Evaluating the Accuracy of the Global DEMs ASTER, SRTM and Elevation Data Derived from Google Earth Program in Urban Areas over Egypt

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ملخص البحث

تعد نماذج الارتفاعات الرقمية احد اهم عناصر انتاج الخرائط ذات مقاييس الرسم الكبيرة. يمكن انتاج نماذج الارتفاعات الرقمية باستخدام عدة طرق مختلفة و معتمدة على مصادر بيانات متعددة منها على سبيل المثال الرفع المساحى باستخدام تقنية ال GPS او باستخدام محطات الرصد الارضية المتكاملة الـ T.S. او التصوير الجوى او النماذج المتاحة مثل SRTM او ASTER او الارتفاعات المشتقة من برنامج جوجل ايرث. لتقييم الدقة الراسية لهذه النماذج يجب مقارنتها بارتفاعات تم الحصول عليها من اعمال الرفع المساحى الارضى و هذا التقييم يتم عن طريق حساب قيم الـ RMSE. الهدف الرئيسى للبحث هو تقييم الدقة الراسية للنماذج الارتفاعات الرقمية العالمية مثل ASTER او SRTM او الارتفاعات المشتقة من برنامج جوجل ايرث خاصة فى المناطق العمرانية شبه المستوية. نتائج البحث اعطت 0.16 m للنموذج الارضى و 1.84 m للارتفاعات المشتقة من برنامج جوجل ايرث و 2.43 m لنموذج SRTM و3.4 m لنموذج ASTER و قد استخلصنا من هذة النتائج أن النموذج المنتج من الرفع المساحى هو الوحيد الذى يمكن من خلاله انتاج خرائط كنتورية ذات مقياس رسم كبير مثل 1 : 2500 بفترة كنتورية 0.50 m نظرا لان الخطأ الناتج عنة اقل من نصف الفترة الكنتورية لهذه الخرائط اما باقى النماذج فتصلح لانتاج خرائط كنتورية ذات مقياس رسم متوسط مثل 25000:1 بفترة كنتورية 2.5 m من الارتفاعات المشتقة من برنامج جوجل ايرث و SRTM و 50000:1 من ASTER بفترة كنتورية 5.0 m .

1. Abstract

Digital Terrain Model is the most critical and cumbersome element of any large-scale mapping projects **[1].** Digital Terrain Models can be generated by various methods from different sources as global positioning system (GPS) or using Total Stations or photogrammetry or non-imaging airborne techniques also global DEMs which can be downloaded like SRTM, ASTER and elevation data derived from Google Earth Program. For evaluating the vertical accuracy of these DEMs we should compare the interpolated values of these elevations with the actual elevation values from ground field surveying in terms of its Root Mean Square Error (RMSE) **[2]**. The main objective of this research was evaluating the vertical accuracy of the global DEMs ASTER, SRTM and elevation data derived from Google

Earth Program especially in flat urban areas. The results show that the RMSE of these DEMs where 0.16m for ground DEM, 1.84m for elevation data derived from Google Earth Program, 2.43m for SRTM and 3.4m for ASTER. These RMSE shows that only Ground DEM were accepted to produce large scale maps of scale 1:2500 because its RMSE less than one half the contour interval 0.25m and the other DEMs can be used to produce small contour scale maps of scale 1:50000 for derived elevations from Google earth program and SRTM and 1:100000 for ASTER.

2. Introduction

Digital terrain models (DTMs) can be defined as digital representations of variables relating to a topographic surface, namely: digital elevation models (DEMs), digital models of gradient (G), aspect (A), horizontal (kh) and vertical (kv) landsurface curvatures as well as other topographic attributes **[3]**. DEMs can be produced in different ways and there are free Global DEMs which can be downloaded free as SRTM, ASTER and elevation data derived from Google Earth Program. Most of these DEM values are interpolated because the elevations measured seldom coincide with the grid intersection, so every DEM will be affected by different errors. These errors can be evaluated by the comparison of the DEM estimated values at specific locations and the ground measurements at the same locations. DEMs errors can be evaluated using the Root Mean Square Error (RMSE) which quantifies the average error between DEM values and ground measurements at specific locations. In this paper, the main objective was the evaluation of the vertical accuracies of different Global DEMs (ASTER, SRTM and elevation data derived from Google Earth Program) especially in flat urban area. The paper is organized as follows: Section 3 introduces the Previous Experience of evaluating the vertical accuracies of different DEMs. In section 4 the Available Data and Methodology were described. And finally Section 5 draws the conclusions of this research.

3. Previous Experience

The Digital Terrain Model has become a central storage carrier for height information. Automatic generation of DTMs is a subject of research, since the 1980s when the first experiment with intensity based matching have been carried out **[8]**. However, software modules exist at photogrammetry software workstation which processes aerial image pairs (stereo pairs) and produce high quality DTMs. With the use of three-line linear CCD (Charged Couple Devices) arrays (by SPOTS, MOMS02, etc) for direct digital data acquisition, direct DTM production from satellite imageries with standard techniques and algorithms are now possible. DTM, besides its many exciting uses also serves as a veritable source for a clearer exploration and better understanding of the details of the physical surface of the earth **[1].**

The accuracy of DTMs is of concern to both DTM producers and users. For a DEM project, accuracy, efficiency, and economy are the three main factors to be considered. Accuracy is perhaps the single most important factor to be considered because, if the accuracy of a DEM does not meet the requirements, then the whole project needs to be repeated and thus the economy and efficiency will ultimately be affected **[10].**

The procedure for assessing DEM quality involves examination of height differences between check points, measured using independent field survey, and the corresponding DEM points **[9]**.

In this research, an attempt to evaluate vertical accuracies of different DEMs especially in flat urban area.

4. Available Data and Methodology

4.1. Available Data

A pan-sharpened image with 60 cm spatial resolution over a chosen area has been selected for this study. This high resolution image was collected in May 31, 2005 by spacing imaging’s QUICKBIRD satellite and supplied in a TIFF digital format. This image has been obtained radiometrically corrected and rectified by the producer before publishing where some shift errors still exist. To overcome these errors a precise rectification for the QUICKBIRD satellite image has been done using fifteen Ground Control Points (GCPs) which have been evenly distributed over the area under investigation and collected (using Lieca GPS units on well defined places at sharp edges such as end of walls or corners of buildings) (Figure-1). Spot height points obtained from classical land surveying have been collected for the purpose of generating a ground DEM. Elevation data derived from Google Earth Program is available for the study area was downloaded and Free Global DEMs (ASTER and SRTM) from websites were also downloaded. There are many software packages were used for achieving the main aim of this research, such as ARCGIS of version 9.3, ERDAS IMAGINE of version 9.2, AutoCAD 2011 and GPS data processing program. The study area was chosen at Qalyuob city in Qalyuobia governorate, covers about two square kilometers and located in zone 36 in UTM projection system. The chosen area is an urban area contains buildings and roads network which is suitable for the study requirements.

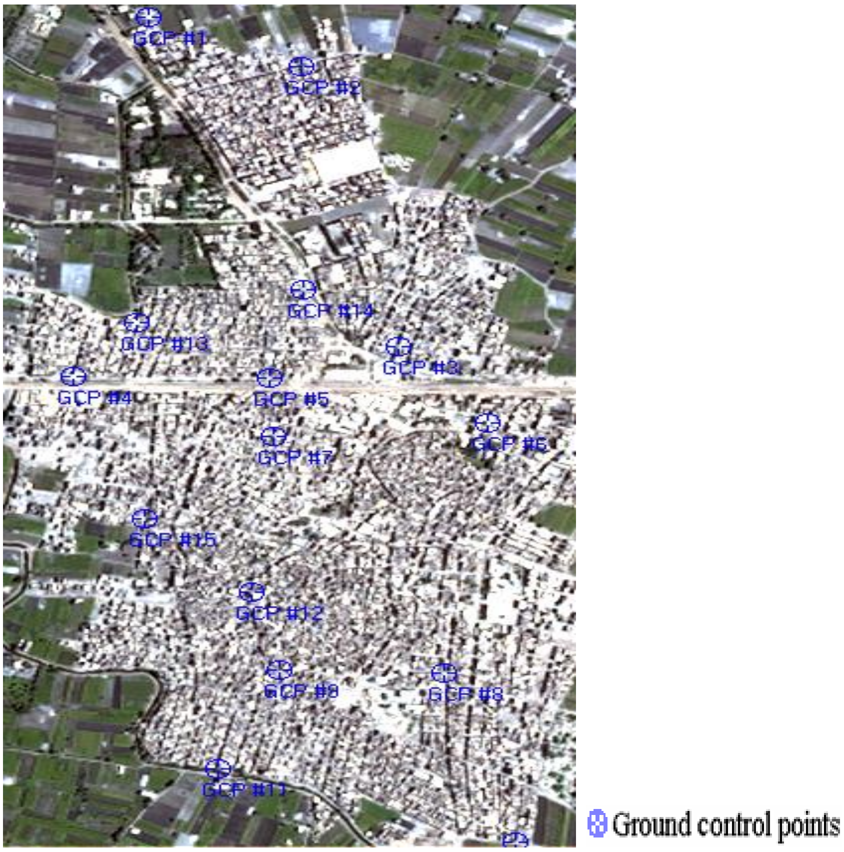

Figure (1): Well observed and distributed GCPs over the area under investigation on QUICKBIRD satellite Image.

4.2. Methodology

The evaluation of vertical accuracies of these DEMs for the study area will be discusses as follows:

4.2.1. Preparation of the Digital Elevation Models

4.2.1.1 Generation of the Ground Digital Elevation Model

1) Ground DEM was performed as follows:

a. Rectification of QUICKBIRD satellite image using the GPS ground control points

b. A leveling was performed for all the streets of the study area using the leveling program on the total station (3522 point). The leveling points were projected in their planimetric locations using the rectified QUICKBIRD satellite image as shown in Figure (2).

c. The Ground DEM was built from these points by ERDAS IMAGINE 9.2 software using nonlinear rubber sheeting interpolation method. In order to distribute the slope change smoothly across triangles, the nonlinear transformation with polynomial of order larger than one is used by considering the gradient information. The fifth order polynomial transformation is chosen as the best nonlinear rubber sheeting technique in this software. It is a smooth function. The transformation function and its first order partial derivative are continuous. has the following equation:

$$\sum_{i=0}^{5}\sum_{j=0}^{5} a(i)k.Xi-j.Yj \tag{1}$$

Where a (i) are the coefficients which can be computed using the common 3522 points of the two systems and the subscript k = (i*i + j) / 2 + j. Where each 3 meters cell has a unique elevation value derived from the elevation points as shown in Figure (3).

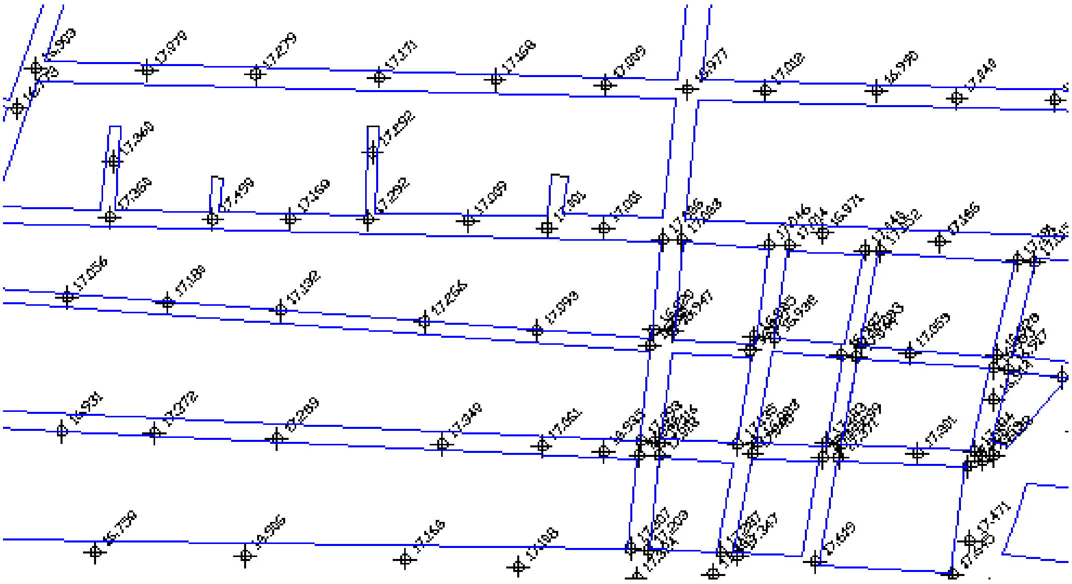

Figure (2): Part of The elevation points of the ground surveying

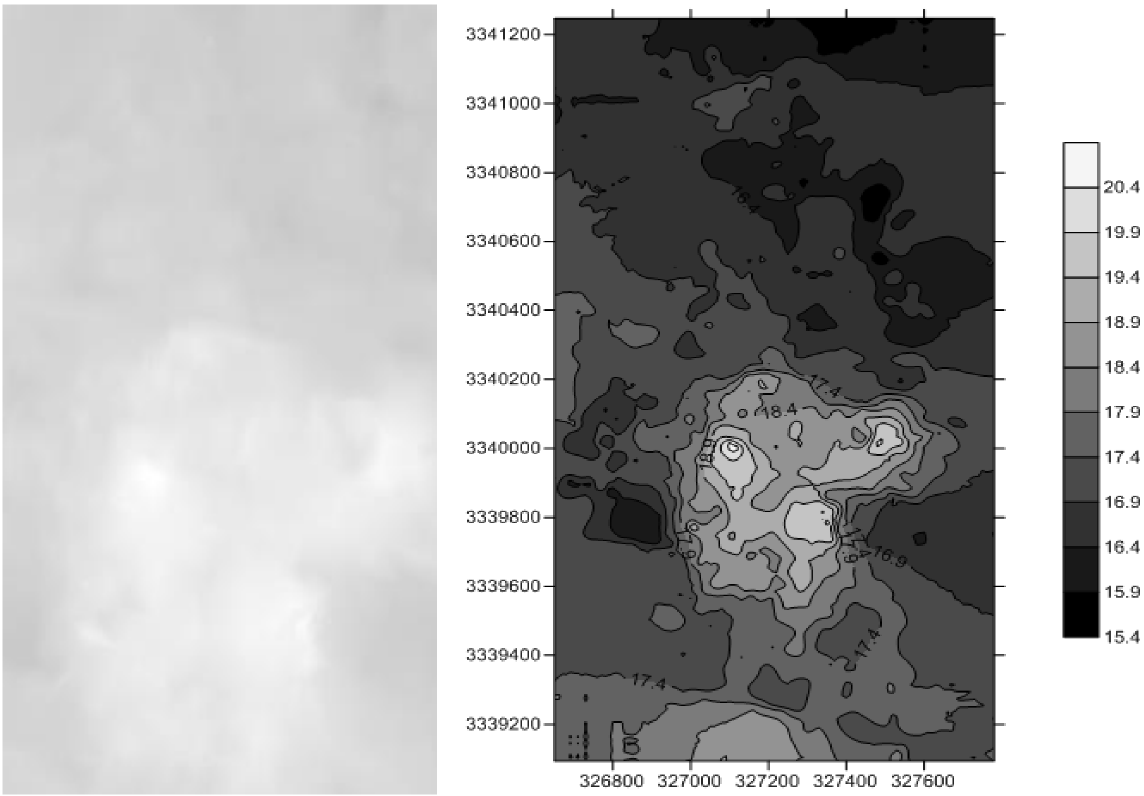

Figure (3): The Ground Digital Elevation Model of the study area

4.2.1.2 Preparation of the Global Digital Elevation Model (ASTER)

The ASTER Global Digital Elevation Model (ASTER GDEM) is a joint product developed and made available to the public by the Ministry of Economy, Trade, and Industry (METI) of Japan and the United States National Aeronautics and Space Administration (NASA). It is generated from data collected from the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER), a spaceborne earth observing optical instrument. The ASTER GDEM is the only DEM that covers the entire land surface of the Earth at high resolution. Since the release of the Version 1 on June 29, 2009 (*1), The ASTER GDEM covers land surfaces between 83°N and 83°S and is composed of 22,600 1°-by-1° tiles. Tiles that contain at least 0.01% land area are included. The ASTER GDEM is in GeoTIFF format with geographic lat/long coordinates and a 1 arc-second (30 m) grid of elevation postings. It is referenced to the WGS84/EGM96 geoid **[5]**. We subset the part of the study area using ERDAS IMAGINE soft ware as shown in Figure (4).

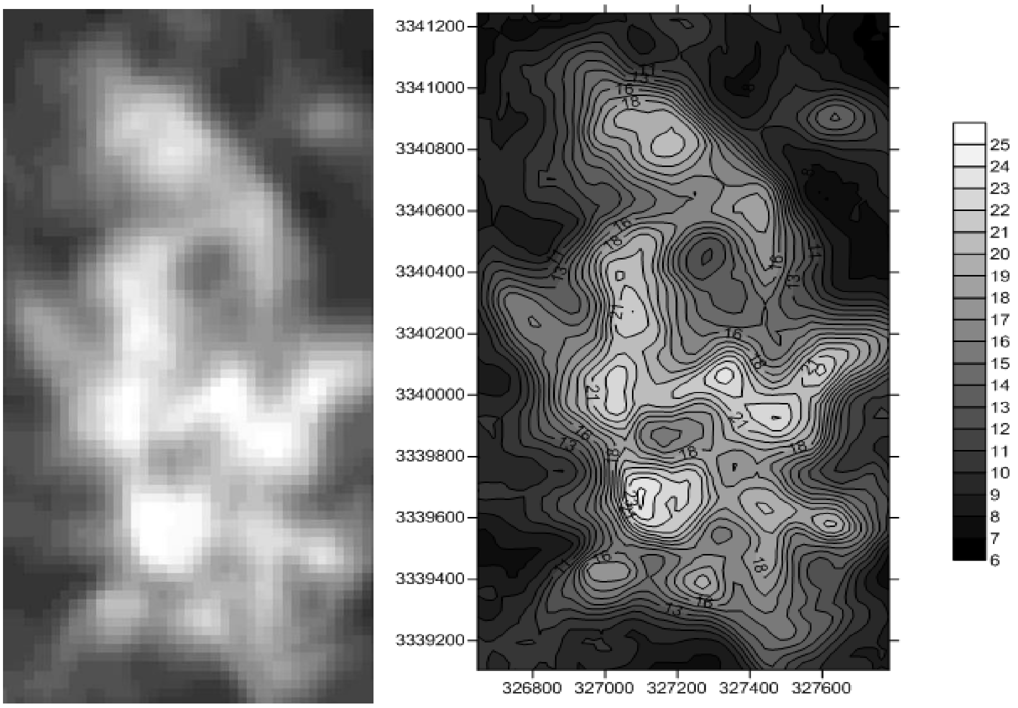

Figure (4): Global (ASTER) Digital Elevation Model subset for the study area.

4.2.1.3 Preparation of the Global Digital Elevation Model (SRTM)

The NASA Shuttle Radar Topographic Mission (SRTM) has provided digital elevation data (DEMs) for over 80% of the globe. This data is currently distributed free of charge by USGS and is available for download from the National Map Seamless Data Distribution System, or the USGS ftp site 2011. The SRTM data is available as 3 arc second (approx. 90m resolution) DEMs. Dr. Andy Jarvis and Edward Guevara of the CIAT Agroecosystems Resilience project, Dr. Hannes Isaak Reuter (JRC-IES-LMNH) and Dr. Andy Nelson (JRC-IES-GEM) have further processed the original DEMs to fill in these no-data voids. This involved the production of vector contours and points, and the re-interpolation of these derived contours back into a raster DEM. These interpolated DEM values are then used to fill in the original no-data holes within the SRTM data. These processes were implemented using Arc/Info and an AML script. The DEM files have been mosaiced into a seamless near-global coverage (up to 60 degrees north and south), and are available for download as 5 degree x 5 degree tiles, in geographic coordinate system - WGS84 datum **[4]**. The result of this processing is raster DEMs provided in (approx. 30m resolution) and we subset the part of the study area using ERDAS IMAGINE soft ware as shown in Figure (5).

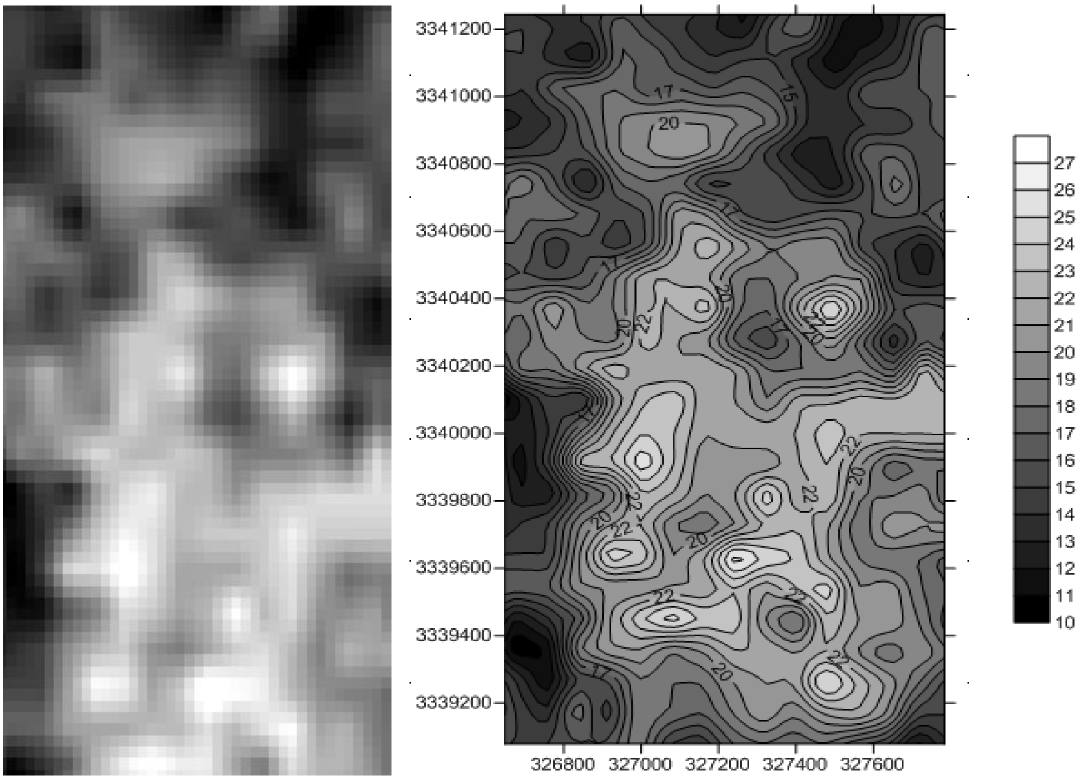

Figure (5): Global (SRTM) Digital Elevation Model subset for the study area.

4.2.1.4 Generation of the elevation data derived from Google Earth Program

An elevation data derived from Google Earth Program downloaded from websites is available for the study area was downloaded as points (3872 point) as shown in Figure (6), so the DEM was built from these points by ERDAS IMAGINE 9.2 software. Google Earth derived these points from USGS DEMs and it has different resolutions for different areas and it based on global SRTM (30m) DEM. This is performed by nonlinear rubber sheeting interpolation method (show Equation-1). Where each cell has a unique elevation value derived from the elevation points where cell size was 3 m as shown in Figure (7)

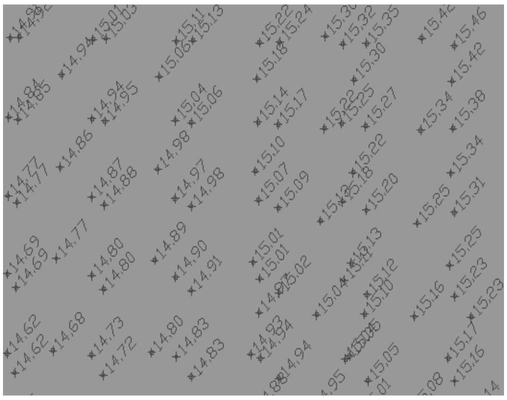

Figure (6): Part of the elevation data derived from Google Earth Program

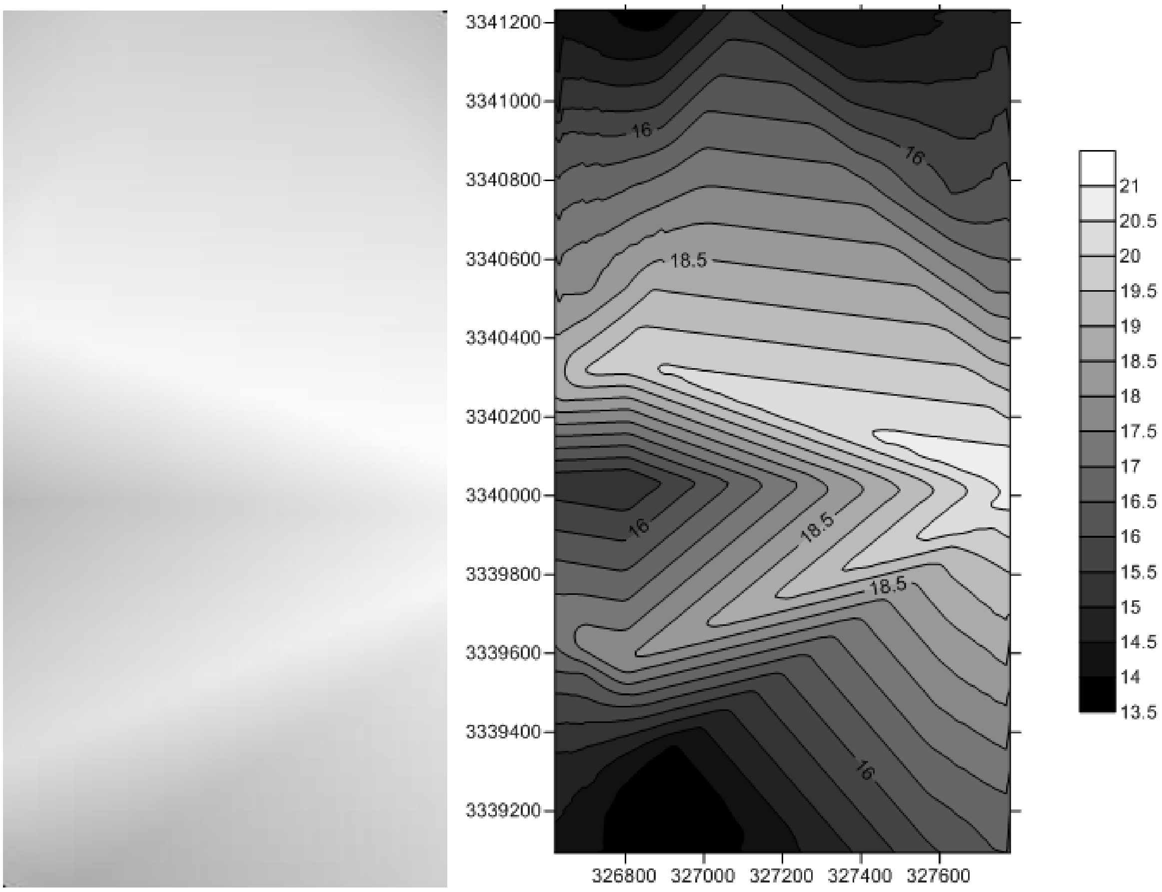

Figure (7): Digital Elevation Model derived from the elevation data derived from Google Earth Program

4.2.2. Checking the Vertical Accuracy of these Digital Elevation Models

4.2.2.1 Checking the Vertical Accuracy of the Ground Digital Elevation Model

Testing the Ground DEM using 20 points removed from the Ground DEM and evenly distributed across the area of interest as shown in Figure (8) against vertical control points derived precisely by total station data for the same 20 points, indicate that root mean square error (RMS) of elevations of the Ground DEM have been computed using the following formula:

$$\mathrm{RMSE} = \sqrt{\sum \frac{(\mathrm{Zi} - \mathrm{Zt})2}{\mathrm{n}}} \qquad (2)$$

Where Zi = interpolated DEM elevation of a test point, Zt = true elevation of a test point, n = number of test points **[6 and 7]** and were 0.16m. The *min*. diff. is 0.11m, The *max*. diff. is 0.19m, the *mean* is 0.037m and the *st.dev*. is 0.1558m. Table (1) shows the elevations of the interpolation Ground DEM and the ground vertical control points derived precisely by total station.

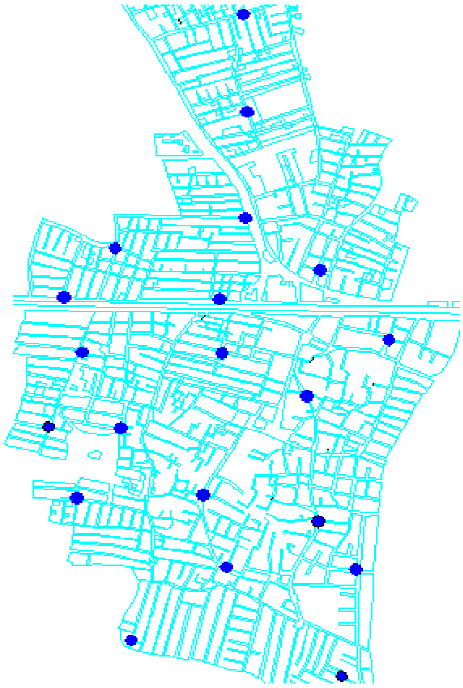

Figure (8): Distribution of the check points over the study area

Table (1): Heights from Ground DEM versus those from vertical control points

Point	Vertical Ground control points. (Z_G)	Interpolated Ground DEM Elev. (Z_i)	(Z_i- Z_G)
1	16.723	16.906	0.18
2	16.736	16.579	-0.16
3	16.563	16.484	-0.12
4	17.347	17.415	0.13
5	16.855	16.968	0.11
6	16.846	17.083	0.14
7	18.451	18.386	0.16
8	16.779	17.057	0.18
9	16.764	16.947	0.19
10	17. 292	17. 104	-0.19
11	18. 977	18. 868	-0.11
12	17.988	17.827	-0.15
13	17. 638	17. 468	-0.17
14	17.517	17.719	0.19
15	17.469	17.659	0.17
16	17.068	17.148	0.12
17	17.120	16.992	-0.13
18	16.523	16.428	-0.14
19	18.686	18.840	0.16
20	16.089	16.261	0.18

4.2.2.2 Checking the Vertical Accuracy of the Global (ASTER) Digital Elevation Model

Testing the Global DEM using 20 points evenly distributed across the area of interest as shown in Figure (8) against vertical control points d precisely by total station data for the same 20 points, indicate that root mean square error (RMS) of elevations of the Global DEM have been computed using Equation (2) **[6 and 7]** and were 3.4 m. The *min.* diff. is -0.462 m, The *max.* diff. is -7.139 m, the *mean* is 0.891m and the *st.dev.* is 3.3995 m. Table (2) shows the elevations of the interpolation Global ASTER DEM and the ground vertical control points derived precisely by total station.

Table (2): Heights from Global ASTER DEM versus those from ground vertical control points

Point	Vertical Ground control points. (Z_G)	Interpolated ASTER DEM Elev. (Z_{ASTER})	($Z_{ASTER} - Z_G$)
1	16.883	9.7850	-7.098
2	16.536	13.898	-2.638
3	16.463	15.959	-0.504
4	17.347	18.482	1.135
5	16.975	14.633	-2.342
6	16.946	16.000	-0.946
7	18.451	17.929	-0.522
8	16.979	19.437	2.458
9	16.964	10.707	-6.257
10	17.204	16.742	-0.462
11	18.868	23.079	4.211
12	17.918	20.000	2.082
13	17.568	15.727	-1.841
14	17.717	20.292	2.575
15	17.669	15.398	-2.271
16	17.168	13.730	-3.438
17	17.020	9.8810	-7.139
18	16.523	15.028	-1.495
19	18.856	22.000	3.144
20	16.089	19.608	3.519

4.2.2.3 Checking the Vertical Accuracy of the Global (SRTM) Digital Elevation Model

Testing the Global DEM using 20 points evenly distributed across the area of interest as shown in Figure (8) against vertical control points d precisely by total station data for the same 20 points, indicate that root mean square error (RMS) of elevations of the Global DEM have been computed using equation (2) **[6 and 7]** and were 2.43 m. The *min*. diff. is -0.480 m, The *max*. diff. is 5.771 m, the *mean* is 2.531m and the *st.dev*. is 2.429 m. Table (3) shows the elevations of the interpolation Global SRTM DEM and the ground vertical control points derived precisely by total station.

Table (3): Heights from Global SRTM DEM versus those from ground vertical control points

Point	Vertical Ground control points. (Z_G)	Interpolated SRTM DEM Elev. (Z_{SRTM})	($Z_{SRTM} - Z_G$)
1	16.883	15.367	-1.516
2	16.536	19.967	3.431
3	16.463	22.161	5.698
4	17.347	20.32	2.973
5	16.975	18.605	1.630
6	16.946	19.593	2.647
7	18.451	21.317	2.866
8	16.979	19.386	2.407
9	16.964	14.588	-2.376
10	17.204	22.956	5.752
11	18.868	18.388	-0.480
12	17.918	23.689	5.771
13	17.568	22.706	5.138
14	17.717	21.788	4.071
15	17.669	22.843	5.174
16	17.168	19.421	2.253
17	17.020	18.818	1.798
18	16.523	15.934	-0.589
19	18.856	21.993	3.137
20	16.089	16.932	0.843

4.2.2.4 Checking the Vertical Accuracy of the elevation data derived from Google Earth Program

Testing the Global DEM using 20 points evenly distributed across the area of interest as shown in Figure (8) against vertical control points d precisely by total station data for the same 20 points, indicate that root mean square error (RMS) of elevations of the Global DEM have been computed using equation (2) **[6 and 7]** and were 1.84 m. The *min*. diff. is -0.000 m, The *max*. diff. is 3.460 m, the *mean* is 0.348 m and the *st.dev*. is 1.843 m. Table (4) shows the elevations of the interpolation elevation data derived from Google Earth Program and the ground vertical control points derived precisely by total station.

Table (4): Heights from the derived elevations from Google Earth program versus those from ground vertical control points

Point	Vertical Ground control points. (Z_G)	Interpolated G.E. DEM Elev. ($Z_{G.E.}$)	($Z_{G.E} - Z_G$)
1	16.883	15.686	-1.20
2	16.536	18.858	2.32
3	16.463	19.515	3.05
4	17.347	20.108	2.76
5	16.975	19.518	2.54
6	16.946	19.025	2.08
7	18.451	18.652	0.20
8	16.979	20.436	3.46
9	16.964	15.814	-1.15
10	17.204	16.482	-0.72
11	18.868	18.868	-0.00
12	17.918	17.453	-0.46
13	17.568	17.347	-0.22
14	17.717	15.873	-1.84
15	17.669	15.969	-1.70
16	17.168	13.951	-3.22
17	17.020	17.178	0.16
18	16.523	16.657	0.13
19	18.856	18.418	-0.44
20	16.089	17.284	1.20

5. Conclusion and Recommendations

The main objective of this research was evaluating the vertical accuracy of the free global DEMs SRTM, ASTER and elevation data derived from Google Earth Program especially in flat urban areas. From the results of the study, the following could be concluded:

- The RMSE shows that only Ground DEM were accepted to produce large scale maps of scale 1:2500 because its RMSE (0.16 m) is less than on half the contour interval 0.25 m .

- The Global DEMs can be used to produce medium scale contour maps of scale 1:25000 for elevation data derived from Google earth program and SRTM, and small scale contour maps of scale 1:50,000 for ASTER and these results are according to typical map scale and standards **[11]**, as shown in table (5).

Table (5): Typical Map Scales and Standards.

Scale	Contour Interval(m)	Horizontal accuracy(m)	Vertical accuracy(m)
1:1,000	**0.25**	**0.20**	**0.12**
1:2,500	**0.50**	**0.40**	**0.25**
1:5,000	**1.00**	**1.00**	**0.5**
1:10,000	**2.00**	**2.00**	**1.25**
1:25,000	**2.50**	**12.5**	**2.50**
1:50,000	**5.00**	**25.0**	**5.00**
1:100,000	**5 or 10**	**50.0**	**10.0**

- The RMSE of elevation data derived from Google Earth Program where more accurate than SRTM DEM because it uses higher resolution USGS DEMs for different areas. Also SRTM DEM was more accurate than ASTER DEM, the last result is the same as those obtained in a previous research **[12]**.

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