Accuracy Assessment of SRTM and ASTER DEM's over Egypt

Hanafy M. Kamal, Anas M. A. El-Molla, Hany G. Ahmed, Mostafa H.A. Mohamed, Salem S. Saleh

Abstract— Digital Elevation Model (DEM) is one of the most important, simplest and most commonly used in digital representations of the topography and geodata. DEM's are needed in large number of analyses and applications; the accuracy of DEM' is usually represented by spatial resolution and height. There are several ways to acquire elevation data and generate DEMs; while each method has its own strengths and weaknesses. The SRTM and ASTER GDEM2 are most freely available commonly used DEM's. This paper therefore investigates and assessed the quality of vertical accuracy of the two DEM's with spatial resolution 1 arc sec. over Egypt. Two reference data sets are used as a referenced elevation data. The first data set is a differential GPS ground control points with known orthometric height data set distributed over whole Egypt. Also a digitized spots elevation and contours from the topographic maps 1:50000 cover a specified study area was the second one. The study area located along the river Nile with 81 km * 54 km approximate dimensions from (31° 00′ E to 31° 30′ E) and (29° 00′ N to 29° 45′ N). It was observed that The SRTM DEM performs better than ASTER GDEM2 referenced to the differential GPS elevation data. The root mean square errors RMS for the GPS data set were ± 7.040 m for the SRTM and ±12.658 m for the ASTER GDEM2. Applying the same test for the study area referenced to the topographic map elevation data set after horizontal shift adjustment it was observed that, The RMSE was ± 8.56 m for the SRTM which is better than STER GDEM2 RMS ± 9.78 m. The results from both assessments revealed the suitability and good performance of the SRTM DTM for geomatics applications over Egypt.

Keywords —, DEM, GPS, Accuracy assessment, ASTER GDEM2, shuttle radar topographic mission SRTM, topographic maps.

1 Introduction

Digital Elevation Model (DEM) is a regularly spaced grid of surface elevations. The DEMs recently can be described as "a function of geographic location representing terrain elevations and providing information about the topographic attributes of terrain [1]. All The satellite based DEMs contains a certain amount of errors due to data collection and processing techniques. The DEM's reliability, accuracy and fits the earth's surface are the main target for most analysis and applications.

DEMs are used for many purposes, and considered an important precondition for many applications [2], [3]. They are particularly useful in regions that devoid of detailed topographic maps. DEMs have been found useful in many fields of study such as geomorphometry, that are primarily related to surface processes such as landslides which can directly be depicted from a DEM [4], archaeology as subtle changes due to previous human activity in the sub surface can be inferred on detailed DEMs [5] and hydrology like deriving drainage network and overland flow areas that contribute to suspended sediment loads [6]. Thus for a whole range of different studies, DEMs are provide a good representation of the terrain and are an important support in starting point for further analysis.

The accuracy is always the main aim and in order to get it a lot of coast and efforts are required so, in this paper a study analysis to evaluate and obtain the more accurate and reliable DTM over Egypt are introduced.

The Shuttle Radar Topographic Mission DEM (SRTM) and the Advanced Spaceborne Thermal Emission Radiometer DEM version 2 (ASTER GDEM2) are two freely available world sources for DEM covering the world with spatial resolution 30 m. The research objectives are to assess the quality of vertical accuracy for both DEMs over Egypt.

Synthetic aperture radar (SAR) is the SRTM method for extracting relative or absolute elevation information by radar interferometry or InSAR. The phase difference information between the SAR images is used to measure precisely changes in the range, on the sub wave length scale, for corresponding points in an image pair. Analysis of the differential phase, and therefore change in distance, between the corresponding pixel canter's and the observing antenna can lead to information on terrain elevation [7], [8]. The SRTM mission was the first mission using space-borne single-pass interferometric SAR [9], [10]. SRTM acquired DEMs data in February 2000 by a mission was a partnership between NASA and the German/Italian space agencies.

The SRTM successfully collected data over 80% of the Earth's land surface, for most of the world area between latitudes 60ºN and 56º S. The heart of the SRTM radar was the Spaceborne Imaging Radar-C/X-band Synthetic Aperture Radar (SIR-C/X-SAR) after modified by the addition of C-band and X-band antennas at the end of a 60 m mast. These second-

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ary, or ''outboard'' antennas, allowed the radar to use interferometry to map the elevation of the terrain in a single pass, which was not possible with SIR-C/X-SAR. The Shuttle was flown at an altitude of 233 km with an inclination of 57º.

The Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) is a 15-channel imaging instrument operating on NASA's Earth Observing Terra morning orbital platform since 1999 [11]. ASTER has three separate optical subsystems: the visible near-infrared (VNIR) radiometer, acquiring images in 3 bands with a 15 m instantaneous field of view (IFOV), and an additional backward-looking band for stereo; the shortwave infrared (SWIR) radiometer, acquiring images in 6 bands with a 30 m IFOV; and the thermal infrared (TIR) radiometer, acquiring images in 5 bands with a 90 m IFOV. ASTER acquires images in all bands with a swath width of 60 km.

The Shuttle Radar Topography Mission SRTM DEM is one of the most used freely available DEMs in the Geomatics and by the general public (e.g. SRTM DEMs are used in Google Earth). Synthetic aperture radar (SAR) is the SRTM method for extracting relative or absolute elevation information by radar interferometry or InSAR. SRTM techniques with Radars have two main advantages over ASTER GDEM2 optical techniques [12]; the first one is active system i.e. self-transmit and receives electromagnetic waves. This means image acquisition is independent of natural illumination and therefore images can be taken at night. The second advantage is the observations are not affected by cloud cover since the atmospheric absorption at typical radar wavelengths is very low. The necessary data collected by two antennas during the same pass.

In this study, the C-band SRTM - and ASTER – derived satellite based DEMs are assessed and validated against a reference ground control points distributed over whole Egypt and a set of denesifyed spots elevation data derived from a topographic map 1:50000 concentrated over a study area located at the Egypt delta.

2 OBJECTIVES

The objectives of this study are:

- Study the horizontal and vertical accuracy for the satellite based DEM's.
- Assessment and Compare the SRTM and ASTER GDEM2 performance referenced to two data sets, observed GPS ground control points and a set of ground spots elevation data derived from a topographic maps 1:50000.

3 STUDY AREA

Egypt window are the main objective study area approach however according to a second type of reference data set and a huge number of DTM Elevations loading data a second study area was selected. The area is located along the river Nile. The selected study area measured 81 km bi 54 km approximate dimensions and located from (31° 00′ E to 31° 30′ E) and (29° 00′ N to 29° 45′ N) covered apart of Giza and apart of Bani Swif governorate see figure(1).

1 DATA USED

1.1 SRTM and ASTER GDEM2 DEM's

SRTM and ASTER GDEM2 DEM's are freely available for public globally in 1 arc sec/30m DEM and 3 arc sec/90m for SRTM only. Both DEM's were available in 1º * 1º tiles in computer-compatible raster formats (GeoTiff and ARC/INFO ASCII Grid).The both data sets are provided worldwide with spatial resolution 30m in (Lat. /Lon.) and Coordinate system projected on the WGS 84 Ellipsoid. The DEM's data were downloaded from the United States Geological Survey official website (https://earthexplorer.usgs.gov/).

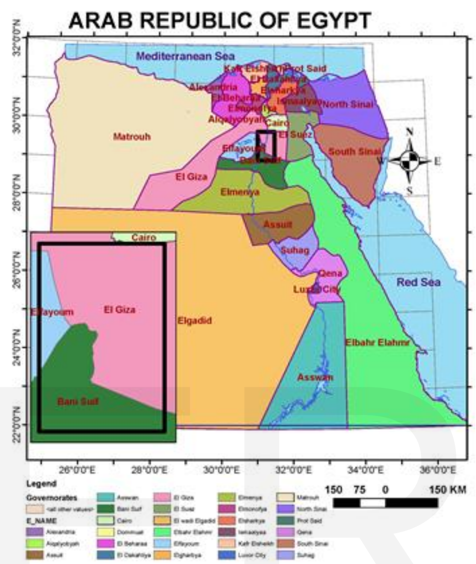


Fig. 1. The arab republic of Egypt map with zooming on the study area.

1.2 GPS Reference Data Set

A reference ground control data set contain a 389 GPS ground control points (GCP) from multiple data sources [13] are available. The reference data set were used for DEM's accuracy assessment over whole Egypt see figure (2). The GCPs' orthometric height is used as an elevation reference to validate the quality of vertical accuracy generated from the DTMs. The GCPs are distributed over whole Egypt randomly however the west desert not covered due to the blockaded mining areas. The data set points coming from national project in Egypt like El-kanater Domitta project by Survey Research Institute, 2000, Ras El- Hekma Road project, Egyptian geodetic control network by Egyptian Survey Authurity, a GPS national network The Egyptian Aviation Authority made, El-WAHAT road GPS networks by the Egypt Surveying Authority during national vertical network establishment[13].

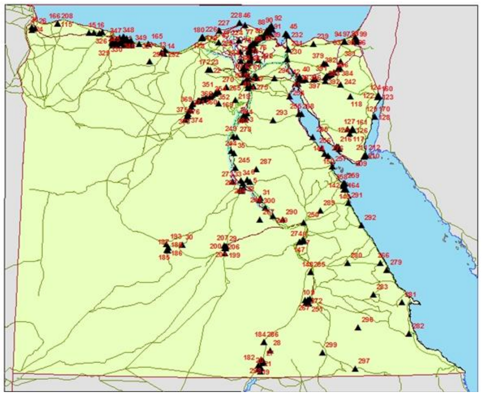


Fig. 2. Distribution of the available GPS Reference ground control points.

1.3 Topographic Maps Reference Data Set

Six hard copy sheets of topographic maps cover all study area; these maps were produced by the military survey authority with scale 1:50,000. Four thousands and nineteen elevation points (spots) were obtained during the digitizing process. Figure (3) show the distribution and spots density of the digitized spots for one sheet cover 15' *15'.

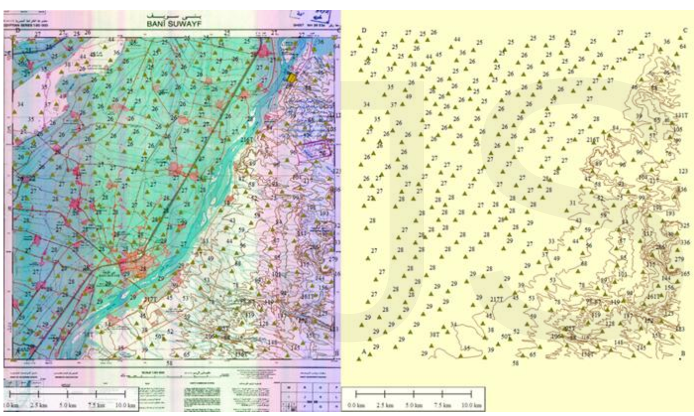


Fig. 3. Distribution and Densifying the digitized spots elevation reference data set.

The maps were scanned with the high resolution scanner (1200 DPI). Contours and spot elevation were digitized manually by mouse courser on screen at scale 1:1000. The Expected accuracy of the generated reference points from the topographic maps reaches half of the contour interval according to American standards [14], [15].

2 Processing Methodology

In this paper, we present a framework for accuracy assessment of Digital terrain models SRTM 1sec and ASTER 1 sec so, the procedure require a good understand for the input data. The study methodology involves the following ordered steps:

- Data preparation.
- Georeferencing and datum unification.
- Horizontal assessment investigation study.
- Vertical accuracy validation.
- DEM's comparisons.
- Results analysis.

The both data sets are provided worldwide in computer-compatible raster formats (GeoTiff and ARC/INFO ASCII Grid) with spatial resolution 30m in (Lat. /Lon.) Coordinate system projected on the WGS 84 Ellipsoid. The accuracy of satellite based digital elevation models can be evaluated by comparing the elevation information's generated by them with the sufficient number of clearly identifiable 'Ground Control Points (GCPs).

Unfortunately, however the elevation data derived from Differential Global Positioning System (DGPS) is expensive, but identifying such GCPs on a satellite based DEM for the accurate undulation is rather problematic so, the semi-detailed topographic maps, i.e. 1:50,000, of study area are the other alternative. After the exploitation of the data sets was therefore the transformation of all the data sets into a common system see figure (4) for the proposed methodology for the study accuracy assessment.

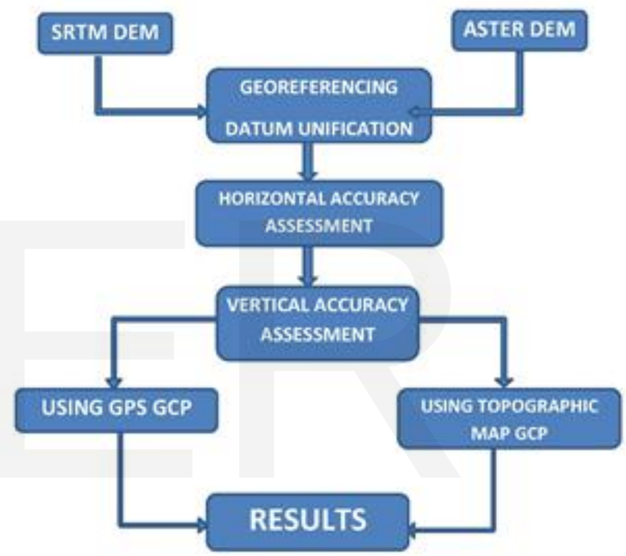


Fig. 4. The proposed methodology for satellite based DEM's accuracy assessment.

The map projection used in all survey maps in Egypt is the "Transverse Mercator" projection. Old maps were produced using "Helmert" spheroid 1906. Since 1959 the maps shifted over to the international spheroid datum "Hayford" 1910[16]. So the geographic coordinates of maps corners were used to transform the coordinate system to the world geodetic reference datum (WGS84) or vies versa which are the DEMs reference. Moreover, the datum conversion operations are an important step to get the two data sets are coincides in the same datum and same coordinate system with the two DEM's. The default transformation parameters in global mapper tool were used in georeferencing even from Hyford 1910 or Helmart 1906 to WGS84 and vies versa. The DEM scenes of SRTM and ASTER were independently mosaicked and then the reference GCPs was overlaid on the mosaicked DEM. an interpolation extracting operation were don in order to carry out the computed relevant heights of the GCP coordinates from the 1 arc sec DEMs. In mapping applications, vertical accuracy is computed by vertical Root-Mean-Squared Error (RMSE) (also called the root mean square deviation, RMSD). This mathematical relation has been widely adopted since the late of 1970s. The American Society for Photogrammetry and Remote Sensing's (ASPRS) Specifications and Standards Committee is establishing RMSE as the pivotal map accuracy parameter [17]. The RMSE measures the difference between the values of the DEM elevations and the values of referenced GCPs elevations. The differences of individual point are called residuals, and the RMSE serves to combine them into a single predictive measure through the equation:

$$\text{RMS} = \sqrt{\textstyle\sum_i^n (\Delta N)^2 / n - 1} \qquad (1)$$

$$\Delta N_i = N_{iG} - N_{iM} \qquad (2)$$

Wher :

N_{iG} The reference GCP elevation at the **i**th point
N_{iM} The DEM elevation at the **i**th point
ΔN_i The DEM height error at the **i**th point
n The number of data set points.

The mathematical relation RMS error used by United States Geological Survey agency (USGS) evaluation for the Aster GDEM2 and SRTM over the CONUS against 18000 GPS points on Bench Marks data set as an absolute geodetic reference [18]. The results show that RMS error of the SRTM is 4.01 m however for ASTER GDEM2 is 8.68 m for over all the CONUS. According to ASTER validation team summary results the performance of SRTM over the CONUS is better than the ASTER GDEM2 performance.

The validation results of ASTER diverse from place to place from 6 m to 30 m. Most papers think ASTER is not stable and should be validated regionally before using [19].In fact, to validate the better performance DEM over Egypt, the SRTM and ASTER GDEM2 should evaluated against a sufficient number of ground data set. The study was one using the available data sets GPS data and the digitized spots elevation from topographic maps 1:50000. Then compute the RMSE for the data sets and the relative extracted one from the satellite based DEM's individually.

3 Statistical Analysis and Results

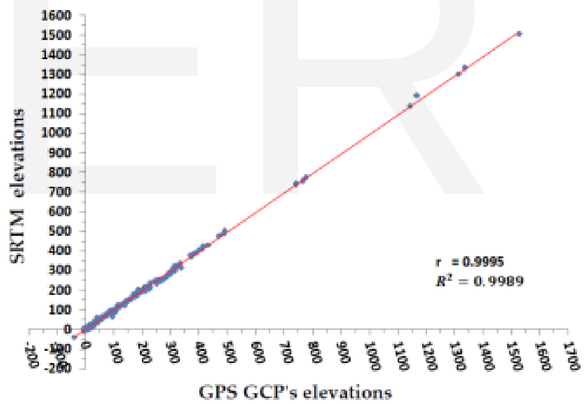
Quantitative statistical and geostatistical tests were performed on the two spatial data sources to determine their suitability for accuracy assessment in different scenarios.

3.1 Differential GPS Reference Data set.

Follow up the proposed methodology on the available 389 deferential GPS ground control point as a reference ground trusted control points, the statistical analysis results are summarized in table (1). The results show that the absolute vertical accuracy of SRTM 1sec for Egypt window represented by RMS is ±7.040 m against ±12.658 m for ASTER GDEM2 and the mean difference elevation of the two DEMs is 2.036 m and 4.749 m which describe the good fit of the SRTM DEM over Egypt than the ASTER GDEM2. Manipulate the correlation between the DEMs elevation with respect to the GPS reference data in a graphic scatter plot see figure (5). The coefficients of correlation between the both models SRTM and ASTER with the GPS data were respectively 0.99949 and 0.99849. The results indicate a strong positive correlation between the two models with the GPS data and there is uniformly distribution between the DEMs elevation data around the zero axes of the GPS data.

Table 1
Results of vertical accuracy of SRTM and ASTER GDEM2 referenced to GPS GCPs data set

PARAMETERS	SRTM	ASTER GDEM2
NO.OF GCP's	389	389
SPATIAL RESOLUTION	30	30
MINIMUM	-25.748	-19.497
MAXIMUM	30.786	70.201
MEAN	2.036	4.749
STDEV.	6.728	11.730
RMS	±7.040	±12.658



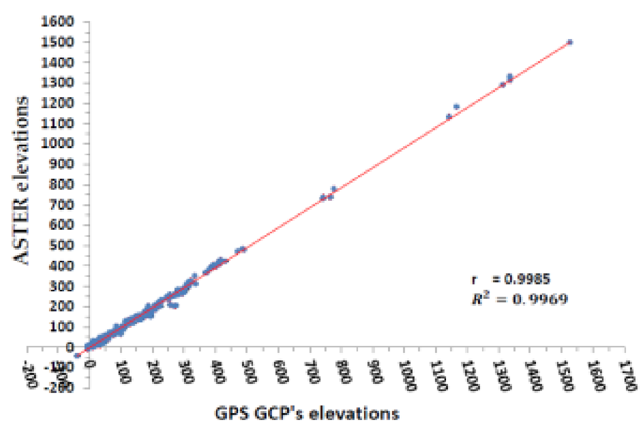


Fig. 5. A correlation graph of the GPS ground control points elevation against SRTM, ASTER GDEM2 DEM's elevations.

The F-test applied individually between the SRTM and ASTER GDEM2 so, standard deviation σ for SRTM is the lower. A Statistical F-Test for the two models. The SRTM and ASTER GDEM2 F-TEST results that the calculated value $F_{calc.} = 3.0396$ is more than the tabulated value $(F_{388, 388, 0.05}) = 1.16$, therefore the null hypothesis that both models are as precise is rejected and the alternative H1 hypothesis that $\sigma^2_{ASTER} > \sigma^2_{SRTM}$ is accepted.

3.2 Topographic Maps 1:50000 Reference Data set.

Four thousands and nineteen GCPs considered a sufficient number and a good covering reference data set for a specified study area were used to assess the vertical accuracy of the SRTM and ASTER GDEM2. The both satellite based DEM coordinate system are different than the Egyptian topographic maps. This fact affect a horizontal and vertical "shift" between the data sets derived values so, the assessment of absolute accuracy rather problematic. Nonetheless, if the shift is consistent over the area, the relative accuracy of DEMs could be assessed after datum and coordinate systems unification.

The horizontal shift study done by comparing the digitized cleared features from the topographic maps and the corresponding one from the satellite based DEMs. After exporting the values of the easting and northing for each pair of digitized points the difference in X-direction and Y-directions were obtained. The standard deviation was computed from the obtained ΔX and ΔY and used as transformation parameters to adjust the DEM's horizontal orientations see figure (6).

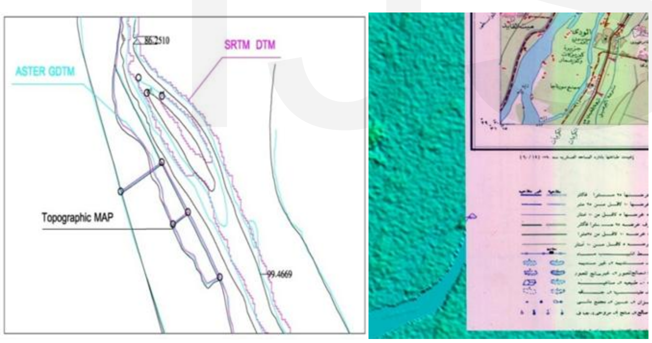
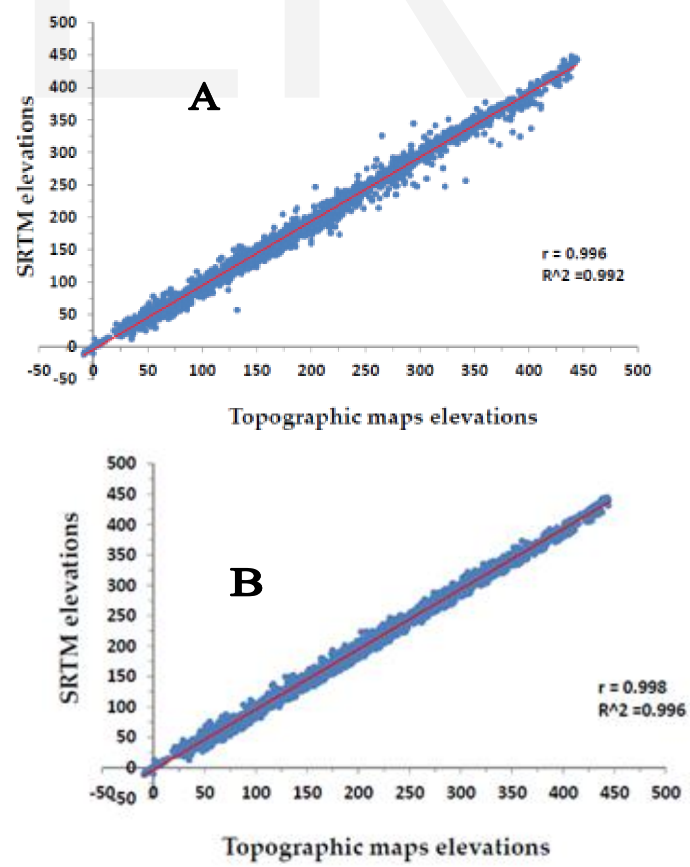


Fig. 6. The horizontal shift between the topographic maps 1:50000 features and the corresponding detected from DEM's.

The SRTM results of horizontal shift corrections for easting and northing were +99 m and +76 m respectively and for ASTER GDEM2 are +50 m and +28 m. the RMSE for elevation difference between the Models and the topographic maps elevation. The vertical accuracy of the two DEMs was calculated from the differences corresponding between the value of the DEM pixel and the reference GCP's after horizontal shift corrections.

A gross error filter is an important process In order to eliminate the points having a gross errors coming from digitizing or typing mistakes to ensure that the input data has the optimum quality [20]. This filter is essential for accuracy assessment and is one of the most common and heuristic measures on determining the size and ultimately the standard deviation of the Gaussian filter. The filter is known as the 3-sigma rule. If you recall from probability, the Gaussian distribution has most of its values centered between [μ - 3*σ, μ + 3* σ]. After making a filter and exclude all points which have a minimal level of reliability only 96 and 86 odd points has been eliminated from the topographic maps Ground control points for SRTM and ASTER GDEM2 respectively to left 3923 and 3933 reference GCP's. The excluded point's percentage was about 2.3% from the total digitized points for SRTM and ASTER, which describe the high accurate digitizing process. The analysis correlation statistical test of both DEMs with respect to the referenced topographic elevation was carried out to measure the strength of a linear association using linear regression before and after horizontal shift adjustment. The graphs in figure (7) below show the measure of association through their goodness of fit, R^2 and correlation coefficient (r) values before and after horizontal shift adjustment applied. That is, from figure (7-B), the graph of SRTM elevation after horizontal shift applied had $R^2 = 0.996$. These R^2 values indicate that 99.6% of the changes in SRTM DEM elevation are correlated with the change of topographic map elevation after shift than 99.2% before shift see Figure (7-A) so, the variation of elevation data after horizontal shift performed with a reliable accuracy.

For the ASTER GDEM2 the goodness value R2 = 0.995 after shift from figure (7-D) is slightly better than the goodness value R2 = 0.994 before shift from figure (7-C). The ASTER GDEM2 graphs explain there is no more changes in correlation for the two variables, also ensure that the ASTER GDEM2 doesn't have a big shift than a topographic maps.



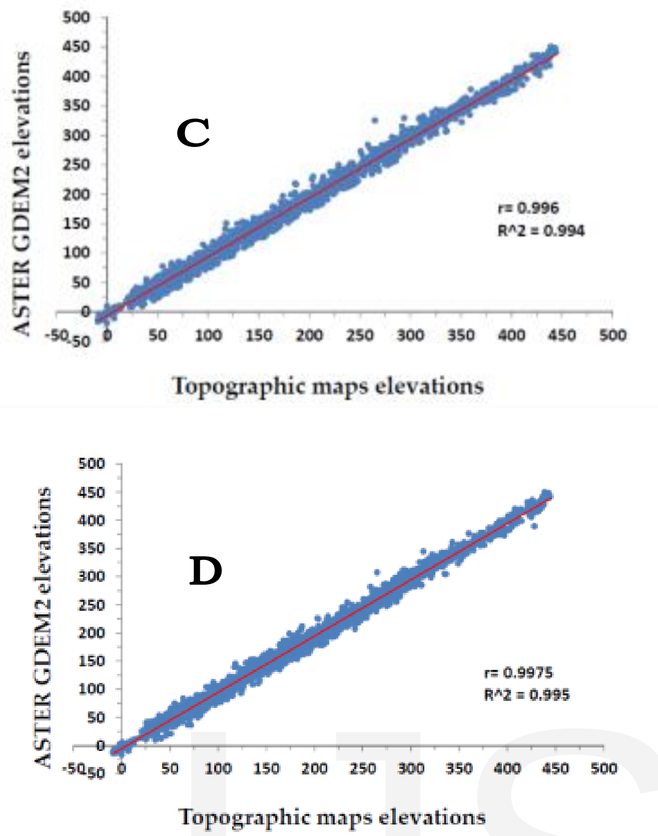


Fig. 7. A correlation graph of topographic maps 1:50000 spots elevation against SRTM, ASTER GDEM2 DEM's elevations.

It was also noticed that the strength of the relationship in the linear regression analysis carried out from SRTM were stronger than that before horizontal correction. Furthermore, this strong correlation is backed up with the observation that vertical accuracy of SRTM is better predicted especially after horizontal shift correction applied. The validation method was represented by using a statistical measurement.

The vertical accuracy of the two DEMs was calculated from the differences corresponding between the value of the DEM pixel and the reference GCP's. After the elevation error estimated, a statistical, maximum error (Max), minimum error (Min), Mean Error (ME), Standard Deviation Error (STD), and Root Mean Square Error (RMSE), were estimated. STD and RMSE are revealing of surface quality and height accuracy performance see table (2).

The statistical analysis results reveal that the absolute vertical accuracy denoted by the RMS error for SRTM ±8.56 m is higher than the corresponding one for the ASTER GDEM2 ±9.78 m. That is reflects the better performance of SRTM over Egypt than ASTER GDEM2 and confirms the GPS GCP's results, also match with the international results. From the minimum and maximum values the SRTM error distribution seems to be concentrated around the mean better than ASTER GDEM2.

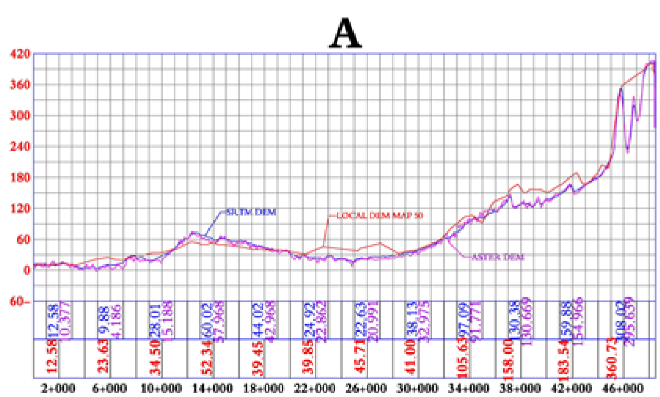
TABLE 2
STATISTICAL ANALYSIS FOR SRTM, ASTER GDEM2 AND FUSED DEM USING A REFERENCED TOPOGRAPHIC MAP GCP'S.

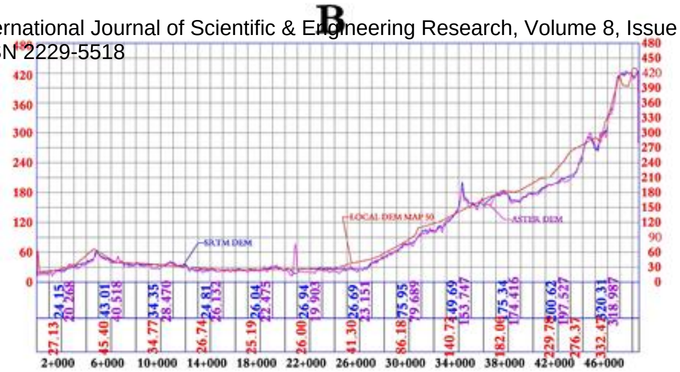
PARAMETERS	SRTM	ASTER GDEM2
NO.OF GCP's	3923	3933
SPATIAL RESOLUTION	30	30
MINIMUM	-20.72	-42.56
MAXIMUM	22.59	38.41
MEAN	5.13	5.73
STDEV.	6.85	7.93
RMS	±8.56	±9.78

Finally F-TEST analysis was applied to test if the SRTM and ASTER population variances are equals at confidence level 95% or not. The calculated value F_{calc}. is more than the tabulated value ($F_{3896,\ 3896,\ 0.05}$) = 1.05, therefore the null hypothesis that both models are as precise is rejected and the alternative H1 hypothesis that σ2 ASTER > σ2 SRTM is accepted.

The tests results proved that the SRTM DEM 1 arc sec is more accurate and fit on the Egypt topography better than ASTER GDEM2 1 arc sec.

Diagrammatic profiles were obtained from the 3 data sources elevations showed in Figure (8) to explain the relation between the DEM's/GCP's topographic behaviors. Three profiles were selected to cover the study area by dividing the study area for four parts and cover all area passing over different terrain types. The profiles were produced using the civil 3d software over the four surfaces SRTM,ASTER GDEM2 and the spots elevation of the topographic maps 1:50000 for the study area where the reference data set was overlaid over the two satellite based DEM's to extract the elevatons at the same location of the data set points.





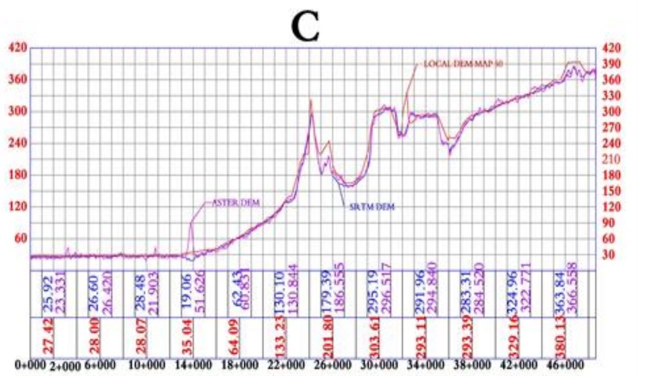


Fig. 8. SRTM DEM, ASTER GDEM2 and Topographic maps profiles.

The profiles pass by the north gridwher figure (8-a) is N755000, (8-b) is N710000 and (8-c) N735000 and N755000 and describe the similarity between both DTMs with a quite slight difference. It shows also that the SRTM and ASTER profiles underestimate the true topographic GCP's elevation. Moreover, the SRTM DEM profile is quite the closest to the topographic map profile at the areas of density of GCP's.

A slope map of the study area was produced from the DEM by the SLOPE function in the GRID module. The slope angle for each grid cell is calculated from a 3 x 3 neighbourhood us-

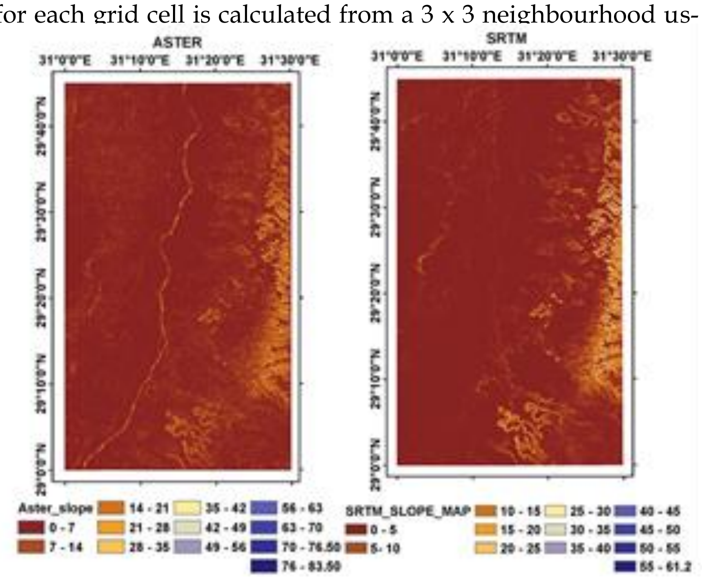


Fig. 9. A correlation graph of topographic maps 1:50000 spots elevation against SRTM, ASTER GDEM2 DEM's elevations.

Standard deviation σ of altitude and slope angle was calculated. In general, the standard deviation of a parameter provides a more stable statistic than ranges and extremes [22].The mean absolute slopes for terrain chart classification by percentage slopes was from 0-10% are flat,11-20% are gentle, 21-33% are moderate, 34-50% are steep and +51% are very steep [23]. From the statistics results of slope map the standard deviation σ = 85.32 for the SRTM and 99.68 for ASTER.

4 Conclusion

Accuracy assessment was investigated to the most used global satellite based DTM's SRTM and ASTER GDEM2 using two references data sets. The first data set are the differential GPS ground control points distributed over whole Egypt, and the second one are about 4374 km2 study area around the nil river at Baniswif. The DEM's validated using the spot elevation and contour data in six sheets topographic maps with scale 1:50000. The vertical accuracy in comparison with differential GPS ground control points are represented by RMS is ±7.040 m for SRTM against ±12.658 m for ASTER GDEM2, the RMS results indicate that the good fit and best performance for SRTM over Egypt topography better than ASTER GDEM2 performance. The height validation accuracy assessment over a study area with referencing the topographic maps 1:50000 GCP's obtained that the RMS for SRTM was ±9.715 m and for ASTER GDEM2 was ±10.536 m before the horizontal shift adjustment while an enhancement were done after shift correction to produce RMS ±8.56 m for SRTM and ±9.78 for ASTER which confirm on the deferential GPS GCP's results that the SRTM perform better than ASTER GDEM2. so, for the geomatic applications the SRTM DEM 1arc sec are perform with high accuracy better than ASTER GDEM2 same spatial resolution over Egypt topography. The visual study for the both DTM's concluded that the ASTER GDEM2 has more details than SRTM so, it is recommended that the fusions between SRTM and ASTER GDEM2 will produce high detailed DTM and more accurate than both of them.

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