Accuracy Assessment of world DEMs versus Local DEM in Egypt.

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ملخص البحث

يهدف هذا البحث الي تقييم الدقة الرأسية لنماذج الأرتفاعات الرقمية العالمية ASTER و SRTM ومقارنه تلك الدقة بدقة النموذج المحلي الناتج من الخرائط الطوبغرافية ذات مقياس رسم 1:50000 , بالتطبيق علي منطقة اختيرت في الجزء الشمالي من وادي النيل بين خطي طول 30-31.5 وخطي عرض 31-28 بمساحة 60,000 كم^2 حيث توافرت فيها محموعة من نقاط الثوابت الارضية التي استخدمت في عملية التقيم. اظهرت النتائج ان الدقة الراسية بدلالة الجزر التربيعي لمتوسط الاخطاء (RMSE) لنموذج SRTM افضل دقة للثلاث نماذج و بفارق ضئيل جدا عن دقة النموذج المحلي الناتج من الخرائط الطوبغرافية, بينما يأتي نموذج ASTER في المرتبة الأخيرة. وقد لوحظ وجود تفاوت في متوسط قيم الفروق في الارتفاع بين الثوابت الأرضية وما يقابلها في النماذج الثلاث, حيث كان الفارق كبير (12.5m) في حالة ASTER وضئيل في حالة SRTM بينما كان هذا الفارق غير محسوس في حالة النموذج المحلي. وبازالة هذه الفروق تحسنت دقة نموذج ASTER بشكل كبير حيث وصلت نسبة التحسن الي 57.8 % فوق الأراضي متوسطة الأنحدار و 48.8 % فوق الأراضي المستوية بينما كان التحسن في الدقة في حالة النموذجين الأخريين طفيف جدا الأمر الذي دل علي أن نموذج ASTER يعاني من وجود ازاحة رأسية منهجية. وحيث أظهرت النتائج ان الجزر التربيعي لمتوسط الأخطاء لنموذج SRTM أقل من نصف الفترة الكنتورية المستخدمة في الخرائط الطوبغرافية ذات مقياس رسم 1:50,000 فان هذا النموذج يصلح لتحديث مثل هذه الخرائط, بينما يحتاج نموذج ASTER الي تصحيح ازاحته الرأسية كي يصلح لتحديث الخرائط الطوبغرافية ذات مقاييس رسم أقل.

1 Abstract

ASTER and SRTM are two free available sources for digital elevation data covering the most of the world. In this paper vertical accuracy of such models over different terrain types compared with the accuracy of the local DEM produced from topographic maps of scale 1: 50,000 has been evaluated. The northern Nile valley was chosen as a study area that extends from (30° to 31.5°) of longitudes and from (28° to 31.5°) of latitudes, where a number of 705 GCPs were available in that area-

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and used to accomplish the evaluation process. The results show that SRTM and the local DEMs are close to each other in terms of the RMSE, they have almost the same accuracy for the different terrain with minute differences, while ASTER DEM lies in the final ranking. The results showed also that there is 12.55 m downward (average shift between the GCPs and ASTER DEM). The vertical accuracy of this DEM was radically improved by 57.8% over steep terrain and 48.8% over flat terrain after eliminating such shift, so these removed values could be considered as systematic errors and such model is therefore considered a relative DEM. From the final results, it can be concluded that SRTM DEM can be used to update topographic maps of scale 1:50,000, since its accuracy was found to be less than half the contour interval of such maps. Simultaneously, the ASTER DEM can be utilized for the same purpose, but for maps of lesser scales after eliminating its vertical shift (vertical systematic errors).

Keywords: Digital Elevation Models (DEMs), Shuttle Radar Topography Mission (SRTM), Advanced Spaceborn Thermal Emission and Reflection Radiometer (ASTER), local DEM, accuracy assesment.

2 Introduction

The DEMs are considered vital for enormous purposes as, orthorectification by satellite or aerial images, the creation of slope maps, the substructure planning, gravity field modeling and many other applications. Hence, there is a great demand for accurate and low cost DEMs. The possible sources of these elevation data can be photogrammetric methods, classical ground survey and the free world satellites DEMs such as ASTER and SRTM. The classical ground survey is accurate but economically only for small areas, in the same time, aerial photogrammetry covers larger areas but is entirely depending on the atmospheric conditions and the existence of clouds and also considered expensive. ASTER and SRTM cover large areas as much as we need and considered free of charge for the end user like us. In this thesis the vertical accuracy of the free world DEMs ASTER and SRTM were evaluated versus the local DEMs produced from topographic maps of scale 1:50,000 over different terrain types. The thesis is organized as follows: Site description and the available data are listed in section three, while in section four the methodology is presented. In section five, DEMs generation and accuracy assessment were descripted. Finally in section six, the results were discussed; conclusions and recommendations were made.

3 Site Description and the Available Data

The study area is located northern Nile Valley. It looks like a rectangle in shape and extends from (30° E to 31.5° E) and from (28° N to 31.5° N), the total area is about 60,000 km² (160 km * 380 km). It contains some mountains with summits reaching up to about (453) meters above sea level, and some valleys with depression about (-50) meters below sea level. The northern and the center part of this region are completely flat while the desert occupies most of the remaining region. Figure (1) shows the study area extensions. The available data in this research are 90 m spatial resolution SRTM DEM; a 30 m spatial resolution ASTER DEM and a 200 m spatial resolution local DEM produced from topographic maps of scale 1:50,000. The local DEM was generated through the process of digitizing contour and the spot elevations of a 64 sheet maps cover the whole subject area. The topographic maps were obtained from the military survey authority, where, a number of 950 ground control points (GCPs) were available in the study area and the final validated number of such ground control points was 705.

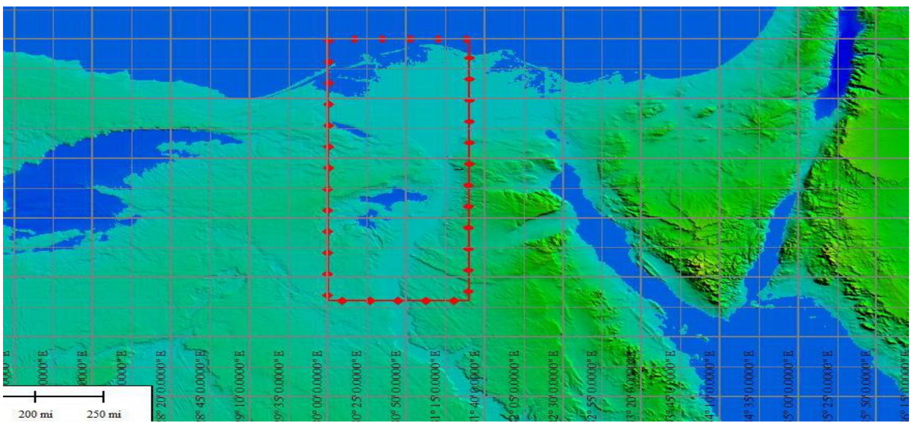


Figure (1): The extension of the case study area.

These points were utilized as a reference data for the purpose of the evaluation process of the DEMs accuracy. The ASTER DEMs have a worldwide vertical RMSE of 10–50 m **[6]**, in the case of SRTM DEMs, the mission expected worldwide vertical RMSE of 10 m **[7].** However, studies in mountainous regions revealed relatively bigger RMSEs, which were in the range of 20–36 m **[8].** The DEM from topographic maps of scale 1:50,000 expected a vertical RMSE reaches half of the contour interval **[2 and 3].**

4 Methodology

The evaluation process has been completed through the following steps:

4.1 Creation of local DEM from Topographic Maps of Scale 1:50,000 Based on Rectangular Grid

The data set used for generating the local DEM from topographic maps were a digital contour and spot elevations data obtained from digitizing a number of 64 sheets of topographic maps of scale 1:50000. The digitized contours and spot elevations were then used in an interpolation and gridding processes to gain a continuous surface of the terrain of the study area, where, interpolation is the mathematical tool used for determining intermediate unknown value between fixed known values or rate of surface change **[11].** The creation of the local DEM is therfore, passes through several phases, starting from data capture represented in map scanning and preparation, digitizing process (raster to vector conversion), data filtering, data conversion. The outcome of all the previous processes was an ASCII file. This file included (1435372) elevation points spread out over the whole study area of (60,000) km^2, with an average density of 25 elevation points / km^2. Accordingly, a grid size of 200 meter was reached based on the obtained density. Surfer program was then utilized for DEM creation through gridding, where gridding is the process used to set all the irregular scattered points in a regular pattern of rectangular grid form. The obtained file after gridding is the local DEM.

4.2 Defining the Proper Window of the World Digital Elevation Models ASTER and SRTM

Advanced Spaceborn Thermal Emission and Reflection Radiometer (ASTER) is a system based on a spaceborn earth observing optical instrument. ASTER Global Digital Elevation Model (ASTER GDEM) is a joint product developed and made available to the public by the Ministry of Economy, Trade, and Industry (METI) of japan and the United States National Aeronautics and Space Administration (NASA). The ASTER GDEM is the only DEM that covers the entire land surface of the earth at high resolution; it covers the land surface between 83°N and 83°S. The ASTER GDEM is in a Geo TIFF format with Geographic latitudes and longitudes and with 1 arc second (30m) grid of elevation postings. It is referenced to WGS84/EGM96 geoid **[5].** Shuttle Radar Topography Mission (SRTM) was a single pass, synthetic aperture radar interferometry (InSAR) campaign conducted in February 2000. For the first time a global high-quality DEM was achieved with a resolution of 1 arc Sec (30 m) and 3 arc Sec (90 m, free availability) covering the Earth's area between 60°N and 54°S **[10].** It is referenced to the WGS84 ellipsoid. ASTER and SRTM were downloaded from their website then Global Mapper program was used to subset the DEMs relevant to the study area, also a transformation from international ellipsoid (WGS84) to Helmert 1906 as adopted datum in Egyptian Surveying Authority (ESA) had been done. The coordinate system of the study area was then converted from geographical coordinates to Cartesian coordinates using ETM as the adopted projection in ESA. Table (1) shows some statistical information of the elevation data of the local and the other two DEMs.

Table (1) : Statistical parameters for the three DEMs.

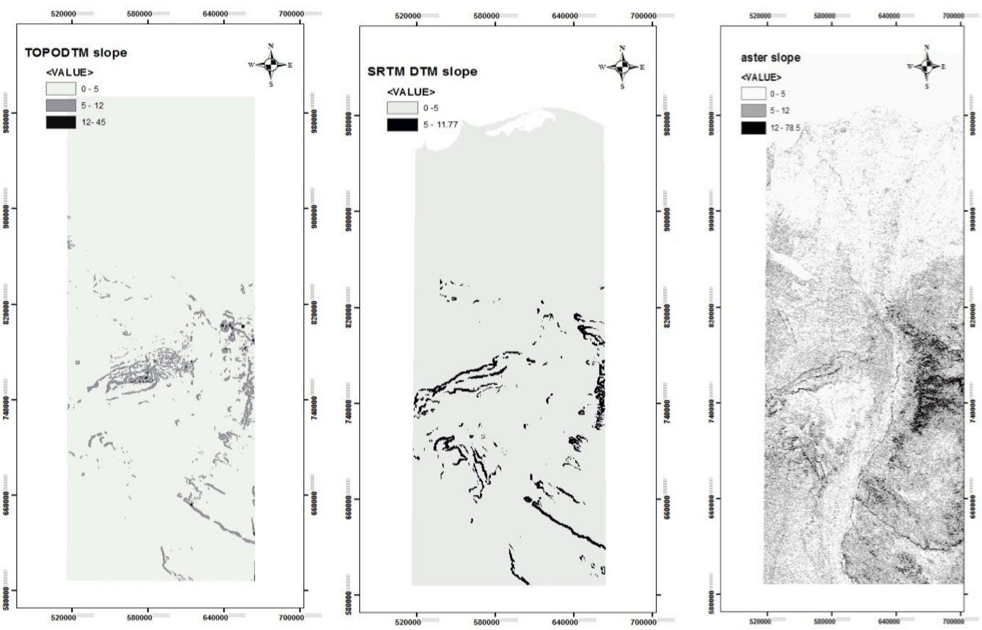
DEMs	Z (elevation) m			Total No. of elevation points	Point density/ km²	Slope % Min-Max	Grid size (m)
	Min.	Max.	Mean				
Local DEM	-53	453	111	1,435,37	25	0 - 45	200
SRTM DEM	-52	435	96	6,886,88	123	0 - 11	90
ASTER DEM	-105	458	74	67,193,2	1109	0 - 78	30

4.3 Overall verification of the DEMs

The verification here has two folds; visual comparison and accuracy assessment, where visual compression concerns with the quality of the DEMs in terms of some attributes in the seen charts like, shaded relief, slopes, images, and elevation maps obtained from the DEMs , while accuracy assessment concerns with the accuracy of the DEMs in terms of RMSE.

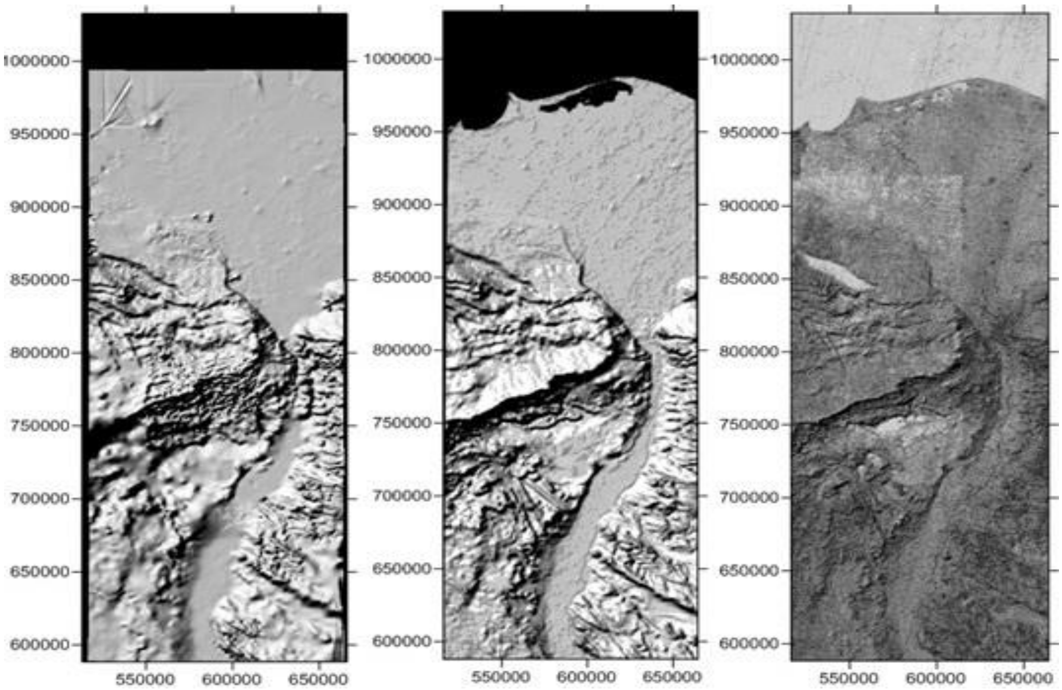
4.3.1 Visual Comparison

Visual inspection and examination of shaded relief, slopes, images, and elevation maps obtained from the DEMs were used to evaluate qualitatively the three DEMs. Figure (2) shows slope maps derived by ARCGIS for the three DEMs. From the derived slope maps, the maximum degree of the slope for local DEM was 45% and this value was 11.8% for SRTM while, it was 78.5% in the case of ASTER DEM. Three shaded relief maps derived from the three DEMs were shown in figure (3). It is clear that the image computed from the local DEM shows few topographic features and much surface smoothing; the pixel resolution (200m) allows only a broad representation of the main topographic features.



(A) (B) (C)

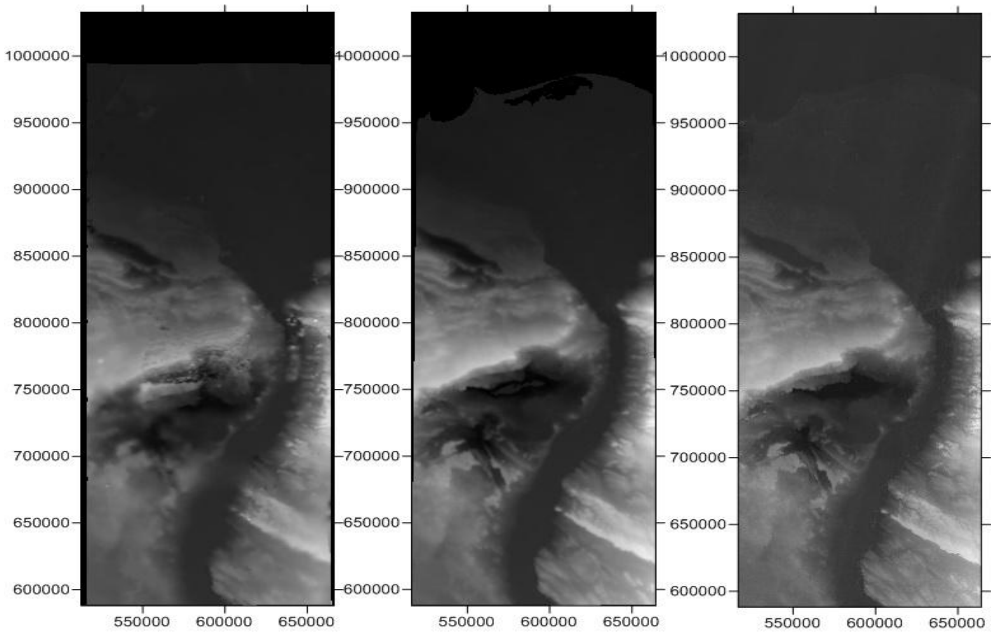
Figure (2): Slope maps created from the local DEM (A), SRTM DEM (B), and ASTER DEM (C)



(A) (B) (C)

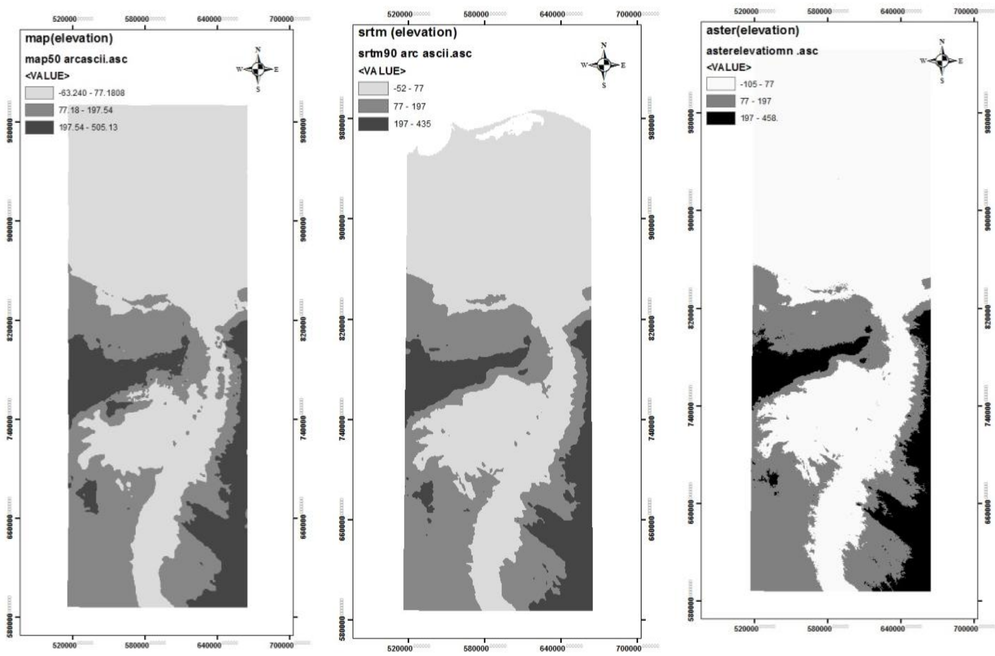
Figure (3): Shaded relief maps created from local DEM (A), SRTM DEM (B) and ASTER DEM (C).

The map computed from the SRTM DEM shows topographic features more than local DEM and a little surface smoothing; the pixel resolution (90m) allows only a broad representation of the main topographic features and some moderate topographic features. Lastly, the map derived from the ASTER DEM shows more topographic features and very little surface smoothing; the pixel resolution (30m) allows more detailed topographic feature representation. Visual inspection of the three shaded relief maps reveals a distinct improvement in the representation of the topography with increasing DEM resolution. Further inspection reveals a moderate increase in topographic details and roughness among the three DEM. The images derived from all DEMs were shown in figure (4), as evidenced from this figure, the local DEM gives a little representation of the topography and the drainage network is not well defined. The SRTM DEM gives a moderate representation of the topography while, the drainage networks are well defined especially in the mountainous regions. ASTER DEM gives a very good representation of the topography and the drainage networks are very well defined especially in the mountainous areas in the contrary to the local DEM, due to the smallest pixel size. All the above results of the visual comparison were completely reasonable and were logically expected due to the variation in the pixel size which varied from 200 m, 90 to 30 m.



(A) (B) (C)

Figure (4): Images created from local DEM (A), SRTM DEM (B) and ASTER DEM (C).



(A) (B) (C)

Figure (5): Elevation maps derived from local DEM (A), SRTM DEM (B) and ASTER DEM (C).

The elevation maps derived from DEMs shown in figure (5) indicate that the minimum elevation of the local and the SRTM DEMs was similar with minor difference, while there is a great difference downward in the minimum height value of the ASTER DEM, this is also obvious in the mean value of the heights of the three DEMs where their values reach 111 m and 96 m, and 74 m respectively.

4.3.2 Accuracy Assessment of the DEMs

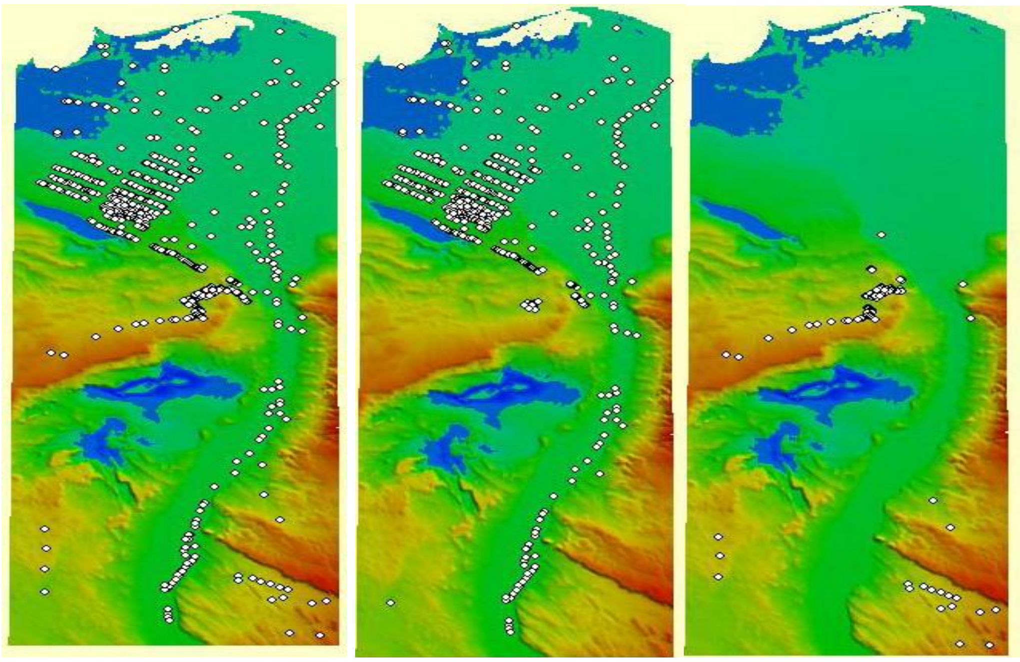
RMS was used to evaluate the accuracy of interpolated DEMs elevations, it is the most widely used statistics as a measure for accuracy **[4]**; it measures the dispersion of the frequency distribution of deviations between the actual values and the estimated value i.e. the accuracy. The RMS error characterizes the interpolation accuracy of the relevant points as well as the accuracy of the relevant models. The accuracy of DEM must be tested using points with known elevations (actual heights) i.e. ground control points (GCPs). The relevant points, interpolated from the DEMs, are compared with the elevations of these GCPs, in other words, the elevation difference between GCPs and the relevant pixels heights in the three DEMs should be calculated in order to verify the DEMs accuracies, where RMSE can be given as;

$$\textbf{RMS} = \sqrt{\sum \frac{(Z_i - Z'_i)^2}{n}} \qquad \textbf{(1)}$$

Where n is the number of check points, z_i is the original or known elevation, (GCPs), z_i' is interpolated elevation from the DEMs. The elevation difference between GCPs and the corresponding pixels in the three DEMs should be calculated at all the specific GCPs in order to verify the DEMs accuracies. The reference data were filtered from gross errors. This step is very important to ensure that the input data has the optimum quality **[1]**, which is essential for accuracy assessment. In that regard, all GCPs were subjected to a validation process that aimed to filter out any data element, which lack a minimal level of guarantee and reliability. All the GCPs will be used to determine predicted new elevation values at the same GCPs, then; one would reject a specific observation (**S**) having gross errors, if the following condition was satisfied:

$$| S_{observed} - S_{predicted} | > 3.0\,\sigma \qquad (2)$$

Where (σ) is the standard deviation of the difference (residuals). In our case the number of the available reference points (GCPs) was 950 and after filtering, the reliable number became 705, they were used to quantify the vertical accuracy of the three DEMs. These GCPs are classified as 643 GCPs lies at the flat terrains, so they were used to quantify the accuracy of the flat terrain, and the remaining 62 GCPs are lying at the steep terrain were used to do the same for the steep terrain.



(A) (B) (C)

Figure (6): The distribution of GCPs over the flat terrain (Fig: A), steep terrain (Fig: B) and over whole terrain (Fig: C).

All the 705 GCPs were then used to assess the accuracy of the whole terrain at the same time. Figure (6) shows the distribution of these ground control points over the flat, steep and whole terrain. Tables (2, 3, and 4) show the statistics of the three DEMs at different type of terrain.

Table (2): Statistics of the Three DEMs at the Flat Terrain.

DEMs	Z (DEFERENCE) m			No of check points	RMSE (m)
	Min.	Max.	Mean		
Local DEM	-16.62	18.18	-0.025	643	4.60
SRTM DEM	-13.96	19.92	1.73	643	4.54
ASTER DEM	-14.45	34.59	12.53	643	14.54

Table (3): Statistics of the Three DEMs at the Steep Terrain.

DEMs	Z (DEFERENCE) m			No of check points	RMSE(m)
	Min.	Max.	Mean		
Local DEM	-11.10	20.27	4.25	62	6.86
SRTM DEM	-14.02	19.11	1.54	62	6.19
ASTERDEM	-7.80	28.06	12.85	62	13.86

Table (4): Statistics of the Three DEMs at the Whole Terrain.

DEMs	Z (DEFERENCE) m			No of check points	RMSE (m)
	Min.	Max.	Mean		
Local DEM	-16.62	20.12	0.04	705	4.85
SRTM DEM	-14.02	19.92	1.80	705	4.72
ASTER DEM	-14.45	34.59	12.55	705	14.53

The investigation of the tables (2,3 and 4) reveals that, the difference between the elevations of the ground control points and the elevations of the related pixels at the three DEMs are suffering from shift, this shift represented by the mean of the elevation difference between the GCPs elevations and the relevant pixel values at each DEM,

In general if the elimination of any difference between the mean height of the GCPs and those of the corresponding model points, make a significant improvement in the computed RMSE, it is then considered a systematic shift. In the following step, these differences had been eliminated and the statistical parameters were recalculated to determine which of them is considered a systematic shift, where the results are shown in Tables (5,6 and7).

Table (5): Statistics of the three DEMs over the flat terrain after shift elimination.

DEMs	Z(DEFERENCE)m			No of check points	RMSE(m)
	Min.	Max.	Mean		
Local DEM	-16.58	18.22	0.0	643	4.60
SRTM DEM	-15.76	18.12	0.0	643	4.11
ASTER DEM	-26.80	22.24	0.0	643	7.43

Table (6): Statistics of the three DEMs over the steep terrain after shift elimination.

DEMs	Z(DEFERENCE)m			No of check points	RMSE(m)
	Min.	Max.	Mean		
Local DEM	-15.35	15.87	0.0	62	5.95
SRTM DEM	-15.56	13.78	0.0	62	5.96
ASTER DEM	-20.65	15.21	0.0	62	5.84

Table (7): Statistics of the three DEMs over the whole terrain after shift elimination.

DEMs	Z(DEFERENCE)			No of check points	RMSE(m)
	Min.	Max.	Mean		
Local DEM	-16.58	20.16	0.0	705	4.85
SRTM DEM	-15.82	18.12	0.0	705	4.33
ASTER DEM	-26.80	22.24	0.0	705	7.33

From the above tables it is clear that the RMSE were significantly improved especially in the case of the ASTER DEM which improved by 49.5 % over the whole terrain after the elimination of the vertical deference. So these removed values could be regarded as a systematic shift that makes this model a relative DEM, table (9) shows the improvement occurred for each DEM after elimination of the vertical deference.

Table (9): Improvement occurred for each DEM after elimination the vertical deference.

DEMs	Flat	Steep	Whole Terrain
	Improvement. %	Improvement. %	Improvement. %
Local DEM	0.00%	13.20%	0%
SRTM DEM	9.47%	3.70%	8.25%
ASTER DEM	48.89%	57.80%	49.50%

5 Conclusion

SRTM and local DEMs have nearly the same accuracy in terms of RMSE, while ASTER DEM lies in a lower ranking , the accuracy of the ASTER DEMs was radically improved (49.5%), after the vertical shifts versus GCPs had been removed. The removed values could be considered as systematic shift and such model is thus considered a relative DEM. SRTM DEM can safely be used for updating the topographic maps of scale 1:50,000 over flat and steep terrain, because the RMSE of such DEM is less than half the contour interval used in such topographic maps, while ASTER DEM can be used safely for updating the smaller scale topographic maps [9].

6 Recommendations

- When using ASTER DEM elevation data, it is recommended to determine and remove the vertical systematic shifts, if exists, using sufficient numbers of GCPs, distributed fairly in the intersted area, to obtain good results.
- It is also recommended to check the horizontal accuracy of the ASTER DEM and to correcte it, if necessary, before eliminating the vertical displacement.
- A suitable integration technique using elevation data of the three DEMs should be applied, to produce a more detailed and accurate fused DEMs.

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