X-band (German) systems, at 1-arc second (30 m) (Foni and Seal, 2004; Rabus et al., 2003; Van Zyl, 2001). The absolute vertical and horizontal accuracy of the data collected was reported to be ±16 m and ±20 m (Kaab, 2005; Kellndorfer et al., 2004; Miliareis and Paraschou, 2005; Rabus et al., 2003). The 3-arc second (90 m) DEM was created by 3 × 3 averaging of the 1-arc second data (i.e. 9 data points combined to form a single 3-arc second data point). Elevation data error has features of random noise. Thus the process of averaging is considered to reduce error by approximately a factor of three and reduces random error but not systematic error (USGS, 2003). Each data tile covers an area spanning 1° in latitude and...
longitude, containing 1201 rows and 1201 columns. Elevation values are given in meters and WGS84 is used as horizontal and vertical datum (Rabus et al., 2003). When corrected to meters, the spacing is 91.666 m by 91.666 m, which in this work is referred to as a 90 m DEM. This giant leap forward in spatial resolution for DEMs with global coverage is likely to change the way in which related research can be performed and applied.

While the data coverage of SRTM is global, the short wavelength C-band and X-band radar cannot penetrate vegetation, that means, not digital elevation models showing the height values of the bare ground, but digital surface models (DSMs) showing the height of the visible surface-top of buildings and vegetation have been generated. By this reason different accuracy has to be expected for open area and forest or cities. Much more importantly, some regions have missing data because of a lack of contrast in the radar image, presence of water, or excessive atmospheric interference. These missing data are especially along rivers, lakes, and steep regions (often on hillsides with a similar aspect due to shadowing). This non-random distribution of the void (missing data), impedes the potential use of SRTM data, and has been subject of a number of algorithms for “filling-in” the voids through various spatial analysis techniques. These include spatial filters, iterative void filling, and interpolation techniques, many of which are still under development and testing.

Although SRTM data produced a number of voids due to lack of contrast in the radar image, a methodology based on spatial filtering was developed to correct this phenomenon (Dowding et al., 2004; Jarvis et al., 2004). The final seamless data set with voids filled in is available at the website of Consultative Group for International Agriculture Research Consortium for Spatial Information (CGIAR-CSI) via http://srtm.csi.cgiar.org/. However, the accuracy of this product is yet to be assessed. Partial assessment of its accuracy was done by the Centro Internacional de Agricultura Tropical (CIAT) in South America to verify performance of the developed DEM (Jarvis et al., 2004), but global user community would gain more benefits from other regional assessments.

Given the demand for a product such as the SRTM DEM, it is important to examine carefully the quality of the dataset (Smith and Sandwell, 2003; Rabus et al., 2003; Falorni et al., 2005; Kobrick, 2006; Grohman et al., 2006), comparing it with alternative sources of terrain elevation data. In several papers, the accuracy of SRTM X- and C-band DEMs was checked against topographic maps and ground control points measured by differential GPS, (Kocak et al., 2005; Gorokhovic and Voustianiouk, 2006; Hancock et al., 2006; Gorokhovich et al., 2006). Also,
Ojigi et al., (2010) attempts a 3-D data validation of the SRTM in Lokoja area of Nigeria with conventional ground survey-based topographic data in order to establish a geospatial resemblance ratio between the two dataset. But the paper has failed to reconcile the different height system between the dataset, it is impossible to obtain the same height by mere super-imposing the two dataset over each other. This however calls for careful and quality approaches on validating the SRTM dataset. Hence, this study will attempt to present the result of an experiment to validate the quality of SRTM DEM data for Zaria and its environs through comparison with GPS Points and topographic DEM. The objectives include; to obtain SRTM DEM data and process it, digitize topographic DEM, extraction of spot heights from the both dataset, GPS observation for ground truthing, process spot height into contour map, superimpose the maps, estimate some topographic attributes e.g. Slope, Elevation, Aspect, e.t.c and perform quantitative analysis using statistical techniques.

**Study Area**

The scope of this research work covers some areas within the Northern part of Nigeria. The study site is bounded by longitude 07°E to 08°E of the Greenwich Meridian and latitude 10°30’N to 11°30’N of the Equator which form a composite map with standard map sheet name and number: Maska; 101, Zaria; 102, Kaduna; 123, Igabi; 124 ( see Figure 1) each at a scale of 1:100,000 with an area of 11,664sqkm. Zaria was chosen as the test site for GPS data Point observations (Figure 2).

![Figure 1: Topographic Map of the Study Area](image-url)
Materials and Methods

With reference to the schematic diagram (Figure 3), this study comprises four main tasks. The first task is to acquire experimental data; the second task is data processing; the third task is to compare the data and the fourth include analysis and data presentation.

Figure 3: Schematic Diagram of Methodology
Data description and data acquisition

Shuttle Radar Topographic Mission (SRTM)

Although SRTM data produced a number of voids due to lack of contrast in the radar image, a methodology based on spatial filtering was developed to correct this phenomenon (Dowding et al., 2004; Jarvis et al., 2004). The final seamless data set with voids filled in is available at the website of Consultative Group for International Agriculture Research Consortium for Spatial Information (CGIAR-CSI) via http://srtm.csi.cgiar.org/. SRTM DEM data covering the study area of interest was downloaded from the seamless dataset website of CGIAR-CSI. The downloaded data mosaicked (Figure 4.0) and masked (Figure 5.0) then projected from geographical to Universal Traverse Mercator (UTM) Zone 32N in WGS 84 Datum for absolute vertical error assessment in comparison with GPS Points and then, also reprojected to Universal Traverse Mercator (UTM Zone 32N) coordinate system in Minna Datum for the comparison of topographic characteristics (i.e. relative altitude, slope and aspect) with the topographic map.

SRTM DEM data was converted from raster into a regular polygon dataset with attribute table storing elevation values using the 3D analyst module in ArcInfo 9.2. Thus, each polygon replicated raster pixel (Figure 6.0). These polygon data was used to find the conjugate GPS Points on the SRTM for absolute vertical assessment. From the SRTM DEM data topographic characteristics such as Slope map (Figure 7.0), Aspect map (Figure 8.0) were also created using ArcInfo 9.2 software with the 3D analyst module.
Figure 5.0: Masked SRTM DEM of the Area

Figure 6.0: GPS data (points) and SRTM pixels (square)
Figure 7.0: Slope map of SRTM

Figure 8.0: Aspect map of SRTM
Figure 9.0: TIN map of the Topo Map

Figure 10.0: Slope map of the Topo Map SRTM

Figure 11.0: Aspect map of the Topo Map SRTM
Topographic Map DEM

Topographic maps (Figure 1.0) covering the area was acquired, mosaicked, vectorized and spot heights extracted. The extracted spot heights from the map in feet was converted to meter and the x,y coordinates projected to Universal Traverse Mercator projection (UTM Zone 32N) system using Minna Datum. The extracted x,y,z was imported into ArcGis 9.2 and used to create a Triangular Irregular Network TIN (Figure 9.0). Slope map (Figure 10.0) and Aspect map (Figure 11.0) were also created.

GPS Ground Control Points Observation

Among various methods of accuracy assessment, GPS survey provides the best way to map features on terrain with high accuracy. GPS Points Data was collected along roads and some locations with specific topographic characteristic (i.e. hill, mountain, water bodies, e.t.c). To establish Points over the study area, two highly accurate GPS reference points were used. The coordinates and heights of these two points was obtained from the Department of Geomatics Engineering, Ahmadu Bello University Zaria. One of the Points was used as base for the measurement of other 57 new Points using Global Positioning System (GPS) (Figure 2.0). The other point was used as a check point.

A pair of Sokkia Stratus GPS System was used for these measurements. When surveying with GPS, the highest possible accuracy of collected data is usually achieved by using a carrier-phase tracking mode (Blomenhofer et al., 1994; Farrell et al., 2003). This mode requires both receivers (remote and reference) to be close enough and maintain tracking carrier phases simultaneously. This limitation might slow down the process of data collection (if remote and reference devices get disconnected) and decrease battery life (waiting for establishing connection and phase carrier mode). Therefore, an alternative is to use post-processing of GPS data with available base station data. This method was used in present study.

Base station data are usually collected by a high end receiver that constantly logs coordinates of its own location and determines an error associated with the satellite position, atmospheric conditions, etc. The base station used in the survey was XSJ37 available at Ahmadu Bello University Zaria. Data from the base station and rover receiver were downloaded and then post-processed with Sokkia Survey 4.0 software.

GIS analysis

The fusion of SRTM-based elevation data from SRTM and GPS data required overlay of two different topological objects: raster pixels and point
data. This required converting both data formats into one compatible form. In the present study, SRTM data were converted into a regular polygon dataset with attribute table storing elevation values. Thus, each polygon replicated raster pixel and was overlain with point data from GPS (Figure 6.0). This operation is also known as “spatial join” (Gorokhovich et al., 2006). It transfers attribute table values from polygons to underlying point data. Figure 6.0 shows an example of both datasets. Visualization of vertical errors in GIS revealed lack of uniform distribution of the errors across terrain. Greater error values were associated with rugged terrain, while smaller error values were associated with coastal plain, suggesting that such terrain characteristics as slope and aspect can influence SRTM accuracy. Slope and Aspect grid created as shown above for both topographic map and SRTM data were overlaid. All data with their respective attributes were organized in a spreadsheet table for subsequent statistical analysis (Appendixes A & B).

SRTM data and it conjugate GPS Points were imported into ArcInfo 9.2 as a dBASE file and with the 3D Analyst module the contours were produced (Figures 12, 13, and 14) at 5m, 15m and 30m contour interval corresponding to topographic map scale of 1:25000, 1:50000 and 1:100000 respectively. The two dataset in the same height system (ellipsoidal height) were overlaid for the purpose of comparing the contour values over the area.

**Statistical analysis**

The main goal of statistical analysis was to answer the following questions:
1. Does absolute vertical accuracy of SRTM data exceed the 16 m value specified for the original SRTM dataset?
2. How does slope and aspect influence SRTM data accuracy?
3. How does interpolation of SRTM DEM affect its representation of the earth terrain?

To address these questions, the magnitude of absolute errors in SRTM data was examined. “Errors” were operationally defined as discrepancies between elevation from SRTM data and corresponding GPS measurements which we assumed to be accurate and, thus, used them as reference values. Also analysis was made on the magnitude of absolute errors in the SRTM data with respect to slope and aspect characteristics of the landscape. To this effect, student-t test analysis was conducted on SRTM and GPS data. The same was done on SRTM and TOPO data. All analyses were performed using SPSS statistical package (ver. 16.0, SPSS Inc., Chicago, IL). In all tests, results with probability values less than 0.05 were considered statistically significant. Presented data are shown as mean ± S. E.M. (standard error of the mean), unless otherwise noted.
Results and Discussion

SRTM Data Accuracy

Tables 1.0 show descriptive statistics for SRTM and GPS data for Zaria area. Tables 2.0 show descriptive statistics for relative altitudinal differences for SRTM and TOPO data for the whole study area. Results of the t-tests statistically indicates that there no significant differences between data obtained by the STRM and GPS Measurement in the study area. Table 3.0 summarizes discrepancies between SRTM and GPS measurements. Average absolute error of SRTM data was found to be 5.586 ± 1.001m (Zaria). Table 4.0 shows the discrepancies between TOPO and GPS data measurements. Average absolute error of TOPO data was found to be 1.398 ± 0.453m. Also Table 5.0 summarizes discrepancies between SRTM and TOPO measurements, where average absolute error of SRTM data was found to be 6.755 ± 0.801m.
The effect of interpolating SRTM DEM at contour interval less than its spatial resolution (i.e. 90x90 cell size).

Figure 12.0 shows overlaid contour of SRTM and GPS Points at 5m contour interval. It reveals that height information at certain locations is unknown. This account for the crossing of the contour lines. Figure 13.0 shows that 15m contour interval has a better result than the 5m contour interval. Figure 14.0 shows a trend of better output as the interval increases to 30m. Table 6.0 gives a statistical report on the relationship between the various contour maps at different contour intervals.
Figure 13.0 The Superimposition of SRTM (blue) and GPS(red) Contour map at 15m contour interval

Figure 14.0 The Superimposition of SRTM (blue) and GPS(red) Contour map at 30m contour interval

Table 8.0: Relationship between the various contour maps at different contour intervals

<table>
<thead>
<tr>
<th>Sr.No.</th>
<th>Data Source</th>
<th>Contour Interval</th>
<th>Pearson's Product moment Correlation Coefficient</th>
<th>Independence Measure</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0</td>
<td>GPS/SRTM</td>
<td>5m</td>
<td>0.110</td>
<td>0.314</td>
</tr>
<tr>
<td>2.0</td>
<td>GPS/SRTM</td>
<td>10m</td>
<td>0.250</td>
<td>0.550</td>
</tr>
<tr>
<td>3.0</td>
<td>GPS/SRTM</td>
<td>30m</td>
<td>0.550</td>
<td>0.652</td>
</tr>
</tbody>
</table>
The influence of slope and aspect on SRTM data accuracy

Analysis revealed significant decrease in accuracy of SRTM data when measurements were performed on terrain characterized by slope values greater than 10° (Table 7.0). Indeed, the average magnitude of errors is more than ten times higher for terrains with slope values exceeding 10° compared to areas where slope values are less than 10° in the study area (3.862 ± 2.444 m vs. 40.564 ± 2.415 m, p < 0.001). Aspect of the terrain was classified into 8 classes and found to have influence on both the magnitude and the sign of errors in the SRTM data.

<table>
<thead>
<tr>
<th>Slope</th>
<th>≤10°</th>
<th>&gt;10°</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>3.862</td>
<td>40.564</td>
</tr>
<tr>
<td>S.E.M</td>
<td>2.444</td>
<td>2.415</td>
</tr>
<tr>
<td>Minimum</td>
<td>0.06</td>
<td>35.15</td>
</tr>
<tr>
<td>Maximum</td>
<td>15.85</td>
<td>42.98</td>
</tr>
<tr>
<td>Count</td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td>p Value (independent measures t-test)</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

The highest magnitude of errors was observed for measurements made on slopes facing north (N) and north west (NW). Correspondingly, SRTM measurements underestimated elevations of slopes facing NW and overestimated elevations of slopes facing N (Figure 15.0). These differences (SRTM data overestimate for north-facing slopes and underestimate for northwest-facing slopes) correlate to the shuttle flight path directions.
Conclusion and Recommendations

Conclusion

In this study, the quality of the DEM acquired by the Shuttle Radar Topography Mission (SRTM) was evaluated through comparison with GPS readings and cartographically derived DEMs. Comparison was carried out analyzing the difference in elevation, relative altitudinal differences and slope angle. Analyses presented in this project indicate the following:

Absolute vertical accuracy of CGIAR-CSI SRTM data for our datasets proved to be more than two times higher than the value of 16m presented in the original SRTM requirement specification.

Both slope and aspect characteristics of the terrain have significant impact on accuracy of SRTM data. Accuracy particularly suffers on terrains with slope values higher than 10°. Aspect of the terrain influences both the magnitude and the sign of errors in the SRTM data. SRTM data underestimate elevations of slopes facing NW and overestimate elevations of slopes facing N, but the errors are significant only on terrains with slope values exceeding 10°. Quality of collected SRTM data also depends on incidence angles that affect differential distances for ground targets and the accuracy of original data (Jarvis et al., 2004). These angles could be potentially taken into account in studies that use original SRTM data.

Role of vegetation was not fully assessed in this study. It is assumed that in the study area vegetation covers uniformly (height and density) 90 × 90m square (pixel size of CGIAR-CSI SRTM product). In this case, the associated error would be constant.

The results of accuracy assessment also depend on the number of GPS observations per one spatial unit of SRTM data (i.e. 90m). The more GPS readings would be available, the more accurate the final estimation will be. However, implementation of this approach requires special planning of GPS surveys and considerable additional resources, and was not within the scope of the present study.

SRTM DEM show good result as revealed by comparison with field-based measurement of GPS points. The SRTM DEM has an average error of 5.586 ± 1.001m. However, some systematic errors were identified in the SRTM data, related to aspect. The errors are found to be higher in north-facing slopes. This can be attributed to the effect of incidence angle of the original radar images used to produce the SRTM DEM. The result of the contour created from SRTM and GPS Points show that SRTM-3 can give a good representation of the earth terrain at contour interval greater than 15m (Figure 6.0). Finally, the SRTM DEM was found to contain more surface detail and roughness than the TOPO DEM.
Recommendations

The following recommendations are hereby made:

(a). Call on the relevant mapping authorities to create a national elevation database for the country.

(b). Re-defining current height system in Nigeria to enhance capability with systems in use for global elevation datasets.

(c). Although, the SRTM data should be compared with more other DEM data sources (i.e. GTOPO30, GLOBE, ASTER DEM, Altimeter data height, Leica Virtual Explorer etc.) and more analysis should be made to validate SRTM data at different areas.

(d). In view of the results obtained in this study, it is further recommended that the SRTM data be used for refining the gravimetric geoid solution computed for the country by Ezeigbo, et al., (2006). It may be used to compute terrain corrections for the computed model as it will certainly improve the accuracy of the model.

(e). SRTM data should be used on the study area (Zaria) and elsewhere upon proper validation as supplementary data for small-scale map such as Geological map.

(f). Efforts should be put at developing mathematical models that will enable accuracy modeling of SRTM data errors (especially at high undulating terrain regions across the country).

(g). African Geoid Project set up by IAG Committee for Developing Countries, now a project of Commission on Gravity should utilize the advantage of SRTM to meet the need for unified vertical reference frame for Africa to support economic development.

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