J. Adv. Agric. Res. (Fac. Ag. Saba Basha)

Cut/Fill Detection Using Multi-Temporal Digital Elevation Models

Mohamed, W.H. , M.A. Hussein, N.E.A. Alabsi, and A.M. Elprince
Department of Soils and Agricultural Chemistry, Alexandria University, Alexandria, Egypt

ADDITIONA INDEX WORDS : Geostatistics, Global Positioning System, Geographical Information System, Land leveling.

ABSTRACT

The online available shuttle radar topographic mission (SRTM) elevation data were collected during 11-day mission in February 2000 for the Earth's surface. Comparing these data with cartographic data and GPS measurements dated differently means that we are comparing multitemporal DEMs. The objective of this study was to employ these multitemporal DEMs to detect the cut/fill activities in a land reclamation project area subject to temporal land leveling for the installation of an irrigation and drainage network, NW Egypt. The SRTM product used was the processed SRTM 90 m re-sampled to 43.7 m higher resolution using Gaussian semivariogram and ordinary kriging. The vertical accuracy of the SRTM 43.7 m, relative to a topographic (1:50,000) MAP dated 1990 and GPS measurements dated 2008 (in raster format using spherical semivariogram and ordinary kriging) were computed only in areas unaffected by land leveling [N = 1661 (43.7 m x 43.7 m)]. The SRTM 43.7 m had absolute vertical error equal to 1.4 m which was much less than the global (± 16 m) and local (± 6 m) errors targeted by the SRTM mission. The observed biases in SRTM 43.7 m elevation relative to GPS elevation (+2.21 m) and MAP elevation (-1.31 m) were added to the GPS and MAP datasets [N = 120705 (43.7 m x 43.7 m)] and the corrected elevations were referred to as gpsc and mapc, respectively. The two raster maps for the differences (mapc-srtm) and (srtm – gpsc) showed regions where material was cut, filled, or where surface did not change in terms of volumes and areas. Overlying the soil $CaCO_3$ (0-30 cm depth) spatial pattern with the cut/fill spatial patterns gave maps that identify the cut/fill directions during the 1990-2000 and 2000-2008 periods. The readily available multi-temporal DEMs (map, srtm, and gps) were successful in detecting the cut/fill extent, volume, and directions in areas subject to land leveling.

INTRODUCTION

Shuttle radar topographic mission (SRTM) data were collected during 11-day mission in February 2000 by the Space Shuttle Endeavour using single-pass synthetic aperture radar (SAR) interferometry remote sensing technique with two antenna pairs operating in C (5.66 cm) and X (3.1 cm) bands, simultaneously illuminating the Earth's surface and recording backscattered radar signals. SRTM was jointly performed by NASA, the German Aerospace Center (DLR) and the Italian Space Agency (ASI).The SRTM and SAR have been well described (Zebker and Goldstein 1986, Gabriel and Goldstein 1988, Bamler and Hartl 1998, Massonnet and Rabaute 1993). The targeted landmass consisted of all land between 57° south and 60° north latitude, which comprises 80% of Earth's total landmass. The absolute and relative vertical accuracy specifications of the SRTM DEM is respectively defined as ± 16 m for 90% of the data across the entire mission and ± 6 m on a local, 50–100 km scale (Farr and Kobrick 2000, Werner 2001, Rabus et al. 2003).

SRTM data are organized into individual rasterized cells, each covering 1° by 1° in latitude and longitude. Sampling spacing for individual data points was either 1 arc-second (~30x30 m) or 3 arc-second (~90x90 m); the later was produced by averaging 3x3 one arc-second pixels. Only 90 m data are available globally while the 30 m data are available only for the USA territory. A seamless dataset (5° by 5° tile) with voids filled in (interpolation by Regularized Splines with Tension, RST) is available at the website of Consultative Group for International Agriculture Research Consortium for Spatial Information (CGIAR-CSI) via http://srtm.csi.cgiar.org/. These voids occur mainly over water bodies (lakes and rivers), areas with snow cover and in mountainous regions (e.g. the Himalayas has the greatest concentration of data voids). The SRTM is now been widely used as source for digital elevation models (DEMs) employed for applications in geomorphology and hydrology (Guth, 2003; Stock et al., 2002; Finlayson et al., 2002; Lave and Avouac, 2001); prediction of areas at risk from salinity in a catchment area (Liu et. al., 2005), vegetation cover (Kellndofer et al., 2004; Miliaresis and Delikaraoglou, 2009); and climate change (Burbank et al., 2003; Blumberg et al. 2005).

Several SRTM data verification attempts were made using various altimetry data (Helm et al. 2002, Sun et al. 2003) and digital elevation models (Smith and Sandwell 2003, Jarvis et al. 2004, Bhang et al. 2007, Gorokhovic and Voustianiouk 2006). Comparing SRTM data, which are in raster format, with GPS data in vector format requires converting both datasets to the same topological format. For this purpose two methods are possible: either converting SRTM raster data to vector format or converting GPS vector data to raster format. Both conversions can be readily executed in the ArcGIS (Spatial Analyst) environment. The former approach has been adopted by Rodriguez et al. (2005) for a global assessment of SRTM accuracy, whereas the latter method was followed by Gorokhovich and Voustianiouk (2006) for local validation of SRTM data in two regions in the United States and Thailand.

SRTM data products were validated on continental scales through comparison with GPS data (<1m spatial resolution) acquired along roads on most major continents. The absolute vertical accuracy was found better than 9 m (range: 5.6 to 9.0), indicating that SRTM improved on its design goal of 16 m absolute by almost a factor of 2. The spatial patterns of the vertical error showed that the greatest errors were associated with steep terrain (Himalaya, Andes) and very smooth sandy surfaces (Sahara Desert) (Rodriguez et al., 2005; 2006). On a national scale in South America the absolute vertical accuracy for SRTM produced DEM was 8 m as opposed to 20 m for cartographically produced DEM, relative to GPS data (Jarvis et al., 2004). At the catchment-scale the vertical errors were highly similar; 20 m for SRTM DEM and 21m for TOPO DEM using 1:10,000 cartographic maps. However, the greatest errors in the SRTM data were found on ridges and peaks, where they consistently underestimated the elevation (Jarvis et al., 2004). These researches, concluded that if only cartography with scales above 1:25,000 (i.e., 1:50,000 and 100,000) is available, it is better to use the SRTMs. If good quality cartography of scale 1:25,000 and below (i.e., 1:10,000) is available, better results may be expected through digitizing and interpolating the cartographic data. A detailed hydrological analysis showed that cell size was causing significant differences in the hydrological characteristics of the catchment. The results of another regional study, showed that absolute average vertical errors from CGIAR dataset ranged from 7.58±0.60 m in Phuket (Thailand) to 4.07±0.47 m in Catskills Mountains (New York, USA), (mean ± S.E.M); relative to differential GPS data sets (1-9 GPS observations per 90x90m). The error values had strong correlation with slope and certain aspect values. Taking into account slope and aspects considerably improved the accuracy of the CGIR DEM product for train with slope values greater than 10^o; however, for the train with slope values less than 10^o, this improvement was found to be negligible. The importance of slope and aspect in height accuracy determination for SRTM data has been recognized and analyzed by Miliaresis and Paraschou (2005) , Gorokhovich and Voustianiouk (2006), and Rodriguez et al. (2005)

Map scales and the corresponding area (hectares of minimum size [0.4 cm^2 on the map]) of delineation are related by the equation,

$$\text{Scale} \equiv 1:15811.4 \times \sqrt{h}, \quad [1]$$

where, h is the number of hectares per observation (Eswaran et al., 1977; Elprince, 2009). Thus, SRTM 90m and SRTM 30m would yield topographic maps at the scales 1: 12800 and 1: 1420, respectively. A resolution of 90m can be considered suitable for small or medium-scale analysis, but it is too coarse for more detailed purposes such as hydrological modeling.

Hydrological modelers must use the SRTM 30-m datasets (Jarvis et al., 2004). The present alternative is to interpolate the SRTM DEM at a finer resolution. It won't increase the level of detail of the original DEM, but it will lead to a surface where there is coherence of angular properties (i.e., slope, aspect) between neighboring pixels (Grohmann, 2006), an important characteristics when dealing with terrain analysis.

Kriging is an estimation method that gives a best linear unbiased estimators value (Journal and Huijbregts, 1978). Kriged maps can differ based on the variogram model used and the presence or absence of a drift , and concern has arisen about the accuracy of the various methods (Warrick et al., 1988; Weber and Euglund, 1992a,b; Elprince et al., 2004; Elprince and Al-Dakheel, 2010). A criterion in common use is to check for a given estimation point if a different kriging approach leads to a significant decrease of the kriging variance (Wackernagel, 1995, p. 89). Cross validation criteria can also be used to compare diff erent approaches (Isaaks and Srivastava, 1989, p. 353). Gotway Crawford and Hergert (1997) proposed that the "best" approach is the one whose model best accounts for and describes the nature of the causes of variation in the regionalized variable of interest.

It should be mentioned that the readily available SRTM 90 m elevation data were collected during 11-day mission in February 2000 for the Earth's surface. Comparing these data with cartographic data and GPS measurements dated differently means that we are comparing multitemporal DEMs. Validation of the accuracy of SRTM elevations in reference to cartographic or GPS data assumes no changes in relief of the Earth's surface with time. The change in relief could be due to natural or anthropogenic processes. Multi-temporal DEMs were employed in glaciologic applications (Racoviteanu et. al., 2007), detecting the volume change of loose deposit of rock debris accumulated and debris discharged (Jun et. al., 2008), and assessing sand dunes movement in a national park (Michalowska and Glowienka, 2008).

The general objective of this study is to employ multi-temporal DEMs for detection of the cut/fill activities in a new land reclamation project subject to temporal land leveling. The specific objectives are to: (i) resample processed low resolution CGIR-CSI SRTM 90m elevation data to a 43.7 m higher resolution SRTM DEM using semivariogram modeling and kriging, (ii) assess the vertical accuracy of the resulted SRTM DEM dated 2000, relative to a topographic MAP DEM dated 1990 and a GPS DEM dated 2008; only in isolated areas un-affected by land leveling, and (iii) assess relief changes and evaluate the cut/fill extent, volumes, and directions in areas affected by land leveling.

MATERIALS AND METHODS

The Study Area

The study Area is located at 50 km south west of Alexandria city, Egypt (Fig. 1). It lies between latitudes 30º 45' 20" and 30º 53' 35" N and longitudes 29º 32' 20" and 29º 49' 50" E. The study area is 23087 ha (54970 feddans) that includes 23 villages of the Bangar Alsokar agricultural land reclamation project; one of the newly reclaimed areas west of the Nile delta since 1989. According to Abdel-Kader et al. (2004) the area has a Mediterranean climate, characterized by rainy winter and prolonged hot and dry summer. The maximum monthly temperature is 30 ºC in August and the minimum temperature is 6.3ºC in January.

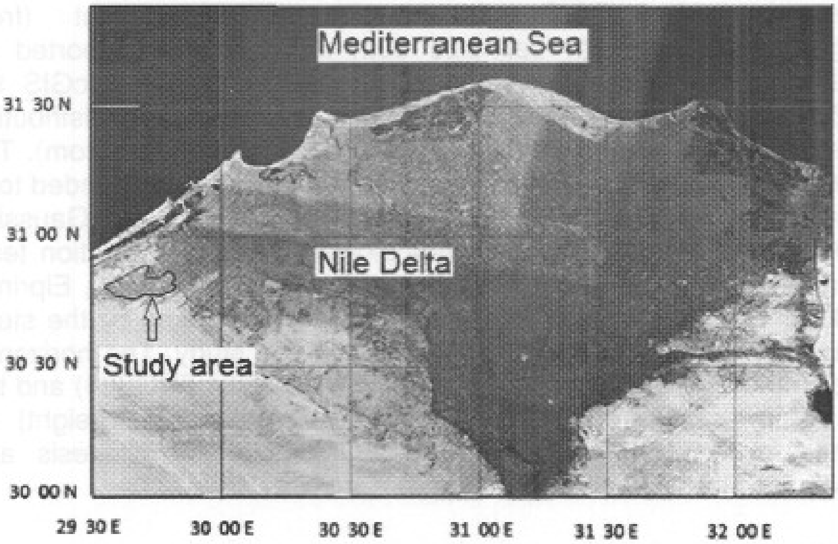


Fig.1. The study area is 23087 ha that includes 23 villages of the Bangar Alsokar agricultural land reclamation project; one of the newly reclaimed areas west of the Nile delta since 1989.

The annual rainfall is low (104 mm) and the relative humidity ranges between 59% and 81%, within an average of 69%. In summer the north trade wind comes from the Mediterranean Sea bringing moisture with it and during the period from February to July the Khamaseen wind, coming from the southwest direction, from the vast area of Western Desert, prevails. Soil moisture regime is Torric or Aridic and the Soil temperature regime is Hyperthermic. These authors studied the Eastern part of the present study area. They recognized five geomorphic mapping units within elongated hills (extensive ridge) and Mena valley (depression) landscapes. They recognized the great groups: Torriorthents, Haplocalcids, Haplosalids, and Aquisalids. They reported that the effective soil depth varied from 60 to 150 cm with mean 120 ± 26 cm; and that the $CaCO_3$ content in surface soil varied from 5.5 to 46.8% with mean 21.2 ± 9.7 %.

SRTM Data

The study area was selected as a specific area of interest using Google Earth Pro (www.google.com) and the boundary was saved in KMZ file. Global Mapper 10.00 (www.globalmapper.com) was used to open the KMZ file and downloaded on line processed SRTM 3 arc-second-based elevation data by CGIR for the area of interest (from http://srtm.csi.cgiar.org) with cell size 90m x 70 m and exported as ArcASCII Grid file to the geographical information system ArcGIS 9.2 (ESRI, 2006). The elevation data 90m x 70 m followed a normal distribution curve as revealed from a linear Q Q plot (SPSS 17, www.spss.com). The resampled elevation values with cell size 43.7 x 43.7 m (corresponded to 1: 3020 scale as of Eq. [1]) were best estimated using Gaussian semivariogram and ordinary kriging as indicated by cross validation tests (Isaaks and Srivastava, 1995, p. 89; Alsaeedi and Elprince 2000, Elprince et al. 2004). The 43 m x 43 m pixel size raster was masked by the study area boundary to yield the SRTM DEM used in this study. The horizontal datum for the SRTM is the World Geodetic System 1984 (WGS84) and the vertical datum is referred to mean sea level (orthometric height) as determined by the Earth GravityModel EGM96 geoid (Miliaresis and Paraschou 2005).

GPS Data

Since the end of SA (Selective Availability) in 2000 the accuracies achievable by GPS receivers in standalone mode have greatly increased. This had led to great improvements in positioning quality achievable by handheld receivers and also reductions in price. The handheld Garmin eTrexLegend 12-chanells personal navigator (GARMIN, 2005) used in this study only cost EP 3500 ($ 600). Experiments have been carried out to assess the accuracy of positioning with the output from the Garmin receivers. In static mode the range residual for the Garmin handheld receivers data usually being around 2-4 m and the standard deviation was 1.98 m (Cosser et. al., 2004). As a rule of thumb, we consider the vertical accuracy of the Garmin unit to be about 1.5 times bigger than horizontal errors (~5 m). The horizontal datum for the GPS data is the WGS84 and the vertical datum is referred to mean sea level (orthometric height) as determined by the Earth GravityModel (EGM96) geoid (Miliaresis and Paraschou 2005).

Cartographic Data

Two 1:50,000 topographic maps (IKINJ MARYUT and BURJ AL_ARAB sheets), constructed from 1990-91 aerial photography by Egyptian General Survey Authority were needed to cover the study area. The maps used Transverse Mercator Projection Ellipsoid, Helmert 1906; horizontal datum: National Geodetic Net, Venus 1874; and vertical datum: mean sea level Alexandria 1906. The maps were scanned, each was rectified (georeferenced) in decimal degrees and datum WGS84 using Global Mapper software (www. Globalmapper.com). The two maps were mosaiced (joined) using the Raster Stitch 2.31 software and masked for the study area boundary. Contour lines with 5 m spacing were digitized on screen, and attributed the corresponding elevation values read from the topographic map. Additional ArcGIS layer digitized from the topographic maps included spot heights. These topographic data were interpolated using semivariogram analysis and kriging to produce 43.7 m x 43.7 m pixel size MAP DEM.

Soil $CaCO_3$ Determination

Calcium carbonate content in the soil samples (0-30 cm depth; N = 464) were measured using a calcimeter that measured the volume of CO_2 evolved at constant temperature and pressure when the soil sample was treated with acid (Page et. al., 1982).

Spatial Estimation

Variogram models tested in this study were:

$$\gamma(h) = c_0 + c\, f(h/a) \quad [2]$$

where γ = semivariance, h = separation distance, a = range, c_0 = nugget, $c_0 + c$ = sill, f(h/a) = [h/a] for the linear-plateau; $f(h/a) = [1.5\ (h/a) - 0.5\ (h/a)^3]$ for the spherical; $f(h/a) = [\ 1 - \exp(-h/a)])$ for the exponential and $f(h/a) = [1 - \exp\text{-}\ (h^2/a)]$ for the Gaussian model (Journal and Huijbregts, 1978; Wackernagel, 1995). The experimental and model variograms were assumed isotropic, i.e., the nature of the spatial correlation between data at two locations depends only on the distance between the locations and not on the vector direction of their separation. The kriging models tested in this study were ordinary kriging and universal kriging as two types of surface estimators. This preliminary test indicated that the soil variable (SRTUM 43.7 m, GPS, and MAP elevations and $CaCO_3$ content) values were best estimated using spherical variogram and ordinary kriging as indicated by cross validation tests.

RESULTS AND DISCUSSION

Descriptive Statistics

Table 1 shows descriptive statistics for three DEMs derived from 1:50,000 topographic maps, srtm elevation data, and gps measurements, namely MAP(1990), SRTM(2000), and GPS(2008), respectively, together with $CaCO_3$ contents in the study area. The elevation range of SRTM is wider than the MAP and GPS ranges; and the elevation means ± st.dev are 40.6 ± 6.5 m, 43.0 ± 6.7 m, and 37.1 ± 5.3 m, respectively. The $CaCO_3$ content in soil (0-30 cm depth) varies from 7.5 to 65.5 % with a mean ± std. dev. equal to 35.6 ± 9.2%.

Table 1. Descriptive statistics for three DEMs derived from 1:50,000 topographic maps, srtm elevation data, and gps measurements at different dates; and $CaCO_3$ contents in the study area.

	MAP (m) 1990	SRTM (m) 2000	GPS (m) 2008	CaCO3 (%) 2008
N	197	120705	521	464
Minimum	30	21.56	23.58	7.5
Maximum	55	70.77	50.79	65.5
Mean	43	40.6	37.1	35.6
St. Dev.	6.7	6.5	5.3	9.2

Normal Q Q plots (SPSS 17, www.spss.com) indicated that the elevation datasets from the topographic MAP (N = 197), SRTM (N =

120705), and GPS measurements (N = 521) are normally distributed while the $CaCO_3$ content in soil (N = 464) measurements are log-normally distributed (Fig. 1). Subsequently, variogram and kriging in this study utilized the values without any transformation for the regionalized elevation-variables MAP, SRTM, and GPS; and log transformation for the $CaCO_2$ contents.

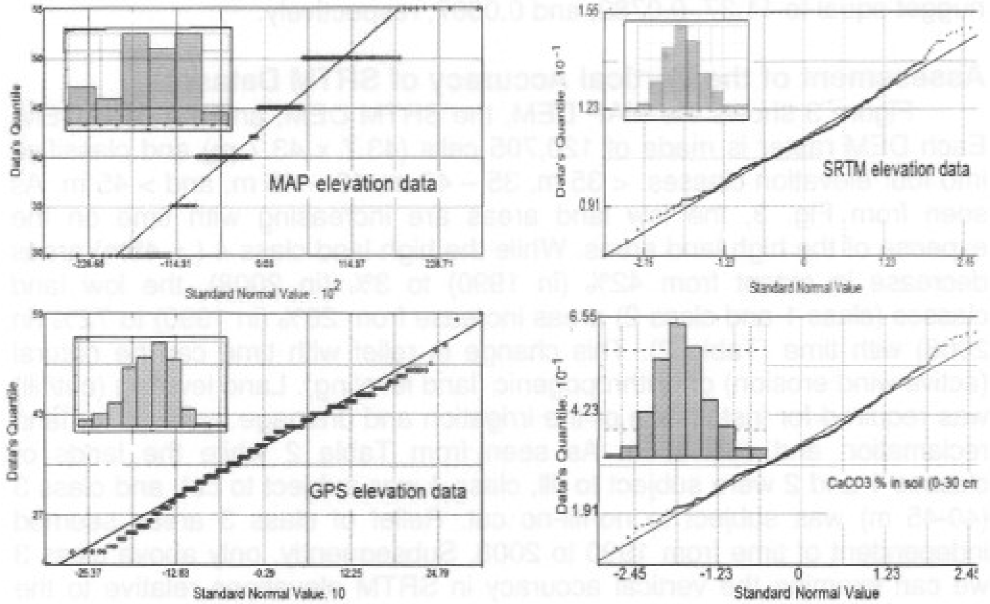


Fig. 2. Normal Q Q plots and histograms for MAP, SRTM, and GPS elevation datasets; and logarithm of CaCO3 contents in soil of the study area.

Variogram's Parameters

The spherical semivariogram model for the GPS elevation dataset has range, sill, and nugget equal to 2.66 km, 68.40 m^2, and 17.88 m^2, respectively. Similarly, a spherical semivariogram model for the MAP elevation dataset has range, sill, and nugget equal to 2.59 km, 79.31 m^2, and 9.26 m^2, respectively. While the range values seem comparable, the nugget/sill ratios are different. Thus, 26 per cent of the total spatial variability in GPS elevation in the field is attributed to micro-structure in an area of radius less than the sampling intervals (i.e. ~ 680 m) and that 74 per cent is due to macro-structure in an area of radius equal to 2.66 km (Journal and Huijbregts, 1978). On the other hand, 11 and 89 per cents of the total spatial variability in MAP elevation are attributed to micro- and macro-structures, respectively. A cross-validation test indicates that the spherical semivirogram model fitted the MAP data more accurately than the GPS datasets; where the root mean square (RMS) errors are found equal to 2.2 m and 3.5 m for the MAP and GPS datasets, respectively. Experimental semivariogram for the $CaCO_3$ regionalized variable after log transformation has been fitted to a spherical model with range, sill, and nugget equal to 11.37, 0.0782, and 0.0607, respectively.

Assessment of the Vertical Accuracy of SRTM Dataset

Figure 3 shows the MAP DEM, the SRTM DEM, and the GPS DEM. Each DEM raster is made of 120,705 cells (43.7 x 43.7 m) and classified into four elevation classes: < 35 m, 35 – 40 m, 40 – 45 m, and > 45 m. As seen from Fig. 3, the low land areas are increasing with time on the expense of the high land areas. While the high land class 4 (> 45m) areas decrease in extent from 42% (in 1990) to 3% (in 2008), the low land classes (class 1 and class 2) areas increase from 26% (in 1990) to 72% (in 2008) with time (Table 2). This change in relief with time can be natural (active wind erosion) or anthropogenic (land leveling). Land leveling (cut/fill) was required for installation of the irrigation and drainage systems for land reclamation and cultivation. As seen from Table 2 while the lands of classes 1 and 2 were subject to fill, class 4 was subject to cut, and class 3 (40-45 m) was subject to no-fill-no cut. Relief of class 3 areas seemed independent of time from 1990 to 2008. Subsequently, only above class 3 we can examine the vertical accuracy in SRTM elevations relative to the GPS and the MAP elevations.

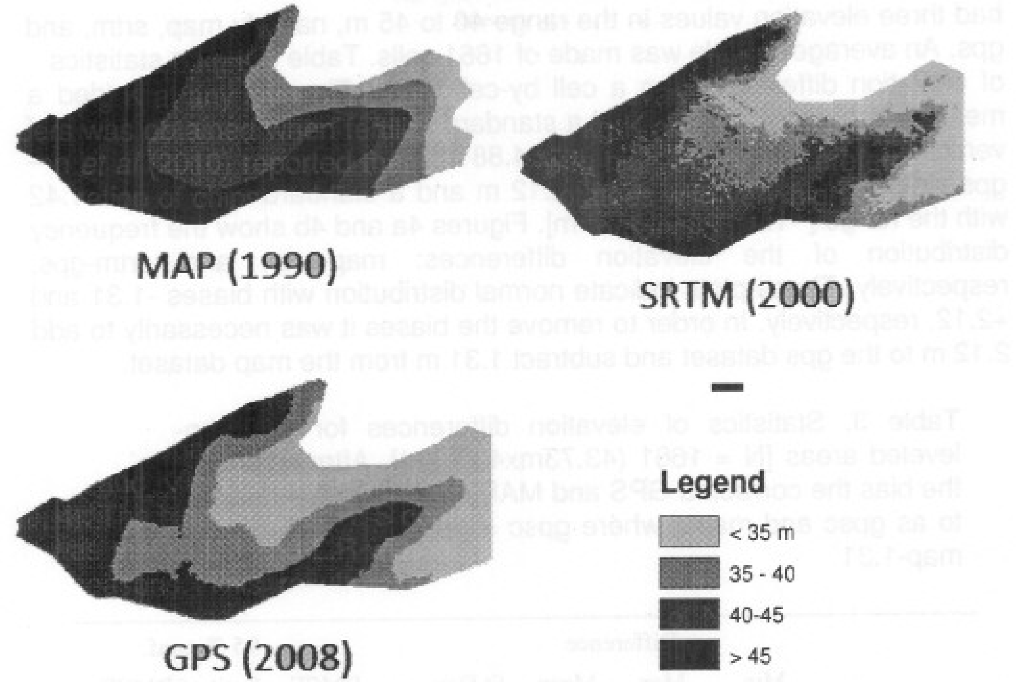


Fig. 3. Multi-temporal DEMs derived from topographic MAP (1990), SRTM (2000) and GPS (2008) elevation datasets for Bangar Alsokar land reclamation project , Egypt.

Table 2. Elevation class areas for multi-temporal DEMs derived from cartographic MAP, SRTM, and GPS datasets for a land reclamation project, North West Egypt.

(N = 120,705 cells).

	Class area%		
Elevation class	MAP (1990)	SRTM (2000)	GPS (2008)
Class 1 (<35 m)	10	22	33
Class 2 (35-40 m)	16	21	29
Class 3 (40-45 m)	32	31	35
Class 4 (>45 m)	42	26	3

The common cells of the class 3 have been randomly sampled from the MAP DEM, SRTM DEM, and GPS DEM (on a cell-by-cell basis). Each cell had three elevation values in the range 40 to 45 m, namely map, srtm, and gps. An average sample was made of 1661 cells. Table 3 shows statistics of elevation differences, on a cell by-cell basis. The map-srtm yielded a mean difference of -1.31 m and a standard deviation of 1.37. The range of vertical differences was [-1.62 m to +4.88 m]. On the other hand the srtm – gps yielded mean difference of +2.12 m and a standard deviation of 1.42 with the range [-1.26 m to +4.99 m]. Figures 4a and 4b show the frequency distribution of the elevation differences: map-srtm and srtm-gps, respectively. These plots indicate normal distribution with biases -1.31 and +2.12, respectively. In order to remove the biases it was necessarily to add 2.12 m to the gps dataset and subtract 1.31 m from the map dataset.

Table 3. Statistics of elevation differences for the non-leveled areas [N = 1661 (43.73mx43.73m)]. After removing the bias the corrected GPS and MAP elevations are referred to as gpsc and mapc, where gpsc = gps+2.12 and mapc = map-1.31

	Difference					95 % conf.	
	Min.	Max.	Mean	St.Dev.	RMSE	limit of RMSE	
	m				m		
map - srtm	-1.62	4.88	-1.31	1.37	1.89	-2.39	6.17
srtm - gps	-1.26	4.99	2.12	1.42	2.55	-2.39	7.49
mapc - srtm	-2.93	3.68	0.00	1.37	1.37	-1.55	4.29
srtm - gpsc	-3.38	2.87	0.00	1.42	1.42	-1.58	4.42
mapc-gpsc	-1.72	1.54	0.00	0.71	0.71	-0.87	2.29

After removing the bias the corrected GPS and MAP elevations are referred to as gpsc and mapc. Once the bias was removed, the mean statistics for the average errors (± stdev) are equal to 0.00 ± 1.37 m, and 0.00 ± 1.42 m for mapc-srtm and srtm-gpsc, respectively (Fig. 4a' and 4b'). The corresponding root mean squares errors (RMSE) are 1.37 m and 1.42 m, respectively (Table 3). These findings indicate that the SRTM 43.7 m has absolute

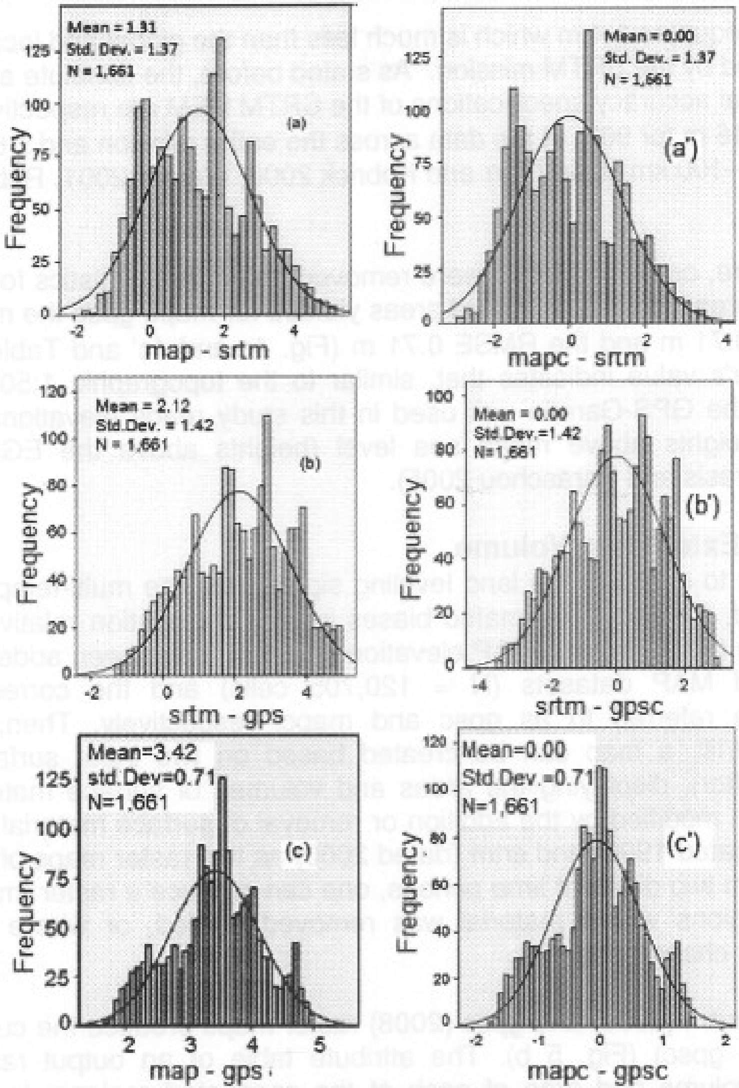


Fig. 4. An average sample is made of 1661 cells (43.7m x 43.7 m) that are subject to no-relief-changes since 1990 to 2008. On a cell by-cell basis: (a and a') map-srtm elevation differences yield a mean difference of -1.31 m and a standard deviation of 1.37. Once the bias 1.31 is subtracted from the map elevations the differences mapc-srtm are normally distributed with average error equal to 0.00 ± 1.37 m; (b and b') srtm-gps elevation differences yield a mean difference of +2.12 m and a standard deviation of 1.42. Once the bias 2.12 is added to the gps elevations the differences srtm-gpsc are normally distributed with average error equal to 0.00 ± 1.42 m; (c and c') Once the biases in map and gps are removed, the mean statistics for the elevation differences yield for mapc-gpsc the mean error 0.00 ± 0.71 m.

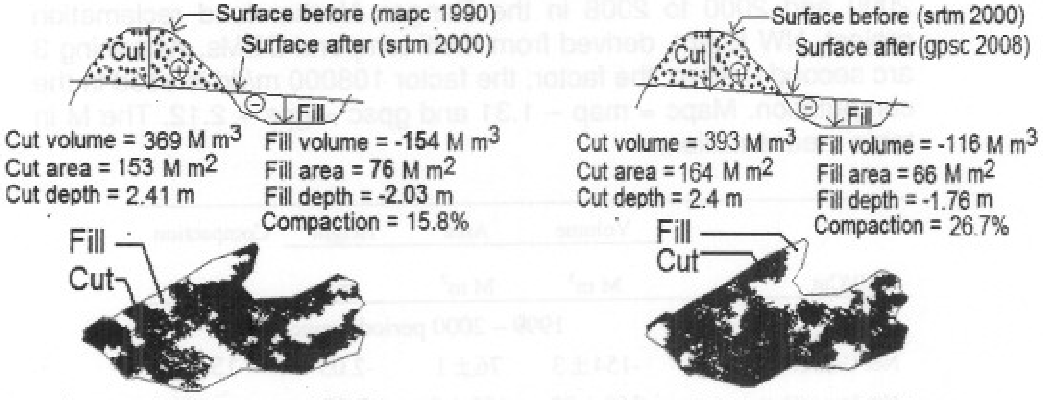
vertical error equal to 1.4 m which is much less than the global and local errors targeted by the SRTM mission. As stated before, the absolute and relative vertical accuracy specifications of the SRTM DEM are respectively defined as ± 16 m for 90% of the data across the entire mission and ± 6 m on a local, 50–100 km scale (Farr and Kobrick 2000, Werner 2001, Rabus et al. 2003).

Furthermore, once the biases were removed, the mean statistics for the elevation differences on non-leveled areas yielded for mapc-gpsc the mean error 0.00 ± 0.71 m and the RMSE 0.71 m (Fig. 4c and 4c' and Table 3). This low error's value indicates that, similar to the topographic 1:50,000 scale maps, the GPS-Garmin unit used in this study reads elevations as orthometric heights above mean sea level (heights above the EGM96 geode) (Miliaresis and Paraschou 2005).

The Cut/Fill Extent and Volume

In order to evaluate the land leveling signal from the multi-temporal DEMs at hand, the above estimated biases in SRTM elevation relative to GPS elevation (+2.21 m) and MAP elevation (-1.31 m) have been added to the GPS and MAP datasets (N = 120,705 cells) and the corrected elevations are referred to as gpsc and mapc, respectively. Then, by calculating cut/fill, a map can be created based on two input surfaces (before and after), displaying the areas and volumes of surface material that have been modified by the addition or removal of surface material. By taking mapc (dated 1990) and srtm (dated 2000) as two raster maps of the study area from two different time periods, one can produce a raster (mapc – srtm) of regions where material was removed, added, or where the surface did not change (Fig. 5a).

Similarly, the srtm (2000) and gpsc (2008) raster maps produce the cut/fill raster (srtm – gpsc) (Fig. 5 b). The attribute table of an output raster contains the volume and area of each of the connected regions. In the attribute table, in regions where material was cut (black areas in Fig. 5a and Fig. 5b) the value in the volume field will be positive. In regions where material was filled (white areas in Fig. 5a and Fig. 5b), the volume is negative. During the second period 2000-2008 some of the cut took place in some previously filled areas and some of the fill in some previously cut areas. Table 4 summarizes the computed cut/fill volumes and areas.



(mapc 1990 – srtm 2000) map
(a)

(srtm 2000 – gpsc 2008) map
(b)

Fig. 5. Cut/fill maps created based on two input surfaces (before and after), displaying the areas of surface material that have been modified by the addition or removal of surface material. The input surfaces are the multi-temporal DEMs derived from topographic MAP (1990), SRTM (2000) and GPS (2008) elevation datasets for Banger Alsokar land reclamation project (23087 ha), Egypt. The cut/fill volumes and areas are during the periods: (a) 1990 to 2000 and (b) 2000 to 2008.

As seen in Table 4 and Fig. 5a the total areas subject to fill and cut are 7600 ± 100 ha and 15300 ± 900 ha, respectively during the 1999 – 2000 period. The corresponding fill and cut volumes are 154 ± 3 M m^3 and 369 ± 22 M m^3, respectively. While the cut area is almost twice the fill area, the cut volume is about 2 and ½ the fill volume. Assuming no cut volumes have been transported outside the study area, soil compaction in the fill areas is estimated equal to 15.8%; using the average fill and cut heights values (Table 4). On the other hand during the second period 2000-2008, the fill and cut areas are 6600 ± 100 ha and 16400 ± 900 ha, respectively. The corresponding fill and cut volumes are 166 ± 4 M m^3 and 393 ± 23 M m^3, respectively. Soil compaction in the fill areas is estimated equal to 26.7% which seems unreasonably high and may indicate that some of the cut volumes have been moved outside the study area. Removal of these cut volumes could be man-made or/and natural due to wind erosion especially during the period from February to July by the Khamaseen wind coming from the southwest direction.

Table 4. The cut/fill volumes and areas during the periods 1990 to 2000 and 2000 to 2008 in the Bangar Alsokar land reclamation project, NW Egypt, derived from multi-temporal DEMs. Assuming 3 arc second = 90 m, the factor, the factor 108000 m/dd is used in the computation. Mapc = map – 1.31 and gpsc = gps + 2.12. The M in table means million.

	Volume	Area	Height	Compaction
Fill/Cut	M m^3	M m^2	m	%
	1999 – 2000 period (mapc-srtm)			
Net Gain (Fill)	-154 ± 3	76 ± 1	-2.03	15.8
Net Loss (Cut)	369 ± 22	153 ± 9	2.41	
	2000 – 2008 period (srtm-gpsc)			
Net Gain (Fill)	-116 ± 4	66 ± 1	-1.76	26.7
Net Loss (Cut)	393 ± 23	164 ± 9	2.4	

The Cut/Fill Directions

Since limestone is the major parent rock, calcic subhorizons prevail in the study area (Abdel-Kader et al. 2004). Depending on the depth of the calcic horizon some cuts may expose subsoil high in $CaCO_3$ while other cuts expose subsoil low in $CaCO_3$ contents. Similarly, some fill areas may utilize soil that is low in $CaCO_3$ while other fill areas utilize soil that is high in $CaCO_3$ content. As previously given in Table 1, the average $CaCO_3$ content and standard deviation in the surface soil (0-30 cm depth) are found equal to 36% and 9%, respectively. A $CaCO_3$ map (Fig. 6a) show two $CaCO_3$ classes, namely the low $CaCO_3$ class (7 – 35 %) and the high $CaCO_3$ class (35 – 65 %). This $CaCO_3$ pattern is essentially the result of the cut/fill processes started about 1989 for the establishment of irrigation and drainage networks. Overlying the $CaCO_3$ pattern with the cut/fill pattern yields a map made of four classes, namely (i) Cut exposes high $CaCO_3$ soil, (ii) Fill with high $CaCO_3$ soil, (iii) Cut exposes low $CaCO_3$ soil, and (iv) Fill with low $CaCO_3$ soil. The output maps are shown in Fig. 6b and Fig. 6c for the periods 1990 – 2000 and 2000 – 2008, respectively.

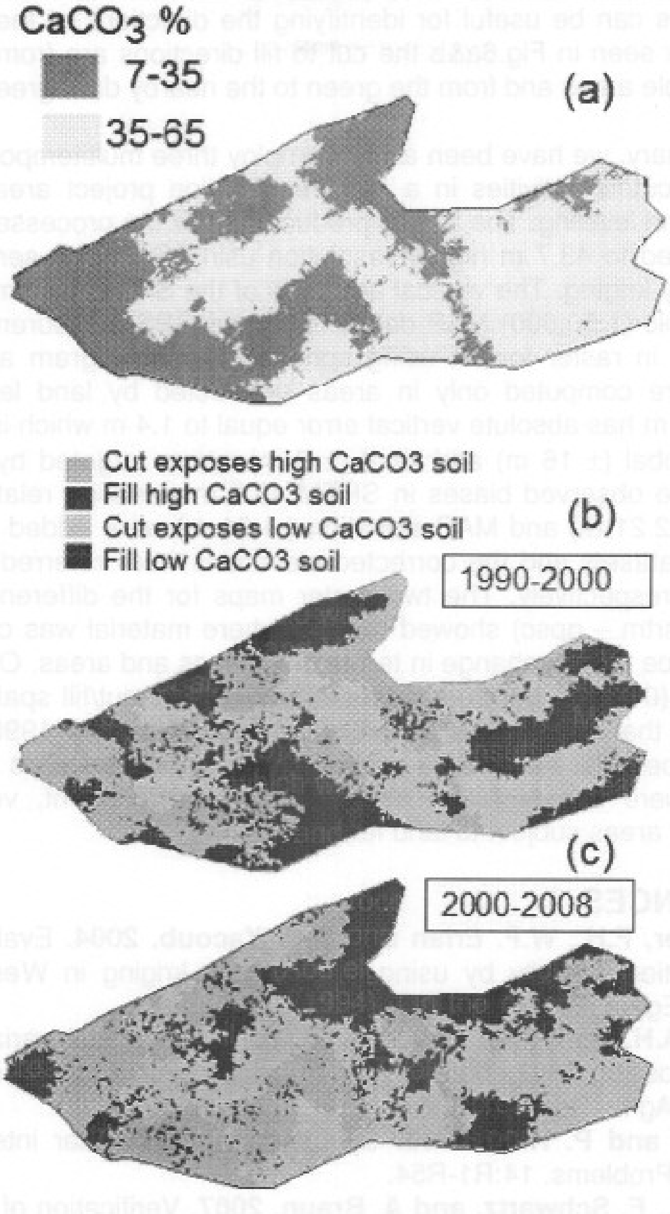


Fig. 6. (a) Two $CaCO_3$ classes in Bangar Alsoker land reclamation project, NW Egypt. The average $CaCO_3$ content and standard deviation are 36% and 9%, respectively. The low and high $CaCO_3$ classes occupy 58% and 42% of the study area, respectively. (b) Cut/fill of the periods 1990 to 2000. (c) Cut/fill of the periods 2000 to 2008. The cut to fill directions are from pink to the nearby purple areas and from the green to the nearby dark-green areas.

These maps can be useful for identifying the directions of the cut and fill process. As seen in Fig.6a&b the cut to fill directions are from pink to the nearby purple areas and from the green to the nearby dark-green areas.

In summary, we have been able to employ three multitemporal DEMs to detect the cut/fill activities in a land reclamation project area subject to temporal land leveling. The SRTM product used is the processed SRTM 90 m re-sampled to 43.7 m higher resolution using Gaussian semivariogram and ordinary kriging. The vertical accuracy of the SRTM 43.7 m, relative to a topographic (1:50,000) MAP dated 1990 and GPS measurements dated 2008 (each in raster format using spherical semivariogram and ordinary kriging) were computed only in areas unaffected by land leveling. The SRTM 43.7 m has absolute vertical error equal to 1.4 m which is much less than the global (± 16 m) and local (± 6 m) errors targeted by the SRTM mission. The observed biases in SRTM 43.7 m elevation relative to GPS elevation (+2.21 m) and MAP elevation (-1.31 m) were added to the GPS and MAP datasets and the corrected elevations were referred to as gpsc and mapc, respectively. The two raster maps for the differences (mapc-srtm) and (srtm – gpsc) showed regions where material was cut, filled, or where surface did not change in terms of volumes and areas. Overlying the soil $CaCO_3$ (0-30 cm depth) spatial pattern with the cut/fill spatial patterns gave maps that identify the cut/fill directions during the 1990-2000 and 2000-2008 periods. The readily available multi-temporal DEMs (map, srtm, and gps) were successful in detecting the cut/fill extent, volume, and directions in areas subject to land leveling.

REFERENCES

Abdel-Kader, F.H., W.F. Erian and R.K. Yacoub. 2004. Evaluating land degradation severity by using the ordinary kriging in West Nubariya region, Egypt. Egypt J. Soil Sci. 44:407-427.

Alsaeedi, A.H. and A.M. Elprince. 2000. Mapping soil variables using global position and geographical information systems: map registration. Alex. J. Agric. Res. 45: 57-67.

Bamler, R. and P. Hart. 1998. Synthetic aperture radar interferometry. Inverse Problems. 14:R1-R54.

Bhang, K.J., F. Schwartz, and A. Braun. 2007. Verification of the vertical error in C-band SRTM DEM using ICESat and Landsat-7, Otter Country, MN. IEEE Trans on Geosci. Remote Sens. 45:36-44.

Blumberg, D., D. Bach, J. Weissel, Y. Gorokhovich, C. Small and D. Balk, D. 2005. The 2004 Sumatra tsunami event: Contribution of SRTM data to the analysis of devastation. The Shuttle Radar Topography Mission—Data Validation and Applications, Workshop, June 14–16, Reston, Virginia.

Burbank, D. W., A. E. Blythe, J. Putkonen, B. Pratt-Sitaula, E. Gabet, M. Oskin, A. Barros and T. P. Ojha. 2003, Decoupling of erosion and precipitation in the Himalayas. Nature. 426: 652-655.

Cosser, E, C. J. Hill, G.W. Roberts, X. Meng T. Moore and A.H. Dodson. 2004. Bridge Monitoring with Garmin Handheld Receivers. International Symposium on Engineering Surveys for Construction Works and Structural Engineering. Nottingham, United Kingdom, 28 June – 1 July 2004.

Elprince, A.M. 2009. Prediction soil fertilization maps using logistic modeling and a geographical Information System. Soil Sci. Soc. Am. J. 73:2032-2042.

Elprince, A.M. and Y.Y. Al-Dakheel. 2010. Using Advanced Spatial Technology in Georeferencing irrigation and drainage networks. European Journal of Scientific Research. 48: 6-15.

Elprince, A.M., A.H. Alsaeedi, and A. Alabdullah. 2004. Mapping soil salinity using geographical information systems: Spatial variability and map projection. *In* Int. Symp. on Prospects of Saline Agriculture in GCC Countries, Dubai, United Arab Emirates. 18–20 Mar. 2001. Int. Ctr. For Biosaline Agric., Dubai, UAE.

ESRI. 2006. Help Topics. Environmental Systems Research Institute, Inc., USA.

Eswaran, H., T.R. Forbes and M.C. Laker. 1977. Soil map parameters and classification. p. 37–57. *In* R.W. Arnold (ed.) Soil resource inventories. Agron. Mimeogr. 77-73. Cornell Univ., Ithaca, NY

Farr, T. G. and M. Kobrick. 2000. Shuttle radar topography mission produces a wealth of data. Transactions of the American Geophysical Union, 81: 583–585.

Finlayson, D. P., D. R. Montgomery and B. Hallet .2002. Spatial coincidence of rapid inferred erosion with young metamorphic massifs in the Himalayas. Geology. 30: 219-222.

Gabriel, A.K. and R.M. Goldstein. 1988. Crossed orbit interferometry: theory and experimental results from SIR-B. International Journal of Remote Sensing. 9:857-872.

GARMIN 2005. eTrexLegend personal navigator. Owner's manual and reference guide. Garmin International, Inc. KS, USA.

Gorokhovich, L. and A. Voustianiouk. 2006. Accuracy assessment of the processed SRTM-based elevation data by CGIAR using field data from USA and Thailand and its relation to the terrain characteristics

Gotway Crawford, C.A.G. and G.W. Hergert. 1997. Incorporating spatial trends and anisotropy in geostatistical mapping of soil properties. Soil Sci. Soc. Am. J. 61:298–309.

Grohmann C. H. 2006. Resampling SRTM 03"-data with kriging. GRASS/OSGeo-News. 4: 20- 25.

Guth, P. 2003. Geomorphology of DEMs: Quality assessment and scale effects. Paper No. 175-2. Proceedings of GSA, Seattle Annual Meeting, November 2–5.

Helm, A., A. Braun, S. Eickschen, S. and T. Schune. 2002. Calibration of the shuttle radar topography mission X-SAR instrument using a synthetic altimetry data model. Canadian Journal of Remote Sensing, 28: 573–580.

Isaaks, E.H., and R.M. Srivastava. 1989. An introduction to applied geostatistics. Oxford Univ. Press, New York.

Jarvis, A., J. Rubiano, A. Nelson, A. Farrow and M. Mulligan. 2004. Practical use of SRTM data in the tropics—comparisons with digital elevation models generated from cartographic data. Working Document, Vol. 198. Centro Internacional de Agricultura Tropical (CIAT) 32 pp.

Journal, A.G., and Ch.J. Huijbregts. 1978. Mining geostatistics. Academic Press, London.

Jun, Q., H. Cheng, Z. Tonggang, and C. minyi. 2008. Multi-tempral DEM matching method without control points. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences. Vol. XXXVII. Part B8. Beijing: 1235-1237.

Michalowska, K and E. Glowienka. 2008. Multi- temporal data integration for the changeability detection of the unique Slowinski national park landscape. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences. Vol. XXXVII. Part B7. Beijing.

Kellndorfer, J., W. Walker, L. Pierce, C. Dobson,J.A. Fites and C. Hunsaker, C. 2004. Vegetation height estimation from shuttle radar topography mission and national elevation datasets. Remote Sensing of Environment. 93: 339–358.

Lavé, J., and J. P. Avouac. 2001. Fluvial incision and tectonic uplift across the Himalaya of central Nepal. J. Geophys. Res., 106:561-591.

Liu, X., and J. Peterson1, Z. Zhang and S. Chandra. 2005. Improving soil salinity prediction with high resolution DEM derived from LiDAR Data. The 9th International Symposium on Physical Measurements and Signatures in Remote Sensing Beijing, China 17-19 October 2005: 41-43.

Massonnet, D. and T. Rabaute. 1993. Radar interferometry: limits and potential. IEEE Transactions on Geoscience and Remote Sensing. 31:455-464.

Michalowska, K. and E. Glowienka. 2008. Multi-temporal data integration for the chnge-ability detection of the unique Slowinski national park landscape. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences. Vol. XXXVII. Part B7. Beijing: 1017- 1020.

Miliaresis, G. Ch., and C.V.E. Paraschou. 2005. Vertical accuracy of the SRTM DTED level 1 of crete. International Journal of Applied Earth Observation and Geoinformation. 7:49–59.

Miliaresis, M. and D. Delikaraoglou. 2009. Effects of percent tree canopy density and DEM misregistration on SRTM/NED vegetation height estimates. Remote Sens. 1: 36-49.

Page, A.L., R.H. Miller and D.R. Keeney (ed.). 1982. Methods of soil analysis. Part 2. Chemical and microbiological properties. 2nd ed. ASA and SSSA, Madison, WI.

Rabus, B., M. Eineder, A. Rothand R. Bamler. 2003. The shuttle radar topography mission—a new class of digital elevation models acquired by space borne radar. Journal of Photogrammetry and Remote Sensing. 57: 241-262.

Racoviteanu, A.E., W.E. Manley, Y. Arnaud, M.W. Williams. 2007. Evaluating digital elevation models for glaciologic applications: An example from Nevado Coropuna, Peruvian Andes. Global and Planetary Change. 59:110-125.

Rodriguez, E., C.S. Morris and J.E. Belz. 2006. A global assessment of the SRTM performance photogram. Eng. Remote Sens. 72: 249-261.

Rodriguez,E., C.S. Morris, J.E. Belz, E.C. Chapin, J.M. Martin and W. Daffer. 2005. An assessment of the SRTM topographic products, Technical Report JPL D-31639.Pasadena, California: Jet Propulsion Laboratory 143 pp.

Smith, B. and D. Sandwell. 2003. Accuracy and resolution of shuttle radar topography mission data. Geophysical Research Letters. 30: 1467.

Stock, J.D., D. Bellugi, W.E.Dietrich and D. Allen .2002. Comparison of SRTM topography to USGS and high resolution laser altimetry topography in steep landscapes: Case studies from Oregon and California. Eos Trans. AGU, Fall Meet. Suppl., Abstract H21G-09. 83:47.

Sun, G., K.J. Ranson, V.I. Kharuk and K. Kovacs. 2003. Validation of surface height from shuttle radar topography mission using shuttle laser altimeter. Remote Sensing of Environment, 88. 401–411.

Wackernagel, H. 1995. Multivariate geostatistics. Springer-Verlag, New York.

Warrick, D., R. Zhang, M.K. El-Haris, and D.E. Myers. 1988. Direct comparisons between kriging and other interpolators. p. 505–510. *In* P.J. Wierenga and D. Bachelet (ed.) Proc. Int. Conf. on Validation of Flow and Transport Models for the Unsaturated Zone, Ruidoso, NM. 23–26 May . New Mexico State Univ., Las Cruses.

Weber, D., and E. Euglund. 1992a. Evaluation and comparison of spatial interpolators. Math. Geol. 24:381–391.

Weber, D., and E. Euglund. 1992b. Evaluation and comparison of spatial interpolators II. Math. Geol. 26:589–603.

Werner, M. 2001. Shuttle radar topography mission (SRTM), mission overview. Journal of Telecommunication (Frequenz), 55:75–79.

Zebker, H.A. and R.M. Goldstein. 1986. Topographic mapping from interferometric synthetic aperture radar observations. Journal of Geophysical Research. 91:4993-4999.

الملخص العربى

دراسة مؤشرات الحفر / ردم بأستخدام نماذج الارتفاعات الرقميه المتعدده زمانيا

وفاء حسن محمد – ماجدة أبو المجد حسين – نظير أبراهيم أحمد العبسى –
عادل محمد البرنس
قسم الأراضى والكيمياء الزراعية – كلية الزراعة سابا باشا – جامعة الاسكندرية

ان بيانات ارتفاعات سطح الأرض الرقميه المتوفرة على شبكة المعلومات العالميه (الانترنت) قد تم جمعها بواسطة مكوك طبوغرافية الارض SRTM خلال احدى عشر يوما في فبراير 2000. ان مقارنة هذه البيانات مع بيانات الخريطة الطبوغرافية MAP و قياسات جهاز تحديد المواقع GPS والمأخوذة فى أزمنة مختلفة يعني أننا نقارن بين نماذج ارتفاعات رقميه متعدده زمانيا. ان الهدف من هذه الدراسه هو استخدام هذه النماذج المتعدده في استنباط نشاطات الحفر و الردم في مشروع استصلاح أراضى تم به تسوية للأرض على فترات زمنية متعاقبه لتنفيذ شبكة الرى والصرف الزراعي شمال غرب مصر . ان ال SRTMالمستخدم فى هذه الدراسة هو SRTM 90m والذى تم زيادة دقته الى 43.7 m باستخدام نماذج جاوسيان– سميفاريوجرام وكريجنج. تم حساب الدقه الرأسيه ل SRTM 43.7 m منسوبة الى الخريطة الطبوغرافيه (1:50000) و التي تم عملها في سنة 1990 و قياسات جهاز تحديد المواقع GPS فى سنة 2008 (في شكل rasters باستخدام تماذج سفيريكال– سميفاريوجرام و كريجنج) وذلك

فقط فى المساحات غير المتاثره بعمليات تسوية الأرض [N = 1661cells (43.73mx43.73m)]. فكان الخطأ المطلق فى الدقه الرأسيه ل SRTM 43.7 m مساوي 1.4 m و الذي يعتبر اقل بكثير من كل من الخطأ المطلق العالمي (± 16 m) و الخطأ المحلي (± 6 m) المتوقعين تبعا لمهمة مكوك طبوغرافية الارض. الانحرافات المقدرة فى قيم ارتفاعات SRTM 43.7 m نسبة الى ارتفاعات GPS والذي يساوي (+2.21 m) وارتفاعات MAP و الذي يساوي (-1.31 m) قد اضيفت الى ارتفاعات GPS و MAP للمساحة الكلية تحت الدراسة [N = 120705 cells] وقد أطلق على الارتفاعات المصححه gpsc و mapc على التوالى. أظهرت خريطتى الفروق (mapc-srtm) و (srtm – gpsc) وجود مناطق حفر ومناطق ردم ومساحات لم تتغير بالنسبة للحجم أو المساحة. وبتقاطع خريطة $CaCO_3$ بالتربة (0 – 30 سم عمق) مع خرطتى الحفر/ ردم تم الحصول على خرائط تبين اتجاهات الحفر/ ردم خلال الفتره من 1990 – 2000 و الفتره من 2000 – 2008. ان سهولة توافر نماذج الارتفاعات الرقميه المتعدده زمنيا (map, srtm, and gps) يمكن أن يكون وسيله ناجحه لاستنباط معلومات عن التطور الزمنى لعمليات الحفر/ ردم من حيث المساحات و الحجوم والاتجاهات فى مناطق تم بها تسوية للأرض على فترات زمنية متعاقبه.