# A Perspective of Reliable and Accurate DEM Using World DEMs Data Fusion

**Mahmoud El Nokrashy Osman Ali**, **Ibrahim Fathy Mohamed Shaker**, **Nasr Mohammady Saba**

Abstract— In Egypt, most of the available topographic maps need updating. Also, there are large areas haven't mapped yet. Western desert is an example of these poor mapped regions. Most of its terrain is flat and it is difficult to have stereoscopic viewing during mapping operations. Globally, there are many sources of the elevation data in the form of Digital Elevation Models (DEMs). These world DEMs are free of charge for users all over the world. In this study, Five world DEMs are selected for evaluation in order to find the best model for making up the shortfall of such information of the elevation data. The selected world DEMs are ASTER, GTOPO30, GMTED2010, SRTM 90 m, as well as SRTM 30 m, which is the newest product among those DEMs. So the research aims to assess the vertical accuracy for these DEMs over Egyptian territory, then the most accurate DEMs is used in a proposal fusion technique in order to gain more accurate and much reliable result to be used for small scale topographic map production and updating. The assessment was made based on accurate GPS ground control points which were collected from national projects over Egyptian territory (359 GCPs after validation process). The elevation of such GCPs is measured by spirit leveling. The results show that SRTM 30 m and GMTED 2010 DEMs have the smallest RMSE for the vertical data. So the two DEMs were used in a proposal Fusion technique after correcting them horizontally and vertically based on GCPs. This proposed technique of the Fusion constructed based on the accuracy of the two DEMs only, in which all the DEMs elevations expressed and fused using RMSEs of the two DEMs as weights. The horizontal and vertical correction process of the DEMs, improves the vertical accuracy by (34% and 20%) than original DEMs of GMTED 2010 and SRTM 30 m respectively. While the proposal fusion technique improves the vertical accuracy of the resulted fused DEM by (7% and 11%) compared with the treated DEMs of GMTED 2010 and SRTM 30 m respectively. Final results conclude that: the obtained fused DEM can be used to Produce and to update topographic maps of scale 1:50,000 Since its accuracy was found to be less than the half of the contour interval of such map. The resolution of the resulted fused DEM is 30m while the original DEMs varied from 30 m for SRTM to multi resolution (250 m to 1000m) for GMTED2010. Therefore, the suggested approach improved DEM accuracy and completeness while maintaining the highest resolution of the input DEMs.

Keywords— Digital Elevation Models (DEMs); Shuttle Radar Topography Mission (SRTM); Advanced Space borne Thermal Emission and Reflection Radiometer (ASTER); GTOPO; Global Multi-resolution Terrain Elevation Data 2010 (GMTED2010); Accuracy assessment; Fusion; Egypt topographic maps.

## 1 Background

As the number of satellite-based DEM sources increases, there is a strong need for careful accuracy assessment of each available DEM. Since different satellite sensors use different wavelength regions and/or viewing geometries, data collected by, these sensors may provide slightly different, but complementary information [9]. Availability of DEMs from multiple sources and their complementary nature open the opportunity to fuse multi-source DEM products to generate a value-added product that is more complete [8].

In another study, a DEM fusion process was introduced, which took advantage of the synergy between InSAR DEM and stereo optical DEM generation [7]. Another study used optical stereoscopic and InSAR techniques to treat the Indian Remote Sensing (IRS-1C) PAN stereo and European Remote- Sensing Satellite (ERS-1/2) tandem data to generate DEMs [19]. They compared the DEMs and fused them by replacing the voids of one DEM with data from the other DEM. Another combination technique had been made between SRTM and ASTER DEMs to remove the voids of SRTM DEM and used the resulting DEM to derive glacier flow in the mountains of Bhutan [3]. In this research a proposal fusion technique is used. After DEMs treatment , the height values of two or more DEMs are merged using the percent of their RMSE as a weight.

## 2 Introduction

DEM and its derivative attributes (slope, curvature, roughness, local relief, etc.) are important parameters for assessment of any process using digital terrain analysis. Various applications used these DEMs such as mapping of the topography, relative tectonic activity modeling, dune volume calculation, flood simulation, volcanic hazards mapping, seismic wave propagation, and soil erosion mapping [10]. DEMs can be generated using different techniques such as air-borne and satellite-borne stereoscopic photogrammetry, RADAR/SAR interferometry, Light Detection and Ranging (LIDAR), and conventional surveying techniques (e.g., GPS, levelling). These techniques can be compared considering four aspects (i.e., price, accuracy, sampling density, pre-processing requirements). Each technique has its exclusive advantages, but also some disadvantages; for a comprehensive review, see [17]. However, four main steps are encountered during the generation process of each DEM, regardless of which technology is used [4]: (1) data acquisition (source of elevation data); (2) resampling to the required grid spacing (3) interpolation to extract height of required point and (4) DEM representation, editing and accuracy assessment. These four steps can introduce errors to the final DEM. Fisher and Tate (2006) investigated errors on gridded data sets and classified them into three main classes: (1) gross errors or blunders; (2) systematic errors and (3) random errors.

A DEM quality depends on several factors, including the [6]. Techniques for DEM validation have been widely investigated. Gonga-Saholiariliva gave an overview and mentioned various papers related to this topic. One approach of investigation uses the terms of internal and external validation depending on whether or not independent reference data are included in the assessment procedure. Another way, often applied, is to group methods for DEM accuracy assessment into quantitative, based on statistics and accuracy measures, and into qualitative based on visual analysis references . Numerous studies were carried out for external validation of DEMs using various kinds of reference data and reference DEMs [13]. Those studies covered different continental areas, but not the north of Africa.

The present study was undertaken to assess the vertical accuracy of different DEMs products using GPS observations as external reference data represented in North Africa (Egypt) then introduce the new proposal technique for the fusion. Section 1 and 2 are introduction and background. Section 3 give information about the study area, used data and brief for the acquisition technologies for the used world DEMs. Methodology, accuracy assessment and DEMs treatment are discussed in the section 4. In Sections 5 a suitable method for fusing two or more DEMs from these products is introduced in order to obtain a new DEM model with high resolution, better accuracy and reliability to be used in topographic map production and updating. Section 6 analyzed the obtained results and gave the general conclusions

## 3 Study Area And Used Data

### 3.1 STUDY AREA

The study area was picked over all areas of the GCPs distribution over Egypt territory

(Approximately 75 % of the total area). Egypt extends from 25° E to 37° E and from 22° N to 32° N. The total area is about 1,000,000 km². It contains some mountains with summits reaching up to about 2700 meters above sea level (at SINAI Peninsula), and some valleys with depression of about -50 meters below sea level (Qatara and Al-Fayoum depression). The most of Egypt territory considered as semi-flat terrain except the south part of SINAI – Peninsula, it is mountainous terrain.

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### 3.2 USED DATA

#### 3.2.1 GLOBAL DEMS

Five free world DEMs, accurate GPS observation data, are the used data in the present study. These DEMs differ from each other in the production procedure, resolution, accuracy, coverage, and the production agency. For example, referring to the technology, there are DEMs have been created by stitching together parts from different data sources (Like GMTED2010 and GTOPO 30), DEMs have been created by missions of shuttle radar for the topography (Like SRTM 90m), and DEMs have been created by the digital image correlation technology of the stereoscopic scenes (Like ASTER 30m), etc.

#### 3.2.1.1 GTOPO30

GTOPO30 is the oldest DEM product it was developed by the U.S. Geological Survey (USGS) in 1996. Global Topographic elevation model designated as GTOPO30 at a horizontal resolution of 30 arc-seconds for the entire Earth. Because no single source of topographic information covered the entire land surface, GTOPO30 was derived from eight raster and vector sources that included a substantial amount of U.S. Defense Mapping Agency data. The quality of the elevation data in GTOPO30 varies widely [5].

#### 3.2.1.2 GMTED2010

Global Multi-resolution Terrain Elevation Data, or GMTED2010 for short, is based on data derived from eleven raster based elevation sources. The primary source dataset for GMTED2010 is NGA's SRTM Digital Terrain Elevation Data (DTED®2, http://www2.jpl.nasa.gov/srtm) (void-filled) 1-arc-second data for USA only. For the geographic areas outside the SRTM coverage area and to fill in remaining holes in the SRTM data, the following sources were used: (1) non-SRTM DTED®, (2) Canadian Digital Elevation Data (CDED) at two resolutions, (3) Satellite Pour l'Observation de la Terre (SPOT 5) Reference3D, (4) National Elevation Dataset (NED) for the continental United States and Alaska, (5) GEODATA 9 second digital elevation model (DEM) for Australia, (6) an Antarctica satellite radar and laser altimeter DEM, and (7) a Greenland satellite radar altimeter DEM. This suite of products at three different resolutions (approximately 1,000, 500, and 250 meters) is designed to support many applications directly by providing users with generic products. These products have been derived directly from the raw input data that would not be available to the general user or would be very costly and time-consuming to produce for individual applications. The source of all the elevation data is captured in metadata for reference purposes, for more see (Carabajal,et al. 2011).

 

#### 3.2.1.3 SRTM

Shuttle Radar Topography Mission (SRTM) is the third DEM product. It 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 grid resolution of 1 arc Sec (30m) and 3 arc Sec (90 m). SRTM is referenced to WGS84 datum as horizontal geodetic datum and EGM96 as vertical geodetic data[15]. The grid spacing is 30m, but outside USA only a 90 m grid is publicly available (90 m grids are the reassembled original data of 30m). The specified accuracy is on the order of 15-20 m (95% confidence level), and empirically the data meets these specifications[15]. SRTM described in details [18] and became accessible for free download over the Internet (e.g. at ftp://e0srp01u.ecs.nasa.gov and http://seamless.usgs.gov). On September 23, 2015 the SRTM 30 m was realized date for some of world territory. SRTM 30 m data is available for all Egypt regions.

#### 3.2.1.4 ASTER

Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER), GDEM were created from data acquired between 1999 and 2009 with stereo matching of image data in the visible and near-infrared range. It covers the landmasses between 83°N and 83°S at ~30 m grid spacing, with some small holes. The accuracy (90% confidence) is 20 m. Empirical valuations have shown that ASTER has somewhat inhomogeneous quality while in most tiles the specifications are met, there are regions with a significant amount of blunders as well as systematic artifacts [12].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. It 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 [16].

### 3.2.2 REFERENCE DATA

The second type of the used data is the GCPs. The Ground Control Points are used for (1) co-registration, (2) elevation datum corrections (3) assessment of the accuracy, and (4) DEM enhancement. A number of 359 ground control points (GCPs) were used in the research. They are well distributed over Egypt territory. All of these GCPs were observed using precise dual frequency GPS receivers to obtain their N, E coordinates. Their elevations were observed using spirit leveling. Figure (1) shows the distribution and coverage of such GCPs.

## 4. METHODOLOGY

The study involves the following:

1. Comparative Study for world DEMs accuracies.
2. Selecting suitable DEMs to be fused based on their vertical accuracy.
3. Treatment of the selected DEMs data before applying fusion.
4. Introducing a proposal fusion technique for DEMs elevation data.

### 4.1 ASSESSMENTS OF THE WORLD DEMS ACCURACY.

Global Mapper software was used to subset the DEMs relevant to the study area. No transformation process was needed since the coordinates of GCPs are obtained in the same WGS84 datum. The accuracies of DEMs were evaluated using external reference points with known elevations. As mentioned in section 4 , 359 GCPs were used for the accuracy investigation of the 5 DEMs products. The relevant or equivalent points interpolated from the DEMs are compared with the elevations of these GCPs. So, for each DEMs, the elevation differences between GCPs and the elevations of the relevant pixels are calculated in order to verify the DEMs accuracies. RMSE was used to evaluate the quality of DEMs elevations; it is the most widely used statistics as a measure of accuracy [2].

RMSE can be given by,

$$\text{RMSE} = \sqrt{\frac{1}{n}\sum_{k=1}^{n}(V_k)^2} \qquad (1)$$

$$V_k = Z_k - Z'_k$$

Where,

n, is the number of checkpoints,

$Z_k$ is the known elevation of ground control point k,

$Z'_k$ is interpolated elevation from the DEMs of point k.

It was felt that the quality of the control points should be evaluated and filtered in order to eliminate the points which may include gross error. In that regard, all GCPs were subjected to a validation process that aimed to filter out any data element, which lacks a minimal level of reliability. All the GCPs were used to determine predicted new elevation values for the five DEMs. Then; one reject the control point if

$$|V_k| > 3.0\,\sigma \qquad (2)$$

Where (σ) is the standard deviation of the differences (residuals).

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TABLE 1
Characteristics of the world DEMs

| PROD-UCT/ ITEM | GTOPO 30″ | GMTED 7.5″ | ASTER 1″ | SRTM 3″ | SRTM 1″ |
|---|---|---|---|---|---|
| Data capture | 1996 | 2010 | 1999-2009 | 2000 | 2000 |
| Technology | Integrated Multi-sources data | Fusion of Multi-sources | Satellite stereo images (Matching) | SAR Interferometry (InSAR) | SAR Interferometry (InSAR) |
| Coverage | 60°N-56°S | 84°N to 56°S | 83°N-83°S | 60°N-56°S | 60°N-56°S |
| abs.Z-error @90% | 66 m | 25-30 m | 20 m | 15-20 m | --- m |
| Vertical datum | MSL | EGM 96 | EGM 96 | EGM 96 | EGM 96 |
| Horizontal datum | WGS 84 | WGS 84 | WGS 84 | WGS 84 | WGS 84 |
| Cost | Free | Free | Free | Free | Free |

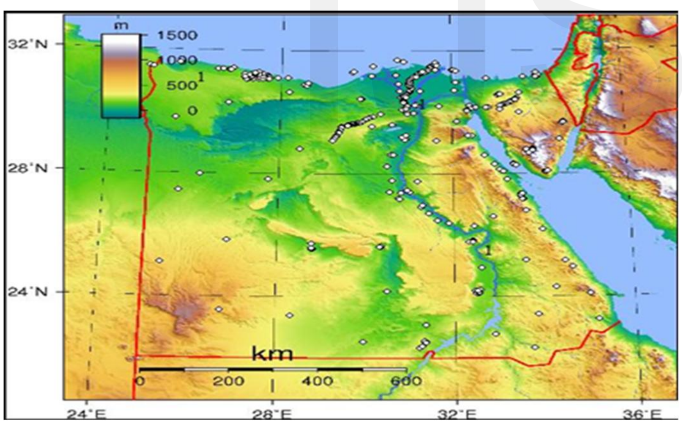


Fig. 1. The distribution of the GCPs over the study area, green dots represent the GCPs locations space. It is good practice to briefly explain the

According to the validation process, 41 ground control points were rejected yielding 359 reliable ones, which were used to assess the vertical accuracy of the five DEMs products. Arc GIS program was used to analyze the study area terrain. After, the terrain of the study area was classified as flat or steep. Flat terrain, the slope gradient is within 0% to 20%, while the slope gradient is greater than 20% for steep terrain [14]. According to this condition, 195 GCPs lies at the flat terrains, so they were used to assess the accuracy of the flat terrain. The other 164 GCPs lies at the steep terrain and were used to assess the accuracy of the steep terrain. Table (2) shows the RMSE, maximum, minimum, mean of the elevations and the correlations of the five used DEM for both flat and steep terrain.

TABLE 2
Accuracy assessment of the World DEMs using the 359 GCPs.

| DATA SOURCE | Z- DIFFERENCE, M | | | RMSE (M) | CORRELATION V'S GCPS |
|---|---|---|---|---|---|
| | Min | Max | Mean | | |
| GTOPO30″ | -90.99 | 57.45 | 3.08 | 14.22 | 0.998 |
| GMTED7.5″ | -36.30 | 19.81 | -2.44 | 7.34 | 0.999 |
| ASTER 1″ | -19.50 | 44.42 | 3.81 | 10.61 | 0.999 |
| SRTM 3″ | -39.26 | 51.08 | 3.56 | 10.07 | 0.998 |
| SRTM 1″ | -19.39 | 20.63 | 1.92 | 6.32 | 0.999 |

From table (2), it can be seen that, differences between the elevations of the ground control points and the elevations of the related points at the five DEMs have shifts. These shifts are represented by the mean of elevation differences. The shift reaches 1.92 m and -2.44 m when using SRTM 1″ and GMTED7.5″ respectively. Problems in the orientation of the used sensors, in addition to use not sufficient GCPs by the production agency in some DEMs products may cause this shift. Pearson and Spearman correlation coefficients were calculated to show the relationship between the DEMs and reference data (GCPs) elevation. Pearson's correlation coefficient represents the association between two variables or the degree of co-variation of the two variables or the tendency of variable to vary together in the sense that one increases as the other increases (positive covariation) or in the sense that one variable increases as the other decreases (negative covariation). Supposing that there are two variables X and Y , each having n values X1, X2, . . . , Xn and Y1, Y2, . . . , Yn respectively. Let the mean of X be $\bar{X}$ and the mean of Y be $\bar{Y}$ (Karkee, et al. 2008). The Pearson correlation coefficient r can be calculated by:

$$r = \frac{\sum(X_i - \bar{X})(Y_i - \bar{Y})}{\sqrt{\sum(X_i - \bar{X})^2 (Y_i - \bar{Y})^2}} \quad (3)$$

Where the summation proceeds across all n possible values of X and Y. Pearson and Spearman Scatter plot of the correlation coefficients for the five DEMs versus GCPs-derived elevation at the overall case were drawn in figure (2). A strong positive correlation can be observed in all DEMs, but it is the greatest in the case of SRTM30m and GMTED. In order to describe and compare the elevation distributions in each DEM, all DEMs data were tested for normality distribution. A perfectly symmetric distribution, like the normal distribution, has skewness equal to 0. Excess kurtosis is a unitless measure of how sharp the data peak is. Traditionally the value of this coefficient is compared with a value of 0, which is the coefficient of kurtosis for a normal distribution. A value larger than 0 indicates a peaked distribution, while a value less than 0 indicates a flat distribution. Since all DEMs derived elevation distributions were close to the normal peaked distribution, as the skewness closed to zeros and the kurtosis coefficient greater than zero see table (3). The sources of the errors in the DEMs are verity, among them is the systematic errors. At the same context, it is important to find the vertical shift that occurs in all DEMs assessments. Consequently, the differences between the GCPs and the related elevations on each DEM, represented in the mean, were removed numerically from all DEMs elevation values. Then the same statistics given in table (2) were recalculated and are given in table (4).

TABLE 3
Skewness and kurtosis coefficient of the five DEMs as a coefficient of the normal distribution.

| Data Source | Skewness Coefficient | kurtosis Coefficient |
|---|---|---|
| GTOPO30″ | -0.34 | 7.55 |
| GMTED7.5″ | 0.09 | 2.13 |
| ASTER 1″ | 0.85 | 1.12 |
| SRTM 3″ | 0.91 | 3.91 |
| SRTM 1″ | 0.90 | 1.54 |

TABLE 4
Accuracy assessment of the five DEMs after eliminating the vertical shifts for both flat and steep terrain

| Data Source | Z- difference, m | | | RMSE (m) | Correlation V's GCPs |
|---|---|---|---|---|---|
| | Min | Max | Mean | | |
| GTOPO30″ | -94.07 | 54.37 | 0.00 | 13.89 | 0.192 |
| GMTED7.5″ | -33.86 | 22.25 | 0.00 | 6.92 | 0.188 |
| ASTER 1″ | -23.31 | 40.61 | 0.00 | 9.91 | 0.191 |
| SRTM 3″ | -42.82 | 47.52 | 0.00 | 9.42 | 0.190 |
| SRTM 1″ | -21.31 | 18.71 | 0.00 | 6.02 | 0.188 |

The values of vertical shift are small in the case of GMTED and SRTM 30 m DEMs. The means of the shifts are zeros after eliminating the vertical shift. Also, the RMSEs improved for all DEMs after eliminating the vertical shift. The improvements are obvious in the cases of the two mentioned DEMs. Table (5) shows the improvements due to elimination of the vertical shift. So, from the results, one can see that, great part of the DEMs vertical errors are systematic. Also, it can be seen that , before removing the shift, a strong positive correlation can be observed in all DEMs (table 2), and SRTM30m and GMTED have the largest positive correlation coefficients. The correlations between GCPs and DEMs after shifting elimination (table 5) are due to a strong convergence and overlapping in certain areas of the DEMs after removing the shift.

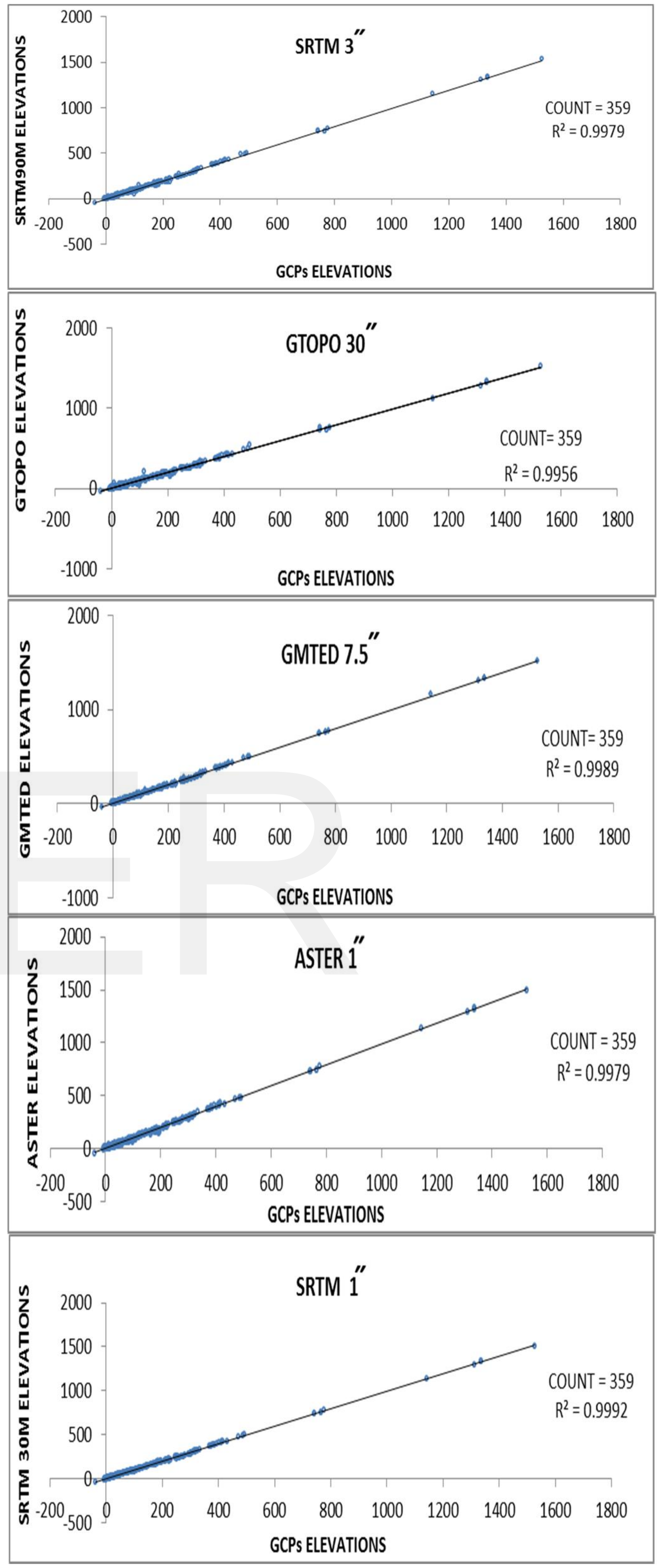


Fig. 2. Pearson and Spearman Scatter plot of the correlation coefficients for DEMs versus GCPs-derived elevation for all GCP.

TABLE 5
Improvements in the RMSE after elimination of the vertical shifts.

| Data Source | Improvement % | | |
|---|---|---|---|
| | Flat | Steep | Both flat & steep |
| GTOPO30″ | 0.10 | 6.29 | 2.32 |
| GMTED7.5″ | 28.04 | 0.00 | 5.72 |
| ASTER 1″ | 0.13 | 20.65 | 6.60 |
| SRTM 3″ | 0.74 | 14.39 | 6.45 |
| SRTM 1″ | 11.23 | 15.64 | 4.75 |

### 4.2 DEMs TREATMENT

It is clear that the data of SRTM 30m and GMTED are referring to the same vertical datum or to two vertical datums close to each other's. So before fusion, it is necessary to integrate the two DEMs in a common vertical and horizontal datums in order to get more reliable fused one. Therefore, GMTED and SRTM 30 m DEMs should be tested first to ensure that there are no horizontal shifts. In order to evaluate a misalignment, an empirical variograms of the two DEMs compared with that of GCPs elevation points were derived, figure 3(A). According to this figure, it is clear that there is a vertical shift between the two DEMs and thus between the two DEMs and the reference data. So, the first assumption is that, the vertical shift may be due to misalignment or horizontal shift between the two datum of DEMs. The horizontal shift, if exist, should be corrected and this procedure is usually referred to as co-registration. Topographic maps of scale 1:50,000 were used to be the planmetric reference for the two DEMs. The DEMs horizontal positions are corrected related to CPs (checkpoints), located in some clear features from the two DEMs. These features were selected to be, mountain peaks, and small islands lie in the middle of the Nile river along study area. The selection of these features was done carefully, the main selective criteria applied is that, they should be clear, small, have sharp visible edges and well distributed over the study area. Seventeen CPs were selected, these CPs locations had been digitized from the reference ETM projected topographic maps of scale 1:50,000 after unifying the horizontal datum between the topographic maps and world DEMs. In which the topographic map features were transformed to WGS84 as the datum used by the USGS. The coordinates of the 17 CPs were compared in the two dimensions. Small shifting was noticed, the average horizontal shift between the SRTM 30 m and topographic maps were 6 m, and 9 m for x and y respectively, with standard deviation 0.11 m in x-direction and 0.30 m in y- direction. While the average were 17 m and 22 m, for x and y respectively, with standard deviation 0.94 m in the x-direction and 1.42 m in the y-direction for GMTED DEM. The RMSE for the two DEM were recalculated again for the elevations after eliminating the horizontal shifts and it is concluded that, small improvements in the vertical accuracy of the two DEMs. After correcting the horizontal shift displacement, ARC MAP was used to derive the error map of the two DEMs, then the vertical shift represented in the mean difference, had been removed for the two DEMs. Figure 4 and 5 visualizes these error maps in raster and vector ( contour) format respectively. Darker regions and larger contour values are areas which have biggest differences between the DEMs and the GCPs surface, while as we move from the dark to the light, the difference is small until it devolve to zeros. The statistics were recalculated after correcting the 2 DEMs horizontally and vertically, table (6) shows the improvements in the RMSEs after DEMs corrections. While the figure (3), shows the variograms of SRTM and GMTED after and before correction.

After correction, the two variograms of SRTM and GMTED became closer and having pattern similar to the GCPs variograms. Before applying fusion process, DEMs data should have the same standard, uniform sample distance, and same format data. To achieve this goal, two operations are involved: resample and interpolation [11]. Resample operation reduces precisions of DEM data according to the demands, while interpolation is used to improve precisions of DEM data. For example, if we want to convert DEM with 30 meter grid into 90 meters grid, just reserve one row (column) and discard two rows (columns) per three rows (columns) which is the resampling process. In the present case, interpolation was used with GMTED to convert it to 30 m grid resolution instead of its original resolution. Radial basis function used for this purpose as it is one of the most accurate and popular functions for DEM interpolation[1]. The used Radial Basis Function (RBF) function defined in terms of distance (radius) from a point is written in the following equation:

$$\boldsymbol{Z(x,y)} = \mathbf{w\varphi}\left(\sqrt{(\boldsymbol{x}-\boldsymbol{x_c})^2 + (\mathbf{y}-\boldsymbol{y_c})^2}\right) = \mathbf{w\varphi}(\|\boldsymbol{x}-\boldsymbol{x_c}\|) \quad (4), \qquad \boldsymbol{\varphi(r)} = \boldsymbol{r}^2\,\boldsymbol{log(r)} \quad (5)$$

Where W is the weight of this RBF;

$c = (x_c, y_c)$ are the coordinates of the point, or center;

And $r$ is the distance from any other point in the xy-plane to this center.

In the form of polynomial term with weights a0,a1,a2

The RBF can be written as:

$$\boldsymbol{Z(x,y)} = \sum_{i=1}^{N} \boldsymbol{w_i\varphi(r_i)} + \boldsymbol{a_0} + \boldsymbol{a_1x} + \boldsymbol{a_2y} \quad (6)$$

TABLE 6
Improvements in the RMSE after correcting the horizontal and vertical shifts.

| Data Source | Improvement in RMSE % | | |
|---|---|---|---|
| | Flat | Steep | Both flat & steep |
| GMTED7.5″ | 46.42 | 35.86 | 34.20 |
| SRTM 1″ | 0.88 | 30.18 | 20.41 |

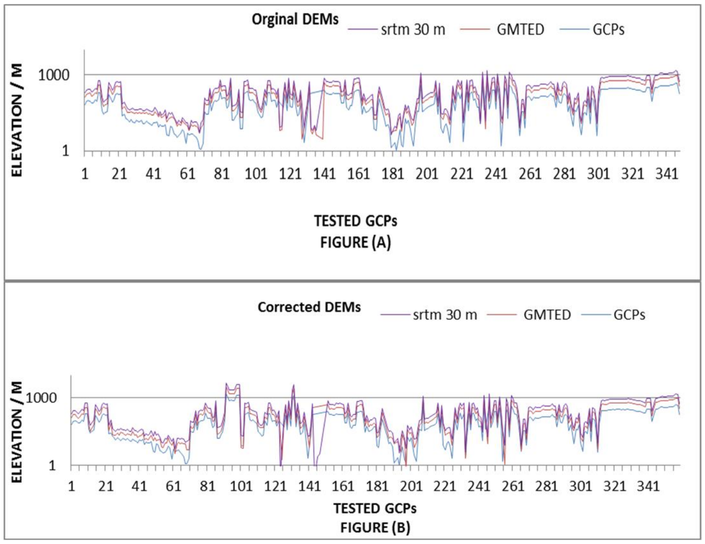


Fig. 3. Empirical variograms of the two DEMs compared with that of GCPs elevation after and before DEMs correction.

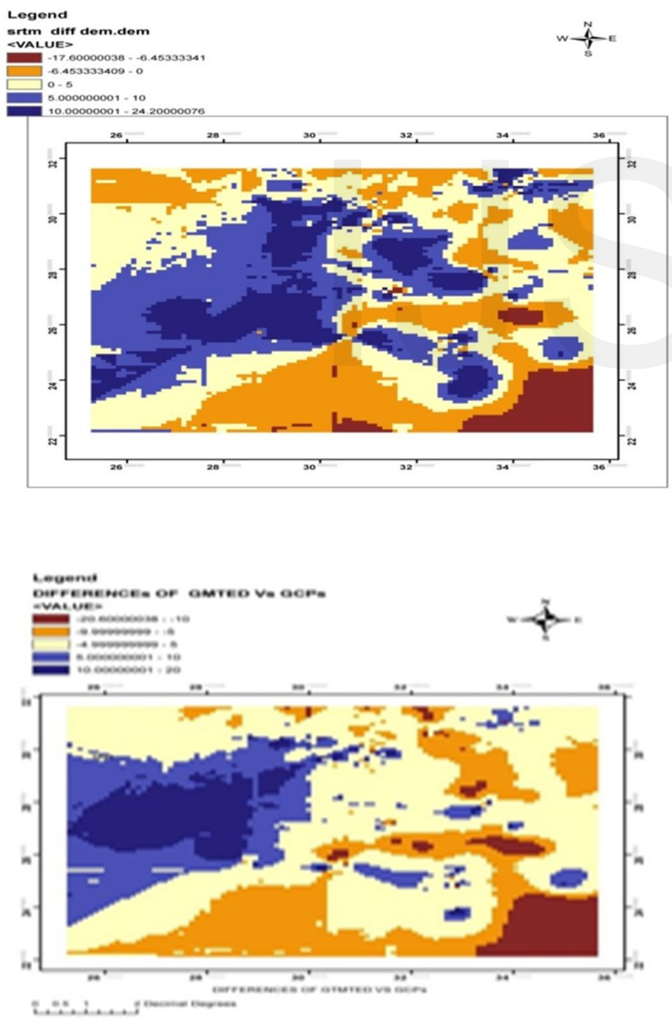


Fig. 4. The raster error map of GMTED DEM V's GCPs (A), while (B), is the raster error map of SRTM 30 m DEM V's GCPs over the Egypt terrain

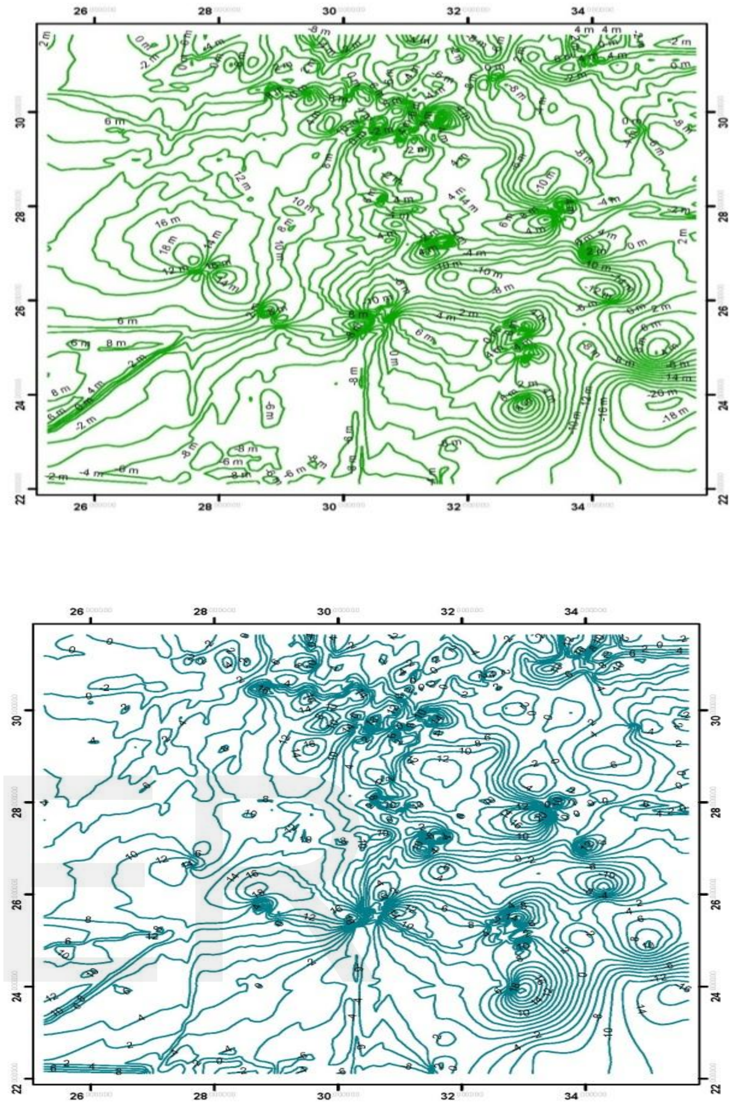

Fig. 5. (A), is a contour map of errors of contour interval 1m for the SRTM 30m DEM V'S GCPs, while (B), is a contour map of errors for the GMTED DEM V's GCPs over Egypt area.

## 5. DEMs FUSION

The overview confirms that nowadays several DEMs of good accuracy exist for almost any region of the earth. The situation gives rise to the natural question, whether this redundancy can be used to create a DEM of higher accuracy. If there are two values of elevations, it is possible to calculate the newer fused value by either taking the average of the two original values or using weights in the fusion process. But the question is how to estimate the weight of each observed value in DEMs elevations. So, the difficulty of DEM fusion that it requires the weights to quantify the impact of the inputs at every surface location. These weights are a function of height accuracy and typically vary significantly across each DEM, due to the sensor technology, scene characteristics, and method used to generate DEM [16]. These weights should be a natural by-product of DEM generation, but are often not available. In which case one can try to estimate them statistically from a comparison by a more accurate and well distributed GCPs. Because the weights

are critical for proper DEM fusion, it will be used in this research to perform the fusion of the DEMs. The proposed fusion flowchart is shown in Figure (6).
The assumption is that we like to fuse DEM1 and DEM2, with a grid spacing M1 and M2, where M1 > M2, to produce a new DEM3, with a grid spacing M3 = M2. In order to fuse the DEMs and generate a new surface model with better accuracy, it is required to have a complete knowledge of the characteristics and accuracy of the initial DEMs. The accuracy of each individual DEM can be expressed by its RMSE. In the following step, the two DEMs are merged into DEM3 using weights from the accuracy analysis. As mentioned, RMSE is selected to be the used weight in the fusion process. Let us assume that, DEM1, DEM2 and DEM3 have (n) node point. From accuracy analysis DEM1 has (RMSE = σ1) and DEM2 has (RMSE = σ2). So the elevation of any node point (i) of the fused DEM3 can be calculated using the following equation:

$$h3_{(i)} = \frac{h1_{(i)}w1+h2_{(i)}w2}{w1+w2} \qquad (4)$$

Where h1$(i)$,h2$(i)$,h3$(i)$ are the elevations of node $(i)$ in DEM1, DEM2, DEM3 respectively.

w1: is the weight of elevations of DEM1 = ( 1/ $\sigma1^2$)

w1: is the weight of elevations of DEM2 = ( 1/ $\sigma2^2$)

$\sigma1$, $\sigma2$: are the RMSE for GMTED DEM and SRTM DEM = (4.83 and 5.03m respectively)

n : is the number of node points input DEMs (two DEMs)

The error map is drawn for the resulted fused DEM, figure (7). It is remarkable that, the darker areas (odd regions) which represent the gaps between the two compared surfaces became smaller than before fusion. Table (7) shows statistical parameters of the fused DEMs resulted from the two original DEMs before treatment. Tables (8,9) show statistical parameters of the fused DEMs resulted by averaging and weighted method after treatment. Also the improvements of the fused DEM in the three cases are introduced in the table (10).

TABLE 7
Accuracy assessment the of the fused DEMs resulted from the original DEMs.

| Data Source | Z- difference, m | | | No of Samples | RMSE (m) |
|---|---|---|---|---|---|
| | Min | Max | Mean | | |
| Fused DEM | -20.40 | 18.73 | -0.10 | 359 | 6.17 |

TABLE 8
Accuracy assessment the of the fused DEMs using average method.

| Data Source | Z- difference, m | | | No of Samples | RMSE (m) |
|---|---|---|---|---|---|
| | Min | Max | Mean | | |
| Fused DEM | -24.31 | 22.12 | -0.26 | 359 | 4.77 |

TABLE 9
Accuracy assessment the of the fused DEMs using weight method.

| Data Source | Z- difference, m | | | No of Samples | RMSE (m) |
|---|---|---|---|---|---|
| | Min | Max | Mean | | |
| Fused DEM | -21.95 | 20.04 | -0.31 | 359 | 4.49 |

TABLE 10
Improvements in the RMSE of the fused DEM produced by both average and weighting methods.

| Data Source | RMSE, m (after Fusion) for original DEMs by weights | RMSE, m (after Fusion) for treated DEMs by averaging | RMSE, m (after Fusion) for treated DEMs by weights |
|---|---|---|---|
| GMTED 7.5″ **SRTM 1″** | 6.17 (16% 2.37%) Improvement than the original GMTED and SRTM respectively | 4.77 (1.25% 5%) Improvement than the treated GMTED and SRTM respectively | 4.49 (7%11%) Improvement than the treated GMTED and SRTM respectively |

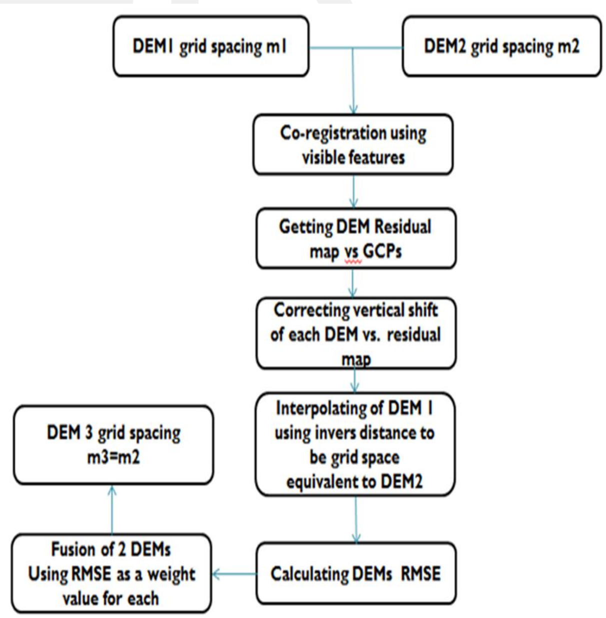


Fig. 6. The flowchart of a proposed fusion

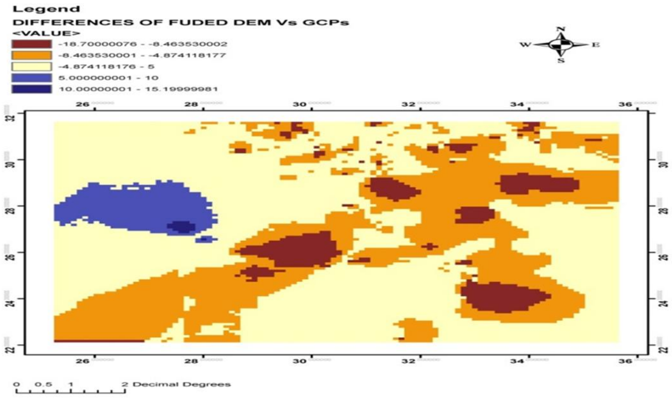


Fig. 7. The raster error map for the obtained fused DEM versus GCPs over Egypt area

## 6. CONCLUSIONS

The elevations of GMTED model were obtained from multiple data sources, which may be subjected to a good treatment process using sufficient GCPs. SRTM 30m DEM depending on radar waves which known by its high accuracy in identifying objects for data acquisition technique. SRTM 30m DEM has high texture, more details, and better accuracy in the elevations due to its small pixel size. After co-registration slight improvement was noticed in the vertical accuracy of GMTED 2010 and SRTM30m, thus proves that the corrected horizontal shifting was small compared with the dimension of the pixel size for the two DEMs. Fusing the two original DEMs before applying any shift gave RMSE of elevation = 6.17 m with improvement (16% and 2.37%) in the vertical accuracy compared with the original GMTED and SRTM30m DEMs. Applying the computed vertical shifts, the DEMs gave a good improvement in the vertical accuracy compared with the original DEMs (34% and 20%) of GMTED 2010 and SRTM 30 m respectively. Using the weighted Fusion technique, the RMSE improved by (7% and 11%) compared with the treated DEMs of GMTED 2010 and SRTM 30 m respectively. While using the averaging technique, the RMSE enhanced by (1.25% and 5%) of GMTED 2010 and SRTM 30 m respectively. Egypt 1:50,000 Maps have a contour interval of 10 m in steep terrain and 5 m in flat terrain. So, the obtained accuracy of the fused DEM satisfies these requirements and can be used for production of such maps in the west desert of Egypt. It is recommended that, before using any DEM, to check its horizontal position and correct any shift. The correction should be done related to features on the surface of the earth like, road intersections. The vertical shift, if exists should be corrected using sufficient numbers of fairly distributed GCPs in the interested area to obtain good DEMs elevations.

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