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ACCURACY ASSESSMENT OF SRTM and ASTER DIGITAL ELEVATION MODELS (COVERING SOME PARTS OF SUDAN)

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Abstract: Digital elevation model (DEM) is a basic component of any geo-information system (GIS) and is required for many geospatial and engineering applications. Nowadays, the production of the worldwide DEMs have been improved with the use of SRTM-DEM and ASTER-DEM. Extracting topographical data by drawing contour lines from SRTM-DEM and ASTER-DEM elevation data requires accuracy assessment of SRTM-DEM and ASTER-DEM elevation data, as well as the quality of the interpolated contours to ensure its suitability for topographical mapping. This paper presents the accuracy assessment of the results obtained through conducting many tests which were performed for places with different types of topography. The overall accuracy of SRTM-DEM R.M.S.E value was found to be in the range of about ±5.873mand the overall accuracy of ASTER-DEM R.M.S.E value was found to be about ±7.411m. The study showed that further processing and improvements are conducted to remove blunders and outliers. In such cases both open global sources of elevation data (SRTM-DEM and ASTER-DEM) could be used for producing topographic maps at 1:50000 scales or less.

Keywords**:** *digital elevation model, cartographic quality, root mean square error, SRTM, ASTER.*

1. INTRODUCTION

Topography is required and considered to be basic for many earth surface processes as well as applications in many fields such as hydrology, security, military, agriculture, climatology, communication, mining works, roads and route (selection, design and execution),beside other disciplines. Hence topographic mapping plays an important role in national development. Due to this fact, topographic mapping received good attention by national, state and local governments in developed countries. Therefore, in the world of today, the importance of topographic mapping as a national project is growing rapidly. The necessity of such growth made geographic information system (GIS) software, topographic maps and digital elevation models as essential components of national geospatial data infrastructure. In most countries, maps revision, maps updating are continuously performed to produce up to date maps by using current elevation obtained from data captured by remote sensing devices carried on board aircrafts and satellites. In developing countries, such as in Sudan, the Sudan Survey Authority, SSA (Governmental Mapping Agency) and private mapping firms are lagging far behind to produce reliable and up-to-date topographic maps. Taking Sudan as an example, only 220 topographic map (1:100,000) sheets out of 610 for the full coverage of the country have been produced (SSA, 1990).

These maps covered partially some selected areas (east, middle and some parts of south and west of Sudan). In addition, up to now no real endeavors have been made by any mapping authority or any firm to generate digital elevation models for the entire territory of Sudan with suitable accuracy.

In the previous year 2021, SSA Attempted to publish a Sudan digital topographic map, but its elevation data extracted from an Open source DEMs requires further verifications and accuracy assessments.

The idea of evaluating the SRTM-DEM and ASTER-DEM quality stemmed from the fact that many DEMs were affected with many types of errors (gross, systematic and random errors). The authors, also, realized that many users of Dems extracted from remotely sensed data or other open source data, were in lack of knowledge about the errors existing in DEMs and their impact in the quality of DEMs and their derivatives such as slope, aspect and surface area…etc.

The major objectives of the research presented in this paper can be summarized as follows:

- Determination of the relative accuracies of the SRTM-DEM and ASTER-DEM data in the study area.
- Evaluation of the impact of topography on the accuracy of SRTM-DEM and ASTER-DEM Quality.
- Assessment of the Cartographic quality of SRTM-DEM and ASTER-DEM.
- Investigation of the suitability of SRTM-DEM and ASTER-DEM as elevation data source for producing digital topographic maps at different scales.

2: DEM ACCURACY, QUALITY AND UNCERTAINTY

Information about the terrain surface plays a key role in uncountable disciplines. The quality of spatial data, in particular DEMs, and their use in GIS-based analysis and modeling applications have received attention since the end of 1980s and beginning of 1990s (Li; 2000).

DEM quality is a complex issue, as there are a number of aspects to DEM quality: elevation accuracy, geomorphometric characteristics, and model limitations. A number of factors influence DEM quality such as data source, sampling pattern, sampling density, distribution of elevation data, and interpolation methods used to generate DEM.

Based on the above mentioned issues concerning DEMs, there is a need for comprehensive tests, investigations and assessment of the quality of DEMs, particularly in the developing countries, such as Sudan where there is a lack of reliable topographic maps and digital elevation models.

3. ESTIMATING ELEVATION ACCURACY

The most reasonable and intuitive way to assess the quality of a DEM is to determine the amount of error in the elevation values. Determining or estimating error for every cell is not practical or otherwise is impossible so a number of sample points are selected to allow for comparing the DEM cell values with their corresponding elevation values of the terrain surface. From this sample, the characteristics of the error distribution over the whole DEM area can be estimated by statistical measures of accuracy.

The accuracy of DEMs is of concern to both DEM producers and users. For any DEM project the three main factors to be considered are accuracy, efficiency and economy ((Li, 1988).). Accuracy is definitely the most important factor to be taken into consideration before and after generating Dems This is due to the fact that, if the accuracy of a DEM does not meet the specified requirements, then the whole project or part of it needs to be repeated, and consequently the economy (extra cost) and efficiency will be affected.

As with all mapping operations, the accuracy of the terrain model must be suited to the chosen or intended application (Li, 1993a). The accuracy of digital elevation models and the factors which affect their accuracy are thus important considerations in relation to both the derived parameters and the application of such models.

4: SOURCE DATA

The accuracy tests conducted in this study employed the following four major sources of spatial data:

- SRTM digital elevation data
- ASTER digital elevation data
- Ground survey elevation data
- RTK-GPS elevation data

4.1 SRTM Digital Elevation Data

The Shuttle Radar Topography Mission (SRTM) for the first time provides a global high-quality DEM at resolution levels of 1arc second (30m) and 3 arc seconds (90m). The SRTM-DEM covered the earth between 60º N and 57º S; it is acquired and produced with single technique-synthetic aperture radar (SAR) interferometry. SRTM was provided with two antenna pairs operating in C- and X-bands. SRTM was jointly performed by NASA, the German Aerospace Center (DLR) and the Italian Space Agency (ASI). Also, SRTM digital elevation model was processed and maintained by the Consultative Group for International Agriculture Research Consortium for Spatial Information (CGIAR-CSI). SRTM digital elevation data sets are provided to the general public in 1º by 1º tiles in computer c-compatible raster formats (GeoTiff and ARC/INFO ASCII Grid). The data set is in Latitude/Longitude coordinate system projected on the WGS 84 Ellipsoid. For the purpose of this research, all tiles covering Sudan country were downloaded from CGIAR-CSI Web site at http://srtm.esiegiar.org.

4.2: ASTER Digital Elevation Data

ASTER was a global digital elevation model (DEM) produced by the Ministry of Economy, Trade and Industry (METI) of Japan and the United States National Aeronautics and Space Administration (NASA) from optical stereo data acquired by the Advanced Space borne Thermal Emission and Reflection Radiometer (ASTER). The ASTER Global DEM (GDEM) was released to the public on June 29, 2009. ASTER is an imaging instrument built by METI and operates on the NASA Terra platform (Li, 1993a).

Images are acquired in 14 spectral bands using three separate telescopes and sensor systems. These include three visible and near-infrared (VNIR) bands with a spatial resolution of 15 meters (m), six short-wave-infrared (SWIR) bands with a spatial resolution of 30m, and five thermal infrared (TIR) bands that have a spatial resolution of 90 m. VNIR Band3 also is acquired using a backward-looking telescope, thus providing along-track stereo coverage from which high-quality digital elevation models (DEMs) are generated as one of a suite of ASTER standard data products. ASTER DEM standard data products are produced with 30m postings, and have Z accuracies generally between 10 m and 25 m root mean square error (RMSE). The methodology used to produce the ASTER-GDEM involved automated processing of the entire 1.5-million-scene ASTER archive, including stereo-correlation to produce 1,264,118 individual scene-based ASTER-DEMs (1°-by-1° tiles).

4.3: Ground Survey Elevation Data

The third source of data is from Aljiniana study area, the data was captured by using differential leveling. Elevation data set was acquired using spirit levels and total stations. Interval of elevation sample points ranges from 50 m to 100 m along road center lines. In addition, heights of points along changes of slope, along ridge lines, tops of hill, and along break-lines such as the base of water courses, have been determined. The accuracy of elevation data set is about ±2cm per point. Since roads are, almost, not running in parallel and they are crossing water courses or passing through areas of rugged terrain, the distribution of elevation data sample is of irregular pattern.

4-4: RTK-GPS Elevation Data

RTK-GPS elevation data was acquired for two study areas (ALnohoud and Algadarif). The survey works were performed using differential mode. The raw elevation data was further processed to remove the effect N-value (N: vertical distance between ellipsoid and geoid) and to unify the elevation datum (mean sea level). To perform this task, benchmarks were established at appropriate locations (corners of study area) and their reduced levels were determined by using spirit level with an accuracy of $\pm 10\sqrt{k}$ mm (k stands for distance in kilometers).

5. STUDY AREAS

Three study areas were selected for assessing accuracy of SRTM and ASTER digital elevation data as shown in table (1) and depicted in Fig (1). First study area (Aljinena) is located in west

Dar-four state near the western border of Sudan. The second study area (Alnohood) is located in west Kordofan state and the third study area (Algadarif) is located in Algadarif state south east of Sudan.

The reasons behind the selection of these three study areas is the availability of high accuracy reference elevation data and represent different geographic locations in the Sudan. Referring to table (2), all three study areas are showing gentle slope. This attributed to the fact that the difference in elevation between maximum elevation and minimum elevation in Alnohood, Aljinena and Algadarif study areas are about 79.138m, 51.550m and 31.100m respectively. While the areas of Aljinena, Alnohood and Algadarif are 115.49km^2, 65.62km^2 and 120.01km^2 respectively.

Table 1. Boundary of study areas

STYDY AREA	MIN E(m)	MAX E(m)	MIN N(m)	MAX N(m)
ALJINENA	652789	666203	1482784	1491470
ALNOHOOD	650560	660092	1399819	1406699
ALGADARIF	751583	763458	1548252	1558357

Table 2. range of elevation data

STYDY AREA	MIN Elevation(m)	MAX Elevation(m)	RANGE (m)
ALJINENA	772.370	823.920	51.550
ALNOHOOD	575.931	655.069	79.138
ALGADARIF	441.230	472.330	31.100

Fig.1. location of study areas

6: METHODOLOGY

The methodology adopted in this study may be summarized in the following:

(i) Determination of the relative vertical accuracy of SRTM-DEM;

(ii) Determination of the relative vertical accuracy of ASTER-DEM;

(iii) Assessment of the Cartographic quality of the SRTM-DEM;

(iv) Assessment of the Cartographic quality of the ASTER-DEM;

(v) Comparing between the SRTM-DEM and ASTER-DEM accuracies.

This paper focuses on the vertical accuracy of SRTM-DEM and ASTER-DEM data covering the study areas. Determining the vertical accuracy of SRTM-DEM and ASTER-DEM essentially involves carrying out statistical computations of the elevation differences between SRTM-DEM and ASTER-DEM data and a reference data set. This step has been performed by superimposing the reference data set SRTM-DEM and ASTER-DEM, then using subtract tool available in ArcGis10.3. Software to apply subtraction operation on the two sets of data. This operation was performed by using pixel by pixel mode. The result of this operation was a dBase table of differences (errors) in elevations between SRTM-DEM and ASTER-DEM and reference data which could be exported to Microsoft Excel to perform statistical analysis (mean, absolute mean, standard deviation, min. error, max. error, root mean square error). To execute the statistical analysis, a small program has been designed, due to the fact that some statistical parameters (root mean square error, average absolute error) cannot be computed directly by built-in scripts or programs available in excel worksheets. The results of the computations and statistical analysis were summarized in Table 2. Table-2 was obtained by using equations (1) → (5) below:

$$\text{Average error} = v_m = \frac{\sum v}{N} \text{------- (1)}$$

$$\text{Average absolute error} = \frac{\sum |V|}{N} \text{--- (2)}$$

$$\text{Root mean square error (RMSE)} = \sqrt{\frac{\sum V^2}{N}} \text{----------- (3)}$$

$$\text{standard deviation } (\sigma_v) = \sqrt{\frac{\sum (v - v_m)^2}{N-1}} - -(\mathbf{4})$$

Accuracy (95% confidence) =

$$1.960 \times \text{RMSE------ ------- (5)}$$

7: RESULTS AND DISCUSSION

The various tests conducted in this study were meant to assess the accuracy of SRTM-DEM and ASTER-DEM and to investigate their suitability for topographic mapping at different scales.

Results of accuracy estimates presented in Table (3) and Table (4) revealed that the average root mean square error value was found to be ±5.307m and ±7.140m for SRTM-DEM and ASTER-DEM respectively. The error frequency histograms of all study areas were similar to the normal distribution curve of errors as depicted in Figs (2→ 3 and 9→10) but there is a little bit positive and negative bias in SRTM and ASTER respectively. These graphs also, confirmed the low frequency of the maximum errors (< 1 %) for all study areas. The errors may be due to ASAR/ISAR imaging system which itself was affected by errors caused by baseline tilt angle, baseline length, platform position, relief layover, phase and slant range vegetation canopy, ground surface roughness; procedures, and interpolation methods. Overall effect of the combined errors will definitely reduce the quality of the generated DEM.

Comparing the results of this study with the results obtained by other investigators for different areas with variant surface roughness, it was found that the results presented here for all study areas are within the expected accuracy values which were ranging between ±10 m and ±25 m as published in the SRTM-DEM data specification [4] [5] [6]. This was confirmed by the overall RMSE value of ±5.307mand ±7.140mobtained for the areas under investigation. These good results of accuracy were due to the fact that the reference data used in this study is very reliable compared to the previous studies carried out for some regions in Sudan but the reference data used was of poor accuracy (extracted from 1:100000 topographic maps).

Referring to tables (1) and (2), the results showed that RMSE of SRTM-DEM and ASTER-DEM are likely identical (difference between them=0.607m) of Aljinena study area. While differences in RMSE between SRTM-DEM and ASTER-DEM are1.752m and2.425m of Alnohood and Algadarif study areas respectively.

Inspection of error frequency histograms and error values as shown in Figs (1),(2),(8) and (9) revealed that SRTM negative errors (80%) were greater than positive errors (20%). This negative bias indicated that SRTM has an overestimation of study area topography, while ASTER positive errors (74%) were greater than negative errors (26%).This positive bias showed that ASTER has an underestimation of study area topography. Accordingly, we can say that errors existing in both SRTM and ASTER digital elevation data are not perfectly of normal distribution (i.e. semi - normal distribution).

Visual inspection of the error maps of the three DEMs revealed that the accuracy of these DEMs decreased as surface slope became steeper, and the elevation became higher as presented in many previous studies carried out by Awadelgeed (2012) for different regions in Sudan (Khartoum; Almanagil; Abugota; Habila; Jebelawlia). Hence surface relief plays an important role in the DEM accuracy. The impact of surface slope appears to be much more complicated than the contribution of elevation for the accuracy of SRTM DEM and ASTER-DEM due to the fact that large errors may occur at low elevations with gentle slopes.

The results of the various tests carried out to evaluate the cartographic accuracy of SRTM-DEM and ASTER-DEM elevation data were presented in Figs:{4(a); 4(b); 4(c) and (6→ 8)}. The tests involved direct interpolation of 2m→5mvertical interval contours from SRTM-DEM and ASTER-DEM. Based on a visual interpretation of the results, the following facts could be deduced about the SRTM-DEM elevation data quality: Direct contouring from the 30m SRTM-DEM and ASTER-DEM without further processing for smoothing contour lines produces artifacts in the form of incomplete contour lines and self-intersecting contour lines. Moreover, it was noted that extra contour lines in the form of small.

Circles were found between the main contour lines and have the same contour values of the main ones, but frequency of their existence is very low. Irrespective of errors noted previously, the contour maps derived from the SRTM-DEM and ASTER-DEM is generally of good cartographic quality. This is confirmed by the fact that, most of the contour lines had similar shape of their corresponding original ones which were drawn from the reference elevation data. These results were verified by inspecting Figs {4(a); 4(b); 4(c)} and (7→ 8)}.

When comparing SRTM-DEM cartographic quality of contour lines with their corresponding ones of ASTER-DEM, it was found that SRTM was better than ASTER. Both SRTM and ASTER digital elevation data are highly correlated with reference elevation data of all study areas. This criterion is confirmed by computing correlation coefficient R. The results revealed that values of ranges from 0.993 to 0.999.

Table 3: Statistical results of SRTM-EM

	ALJINENA	ALNOHOOD	ALGADARIF
MIN(m)	0.010	-0.001	0.005
MAX(-)	-31.390	-28.684	-45.250
MAX(+)	43.810	34.596	31.655
MEAN	0.827	-2.066	-2.049
ST.DEV.	±6.087	±4.849	±5.543
RMSE(m)	±6.355	±5.329	±5.708
Overall. Mean	**±5.813m**		
Accuracy (95% confidence) =	**±11.393m**		

Table 4: Statistical results of ASTER-DEM

	ALJINENA	ALNOHOOD	ALGADARIF
MIN(m)	0.000	-0.001	0.000
MAX(-)	-35.390	-34.942	-34.250
MAX(+)	37.810	29.446	44.244
MEAN	4.376	4.641	4.614
ST.DEV.	±6.243	±55.520	±8.133
RMSE(m)	±6.9.62	±7.081	±7.411
OVERALL. Mean	**±7.411m**		
Accuracy (95% confidence) =	**±14.526m**		

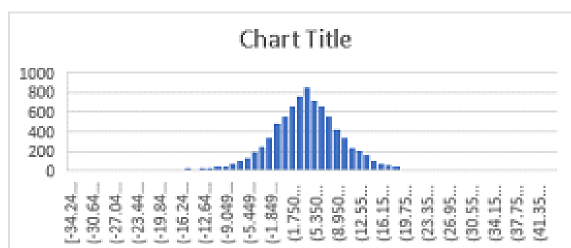

Fig .2. AJINENA SRTM-DEM error frequncy

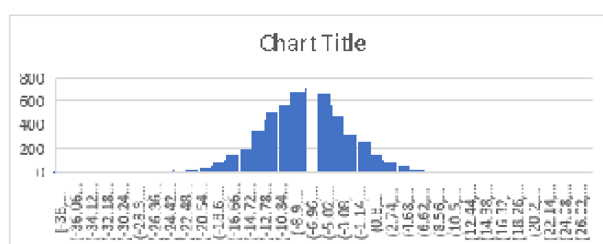

Fig .3. AJINENA ATER-DEM errorfrequncy

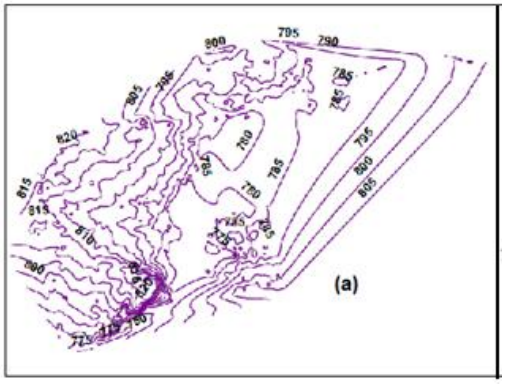

Fig .4. (A) AljiniaASTER-DEM contour

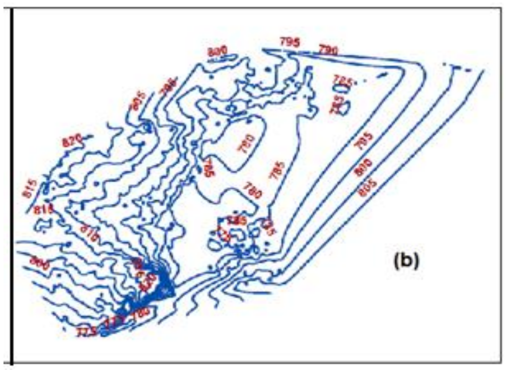

Fig.4. (B) Aljiniareference contour

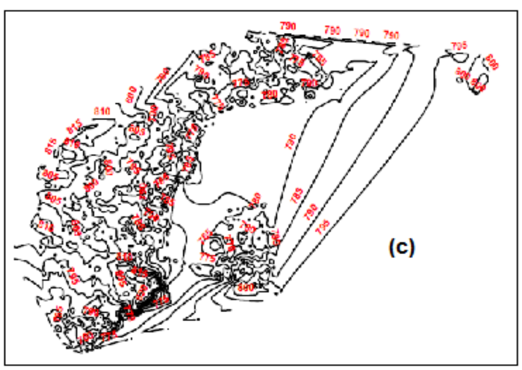

Fig .4. (C) Aljinia SRTM-DEM contour

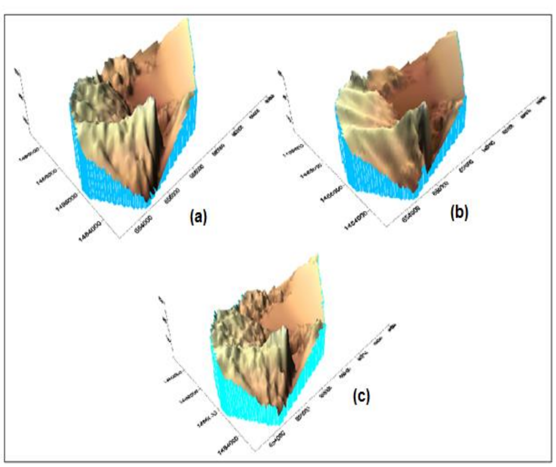

Fig .5. 3-D . (A) ASTER-DEM (B) REFERENCE-DEM (C) SRTM-DEM)

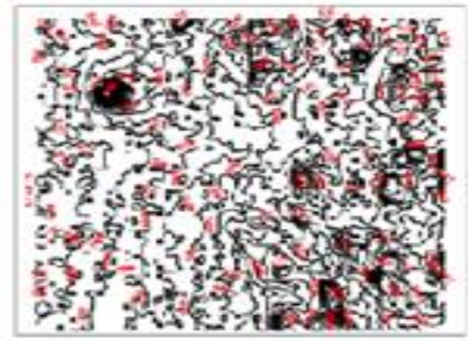

Fig .6. AlnohoudASTER-DEM contour

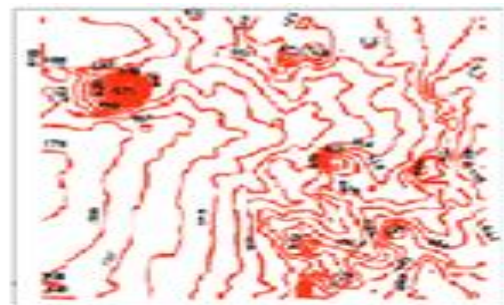

Fig .7. Alnohoudreference contour

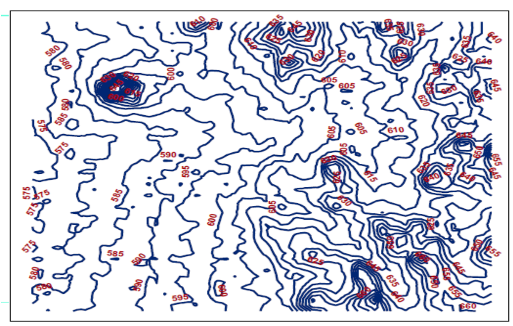

Fig .8. AlnohoudSRTM-DEM contour

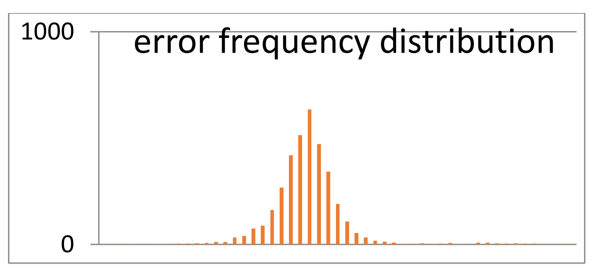

Fig .9. Alnohoud SRTM-M error frequncy

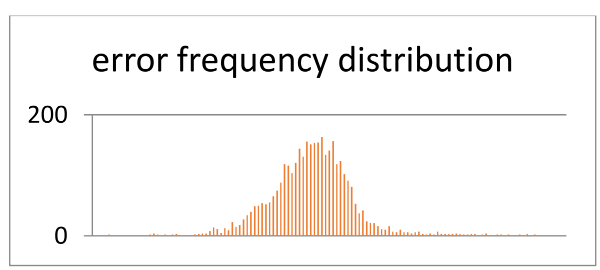

Fig .10. Alnohoud ASTER-DEM error frequncy

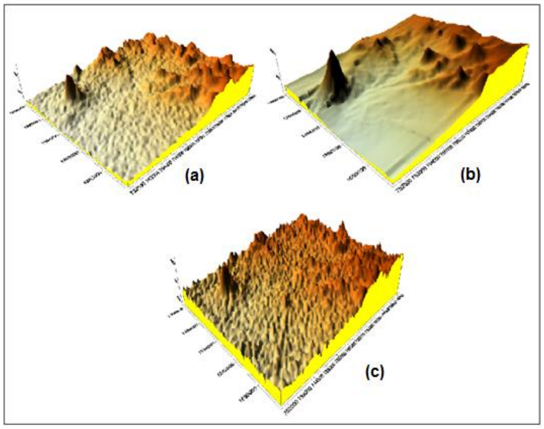

Fig .11. (A) ASTER-DEM (**B**) REFERENCE-DEM (C) SRTM-DEM)

8. **CONCLUSION**

This study investigated the quality of the SRTM-DEM and ASTER-DEM elevation data and their suitability for topographic mapping at different scales. The various statistical processing and visualization were based on reference data of study areas covering three states in Sudan.

The following findings were reached:

1. Many artifacts were encountered in the SRTM-DEM and ASTER-DEM elevation data. These artifacts restrict its usage in disciplines that need accurate elevation data.
2. SRTM-DEM and ASTER-DEM elevation data can be used to create a good representation of terrain surface if further processing is carried out to remove artifacts, and may be utilized for applications of low accuracy such as studying regional climatology, geomorphology, feasibility study of engineering projects (route selection of railway lines, roads, crude oil and gas pipelines,…etc.) and geology.
3. Topography roughness has significant negative impact on the quality of DEMs generated from SRTM-DEM and ASTER-DEM digital elevation data.
4. DEM producers must, at least, specify the accuracy of DEM and state the interpolation method used to generate DEM and the source of elevation data.
5. Contour lines drawn from SRTM and AS TER digital elevation data have good cartographic quality in areas of complex terrain.
6. SRTM and ASTER digital elevation data could be used from open source data for producing topographic maps at scale 1:100000 or less.
7. Errors found in this research study are of random nature; hence they can't be removed or minimized.

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