Accuracy Evaluation of Digital Elevation Model Created Using Handheld Global Positioning System Receivers

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ABSTRACT

This study aims to assess the accuracy of digital elevation model (DEM) created with utilization of handheld Global Positioning System (GPS) and comparing with Advanced Spaceborne Thermal Emission and Reflection Radiometer Global Digital Elevation Model (ASTER GDEM), version 2. It is known that the quality of the DEM is affected by both of accuracy of elevation at each pixel (absolute accuracy) and accuracy of presented morphology (relative accuracy). The University of Baghdad, Al Jadriya campus was selected as a study area to create and analysis the resulting DEM. Additionally, Geographic Information System (GIS) was used to visualize, analyses and interpolate GPS track points (elevation data) of the study area. In this research, three additional DEMs were created using 60%, 30% and 15% of the all GPS track points to deduce the effect of the number of the included points on the accuracy of the resulting DEM. The study findings show a high resolution for the resulting DEM less than 5m when taking into consideration all GPS tracking points that observed in this research. Moreover, the resulting DEM has relative accuracy better than absolute accuracy and reaches to around 2m. By comparing with ground control points (reference points), the quality of handheld GPS DEM shows considerable improvement better than ASTER GDEM. Thus, this study indicates to improve the accuracy level of handheld GPS DEM by about 40% with increasing the observed number of GPS track points to twice.

Key words: digital elevation model (DEM), handheld GPS, DEM accuracy

تقييم دقة نموذج الارتفاع الرقمي المنتج بأستخدام متسلمات نظام تحديد المواقع العالمية المحموله

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الخلاصة

تهدف هذه الدراسة إلى تقييم دقة نموذج الارتفاع الرقمي (DEM) الذي تم تكوينه باستخدام نظام تحديد المواقع المحمول (GPS) ومقارنتها مع نموذج الارتفاع الرقمي العالمي (ASTER GDEM) الاصدار الثاني. من المعروف ان جودة نموذج الارتفاع الرقمي تتأثر بكل من دقة الارتفاع الناتجة عند كل وحدة من وحدات الصورة (الدقة المطلقة) ودقة التشكل الظاهرة (الدقة النسبية). حيث تم اختيار جامعة بغداد/ الحرم الرئيسي في الجادرية كمنطقة دراسة لانشاء وتحليل نموذج الارتفاع الرقمي الناتج في هذة الدراسة. علاوة على ذلك تم استخدام نظام المعلومات الجغرافية (GIS) لغرض عرض وتحليل واستكمال نقاط مسار الـ GPS (بيانات المنسوب) الخاصة بمنطقة الدراسة. كما تم انشاء ثلاث نماذج للارتفاع الرقمي اضافية في هذة الدراسة باستخدام 60% و 30% و 15% من جميع نقاط مسار الـ GPS لاستنتاج تأثير عدد النقاط المضمنة على دقة نموذج الارتفاع الرقمي الناتجة. اظهرت نتائج هذة الدراسة دقة عالية لنموذج الارتفاع الرقمي المنشأ الذي استخدم جميع نقاط مسار الـ GPS اقل من 5 متر. علاوة على ذلك، ان نموذج الارتفاع الرقمي المكون له دقة نسبية افضل من الدقة المطلقة وتصل الى حوالي 2 متر. كما اظهرت جودة نموذج الارتفاع الرقمي للـ GPS المحمول تحسنا ملحوظا عما هو علية في الـ

ASTER GDEM وذلك عن طريق المقارنـة مـع نقاط الضـبط الارضـية (النقـاط المرجعيـة). كمـا اشـارت هذة الدراسـة الـى تحسن مستوى نموذج الارتفاع الرقمي للـ GPS المحمول بنحو حوالي 40% مع زيـادة عدد نقـاط مسـار الــ GPS المرصـوده الى الضعف.

الكلمات الرئيسية: نموذج الارتفاع الرقمي، نظام تحديد المواقع المحمول، دقة نموذج الارتفاع الرقمي

1. INTRODUCTION

Digital elevation models play an important part for several applications such as hydrologic analysis, land use, landslide monitoring and others. Some of these applications require high accuracy of DEM despite of the cost such as planning of dam area and drainage channel networks. Where, high resolution DEM less than 30m does not freely available for most of the world’s regions **Srivastava and Mondal, 2012**. Data of freely available DEM provide varied ground parameters (e.g. Earth's relief, slope and aspect of terrain) to be utilized for 3 dimensional modeling and geospatial analysis. For example, the most common freely available DEM are the Advanced Spaceborne. Thermal Emission and Reflection Radiometer Global Digital Elevation Model (ASTER GDEM, 30m resolution) and the Shuttle Radar Topography Mission (SRTM, 90m resolution). Additionally, several techniques were adopted for DEM production with different level of accuracy such as traditional field survey, photogrammetry, and laser scanning, **Suganthi and Srinivasan, 2010**. Where, traditional survey techniques such as leveling surveys and total stations are utilized for DEM generation with high accuracy for civil engineering project, however its cost comparing with other techniques, **Farah, 2008**. It is known that a geodetic GPS receivers are used for positioning with centimeters/ millimeters level of accuracy (depending on the length of baselines), while positioning accuracy of handheld GPS receivers reach to about a few meters. By Wide Area Augmentation System (WAAS) enabled the positioning accuracy of handheld GPS increases to about 3 meters based on WAAS correction for broadcast signal, **Fry, et al., 2015**. Thus, the objectives of this research were to (1 assess the accuracy of DEM which created based on handheld GPS, (2 develop a high resolution DEM (less than 5m) based on low cost GPS, (3 compare the resolution of freely available DEM (ASTER GDEM) with the resulting DEM of this study.

2. DEM STRUCTURE AND INTERPOLATION TECHNIQUE

Digital Elevation Models (DEMs) represent data files that include the elevation of the earth’s surface for a specified area. Digital elevation data are obtainable in variety formats that consist of Digital Terrain Models (DTM), Digital Surface Models (DSM), and Triangulated Irregular Network (TIN).The difference between a DTM and a DSM is that a DSM represents the ground surface and includes all objects on it whereas a DTM represents the earth’s surface without any objects like building and trees, **De Sawal, 1996**. DEM can be created based on two main sources using interpolation method. The first is the traditional ground surveying (e.g. level, theodolite, and GPS). While, remotely sensed surveying, e.g. satellite image and laser scan, is the second source. After the data collection step, DEM generation needs to interpolation technique (whatever the data collection size). This technique is applied for determining the unknown values for certain locations based on the known values for another points (all points in DEM generation area become known data), **Carlisle, 2002**. Geographic Information System (GIS) is a tool widely used to visualize, manage, integrate, and analyze large quantities of spatial data. There are several interpolation methods available in GIS such as inverse distance weighting (IDW), ordinary kriging (KG), and spline with tension (ST). Most studies showed that kriging is more superiority by comparing with the other methods, **Erdogan, 2009; Svobodová, 2011; and**

Arun 2013. Thus, Kriging is a geo statistical interpolation which based on the spatial distribution of data instead of real values.

3. STUDY AREA AND FIELDWORK DESCRIPTION

In this study, Baghdad University Campus and Al Nahrain University were selected as the study area. The selected area located in the Iraqi, Baghdad, Al Jadriyah on geographic coordinates 33° 16' 20" to the North and 44° 22' 44" to the East (as shown in Fig. 1). The dimensions of the observed region of this study area are approximately 0.8 km in the East-West direction and 1 km in the North-South direction. Regarding this study, fieldwork was accomplished in two stages. From 5 - 17 April 2015, handheld GPS units (2 Garmin eTrex units) as shown in Fig. 3-A, were used to gather elevation of GPS track points (by rate three thousand points per day) for the DEM creation of the interested area as the first stage. GPS track points, which amounted to over thirty-seven thousand points, were distributed to cover all the selected area by arbitrary tracks as shown in Fig. 2 (red points). In the fieldwork of the first stage, the two handheld GPS receivers were set to receive the signal of Wide Area Augmentation System (WAAS). WAAS delivers signal corrections to enhance point positioning accuracy of GPS receivers, **Andreea, 2011; and Donghai et al. 1998**. For the period 18 - 28 April 2015, one hundred fifty two ground control points, which shown as a yellow points in Fig. 2, were created in obvious and specified sites of the study area, and represent the second stage of the fieldwork. Where, Differential Global Positioning System (DGPS) technique using two GR5 receivers, shown in Fig. 3-B, was used to observe these control points, which utilized for evaluating the accuracy of the resulting DEM.

4. DEM CREATION AND ACCURACY ASSESSMENT

In this study, spatial data for both of handheld receivers and geodetic receivers were used to construct DEM and assess its accuracy. Spatial data of GPS was visualized, analyzed and interpolated using Geographic Information System (GIS) **Bussink, 2003 and Salih, and AL-Tarif, 2012**. Thus, the created DEM based on GPS track points was implemented through several stages in GIS. Firstly, GPS points were reviewed and edited for filtering and removing the blunders. This filtering was applied manually by comparing GPS points with data for both of fieldwork and satellite image of the study area. In the second stage, initial DEM for the study area was created based on interpolation method. This interpolation for GPS points was applied using ordinary kriging, which deduces values for unobserved locations based on advanced statistical method **Svobodová, and Tuček, 2009 and Muhsin 2013**. Re-filtering was performed for the initial DEM in the third step. Thus, GPS points, which have elevation values significantly different from the neighboring points, were edited to represent the real terrain as it appeared in field data. Finally, interpolation of ordinary kriging was again achieved to obtain the final DEM of the study area. Moreover, GPS ground control points were considered as reference points (RP) to assess the accuracy for both of ASTER Global DEM (ASTER GDEM) and handheld GPS DEM (HGPS DEM). The absolute accuracy of the resulting DEM can be computed using the root mean square error (RMSE). The RMSE values were computed for the resulting DEMs (ASTER GDEM and HGPS DEM) relative to the reference points DEM (RP DEM) as shown in Eq. (1), **Jenson and Domingue, 1988 and Wechsler and Kroll, 2006**. .

$$\mathrm{RMSE} = \sqrt{\frac{\sum(\mathrm{Ei}-\mathrm{Et})}{\mathrm{n}}} \quad (1)$$

where Ei is the elevation of the interpolated DEM, Et is the reference elevation (RP DEM) , and n is the number of RP. Furthermore, the relative accuracy of DEM also can be computed in addition to the absolute accuracy. Where, the relative accuracy, which is elevation difference for sample of point pairs, was calculated using the following equation, **Bhakar, et al., 2010 and Gu, et al., 2014**:

$$\text{Relative accuracy} = |\text{Dif}_{\text{RP}} - \text{Dif}_{\text{DEM}}| \quad (2)$$

where Dif_{RP} refers to the elevation difference between RP point pairs and Dif_{DEM} refers to the elevation difference between the interpolated DEM point pairs. Additionally, accuracy assessment of DEM is also based on the value of spatial resolution which can be determined by the following spatial equation **Chirico, et al., 2012**:

$$\text{Average spatial resolution} = \sqrt{\frac{\text{D}}{\text{N}}} \quad (3)$$

where D stands for the dimension of the study area, which used to create DEM, and N stands for the number of observed GPS track points. Thus, the quality of a DEM is determined based on the level for both of absolute accuracy and relative accuracy (accuracy of morphology presented). Where, several factors significantly impact on quality of interpolated DEM, **Sulebak, 2000; Guo-an, et al., 2001 and Ashraf, et al., 2012**:

- Earth surface roughness,
- collected data density,
- resulted resolution,
- and interpolation method.

5. RESULTS AND DISCUSSION

In this study, DEM with spatial resolution less than 5m were developed using handheld GPS (low cost GPS) for the study area (Baghdad University) as shown in **Fig. 4** (yellow grid). On the other hand, the open source data (free available DEM) do not provide DEM at this resolution such as ASTER GDEM, which has resolution equals to 30 m, as shown in **Fig. 4** (red grid). Thus, results of this study showed that DEM which created by handheld GPS has high resolution and closer to the reference DEM (ground control points DEM) than open source DEM (ASTER GDEM), see **Fig. 5**. It is worth to mentioning that accuracy of handheld GPS observations was inhomogeneous due to constant changing in both of number and geometry of satellite that observed by the limited scope of handheld GPS. Therefore, the procedure of filtering by GIS, which applied in this study, plays an important factor to improve the accuracy of this resulting DEM (HGPS DEM). Where, the yellow grid in **Fig.4** represents the DEM production based on the collected GPS track points (up to 37000 points) which input to GIS tool as individual shapefile. Thus, the points of this shapefile were interpolated after applying the visualizing and the filtering procedures to get high resolution DEM for the specific region. Moreover, the red grid **(Fig.4)** refers to ASTER GDEM grid which freely uploaded from internet and input to GIS with another shapefile. Meanwhile, ASTER GDEM showed lower resolution than HGPS DEM by over 6 times. Moreover, the significant variation between the reference DEM and ASTER GDEM can be noted in **Fig.5**. In contrary, this Figure shows magnitude similarity between DEM of handheld GPS and DEM of reference points in terms of values of elevation and their distribution pattern in the study area. Additionally, the diagram for both of elevations and difference elevations, which were obtained from DEMS (RP DEM, HGPS DEM and ASTER GDEM), were presented in **Fig. 6**. Regarding the outcome of this study, the root mean square error, which refers to absolute accuracy, for the HGPS DEM is 3.07 m. Where, the ASTER GDEM has root mean square error more than HGPS DEM by over 5 times as shown in **Table 1**, which also presented the values of minimum and maximum difference elevation. In this study, the relationship between the number of GPS track points and the accuracy of resulted DEM was deduced. Where, all GPS track points (up to 37000 points) were reduced to three groups by 60%, 30% and 15% to create three additional DEMs. Thus, accuracy assessment values for the 4 DEMs, which created from either all points or reduced points, were computed depending on each of absolute accuracy, relative accuracy and spatial resolution (shown in **Table 2**). In **Table 2**, it can be noted that the relative accuracy value was significantly lower for all the DEMs than the absolute accuracy. Where, the interest of the relative accuracy is represented by obtaining earth surface parameters such as aspect and slope that depend on differences between elevation points. Regarding **Table 2**, it is noticeable an increase values for each of relative accuracy, absolute accuracy and spatial resolution by reducing the number of GPS track points. For example, DEM for a 50% reduction results in a 2 m increase in spatial resolution. Thus, the number of the observed GPS track points can be determined based on a required spatial resolution and project budget (time and availability of personnel).

6. CONCLUSION

Results of this study showed the ability to generate high resolution DEM, which reached to about 4 m, using low cost GPS that associated with GIS analysis (filtering and interpolation technique) based on the satellite image of the study area and ancillary field data. Additionally, created DEMs using this technique have more certainty for relative elevation accuracy than absolute elevation accuracy. Thus, this procedure provides considerable utility for obtaining earth parameters that rely on elevation difference of points such as earth surface relief, terrain depth, and determination of cut/fill volume. Moreover, ASTER GDEM (freely available DEM) showed lower accuracy than handheld GPS DEM by about 5 times. This study suggests that the quality of the resulting DEM can be improved by increasing the observed number of GPS track points, which determined depending on the required accuracy and the budget of the project.

REFERENCES

- Andreea, B. U., 2011, *Considerations on the Development of Geodetic Network by Classical and GPS Methods*, Agricultura, agricultural practice and science journal, Vol.77, PP.230-234.

- Arun, P.V., 2013, *A Comparative Analysis of Different DEM Interpolation Method*, The Egyptian Journal of Remote Sensing and Space Sciences, Vol.16, PP.133-139.

- Ashraf, A., Ahmad, M.M., and Iqbal, M.B., 2012, *Quality Assessment of Digital Elevation Models in Comparison with Global Positioning Data of a Stream Profile in Dera Ismail Khan,* Vol.49, No.2, PP.131-138.

- Bhakar, R., Srivastav, S. K., and Punia, M., 2010, *Assessment of the Relative Accuracy of ASTER and SRTM Digital Elevation Models Along Irrigation Channel Banks of Indira Gandhi Canal Project Area, Rajasthan,* Journal of Water & Land-use Management, Vol.10, No.1-2, PP.1-11.
- Bussink, C., 2003, *GIS as a Tool in Participatory Natural Resource Management: Examples from the Peruvian Ande,* Mountain research and development, Vol.23, No.4, PP.320-323.

- Carlisle, B. H., 2002, *Digital Elevation Model Quality and Uncertainty in DEM-Based Spatial Modelling,* DISS. University of Greenwich.

- Chirico, P., Malpeli, K., and Trimble, S. (2012). *Accuracy Evaluation of an ASTER Derived Global Digital Elevation Model (GDEM) Version 1 and Version 2 for Two Sites in Western Africa."*GIS Science & Remote Sensing, 49,775–801.

- De Sawal, R., 1996, *Digital Elevation Data and GIS projects,* In Third International Conference/Workshop on Integrating GIS and Environmental Modeling, University of California.

- Donghai Dai, Walter, T., Enge, P., and Powell, J.D, 1998, *Optimal Use of Ionospheric Corrections for Wide Area Augmentation System (WAAS) Users [GPS],* in Position Location and Navigation Symposium, IEEE 1998 , pp.358-365, 20-23.
- Erdogan, S., 2009, *A Comparison of Interpolation Methods for Producing Digital Elevation Models at the Field Scale,* Earth Surface Processes and Landforms, Vol.34, PP.366–376.
- Farah, A., 2008, *Accuracy assessment of Digital Elevation Models using GPS,* artificial satellites, Vol.43, No.4, PP.151-161.

- Fry, M., Ponette-González, A. G., and Young, K. R., 2015, *A Low-Cost GPS-Based Protocol to Create High-Resolution Digital Elevation Models for Remote Mountain Areas,* Mountain Research and Development, Vol.35, No.1, PP.39-48.

- Guo-an, T., Strobl, J., Jian-ya, G., Mu-dan, Z., and Zhen-Jiang, C., 2001, *Evaluation on the Accuracy of Digital Elevation Model,* Journal of Geographical Sciences, Vol.11, No.2, PP.209-216.

- Gu, Y., Wu, X., and Wang, J., 2014*, A Simplification Method of Terrain Modeling Based on Spatial-Autocorrelation,* International Journal of Multimedia & Ubiquitous Engineering, Vol.9, No.5, PP.185-194.

- Jenson, S.K., and Domingue, J.O., 1988, *Extracting Topographic Structure from Digital Elevation Data for Geographic Cartosat1*, International Journal of Geomatics and Geosciences, Vol.1, No.1, PP.41-50.

- Muhsin, I.J., 2013, *High Spatial Resolution Digital Elevation Model (DEM) Production Using Different Interpolations Techniques,* Iraqi Journal of Physics, Vol.11, No.21, PP.116-126.

- Suganthi, S., and Srinivasan, K., 2010, *Digital Elevation Model Generation and its Application in Landslide Studies Using Information System Analysis*, Photogrammetric Engineering and Remote Sensing Vol.54, No.1593-1600.

- Salih, S.A., and AL-Tarif, A.M., 2012, *Using of GIS Spatial Analyses to Study the Selected Location for Dam Reservoir on Wadi Al-Jirnaf, West of Shirqat Area, Iraq,* Journal of Geographic Information System, Vol.4, PP.117-127.

- Srivastava, V. K., and Mondal, K., 2012, March, *Evaluation of Digital Elevation Models (DEMs) generated from ASTER and SRTM Data: a Case Study of Flat Alluvium Terrain of Bakreshwar-Dubrajpur (WB), India,* in Recent Advances in Information Technology (RAIT), 2012 1st International Conference on (pp. 666-671). IEEE.

- Sulebak, J. R., 2000, *Applications of Digital Elevation Models*, DYNAMAP Project, 11.

- Svobodová, J., and Tuček, P., 2009, *Creation of DEM by Kriging Method and Evaluation of the Results,* Geomorphologia Slovaca et Bohemica, Vol.9, No.1, PP.53-60

- Svobodová, J., 2011, *Selection of Appropriate Interpolation Methods for Creation DEMs of various Types of Relief by Complex Approach to Assessment of DEMs,* GIS Ostrava.

- Wechsler, S. P., and Kroll, C. N., 2006, *Quantifying DEM Uncertainty and its Effect on Topographic Parameters,* Photogrammetric Engineering & Remote Sensing, Vol.72, No.9, PP.1081-1090.

Table1. Summary of the mean error and range of elevations from resulting DEMs.

Resulting DEM	Maximum elevation difference (m)	Minimum elevation difference (m)	Root mean square error, RMSE (m)

HGPS DEM	3.05	0.20	3.07
ASTER GDEM	17.17	1.3	16.11

Table2. Accuracy results for the 4 interpolated DEMs based on the number of GPS track points.

HGPS DEMs	**GPS points**	**Spatial resolution (m)**	**Absolute accuracy (RMSE,m)**	**Relative accuracy**
HGPS DEM	37875	4.5	3.0	2.1
HGPS DEM (50%)	18938	6.5	4.0	3.2
HGPS DEM (30%)	11362	8.4	4.8	3.7
HGPS DEM (15%)	5681	11.9	5.2	4.3

Figure 1. Study area, Baghdad and Al Nahrain Campus University.

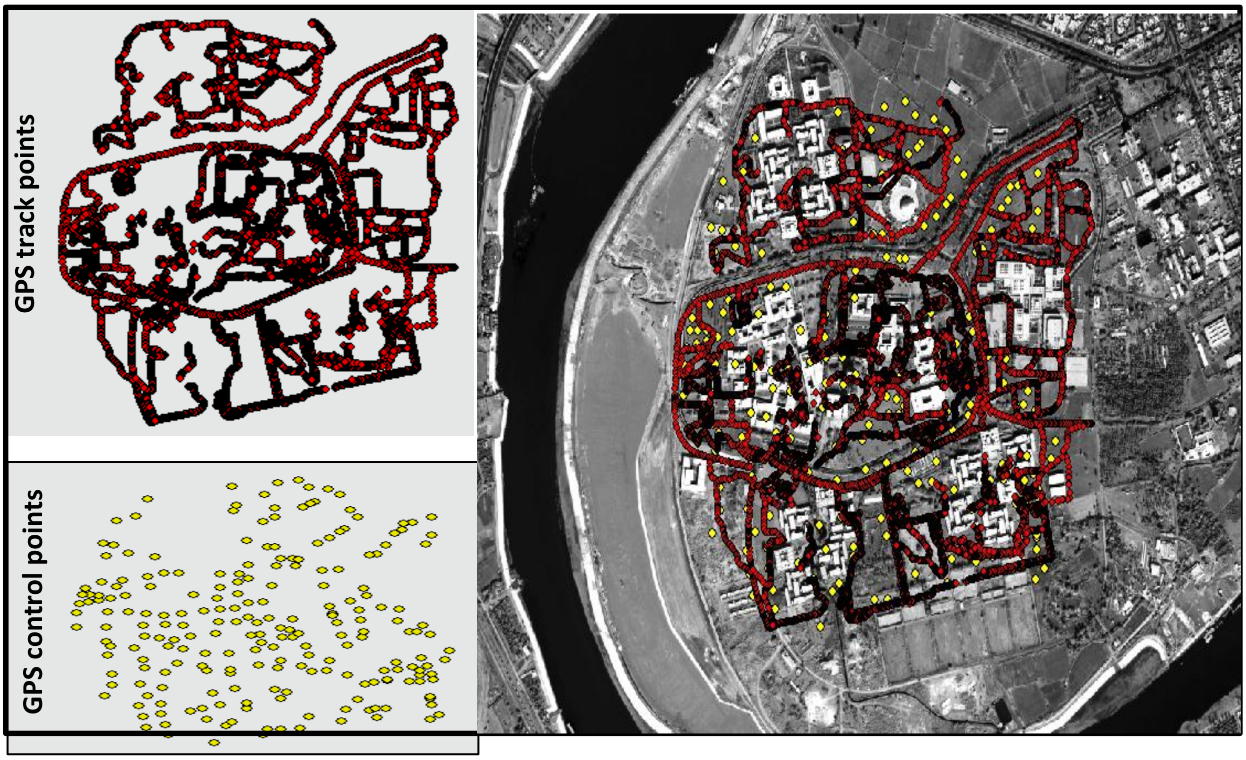

Figure 2. The distribution of points which included both of control points and GPS track points.

Figure 3. The distribution of points which included both of control points and GPS track points.

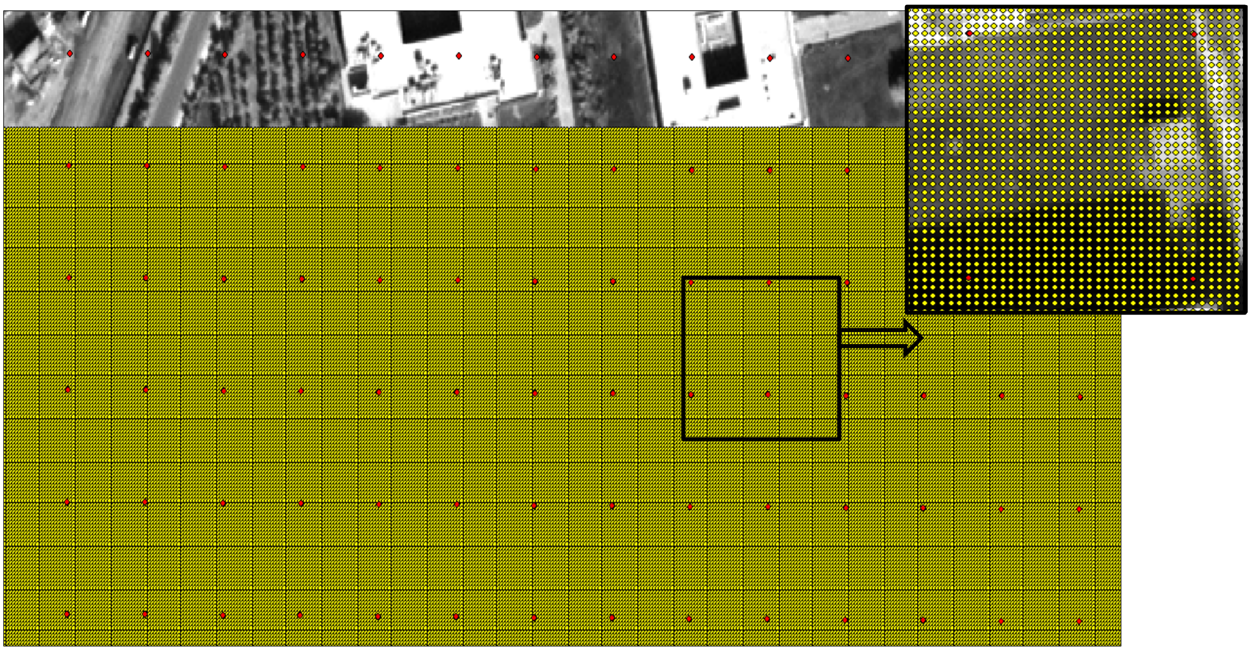

Figure 4. DEM grid production utilizing handheld GPS and ASTER GDEM.

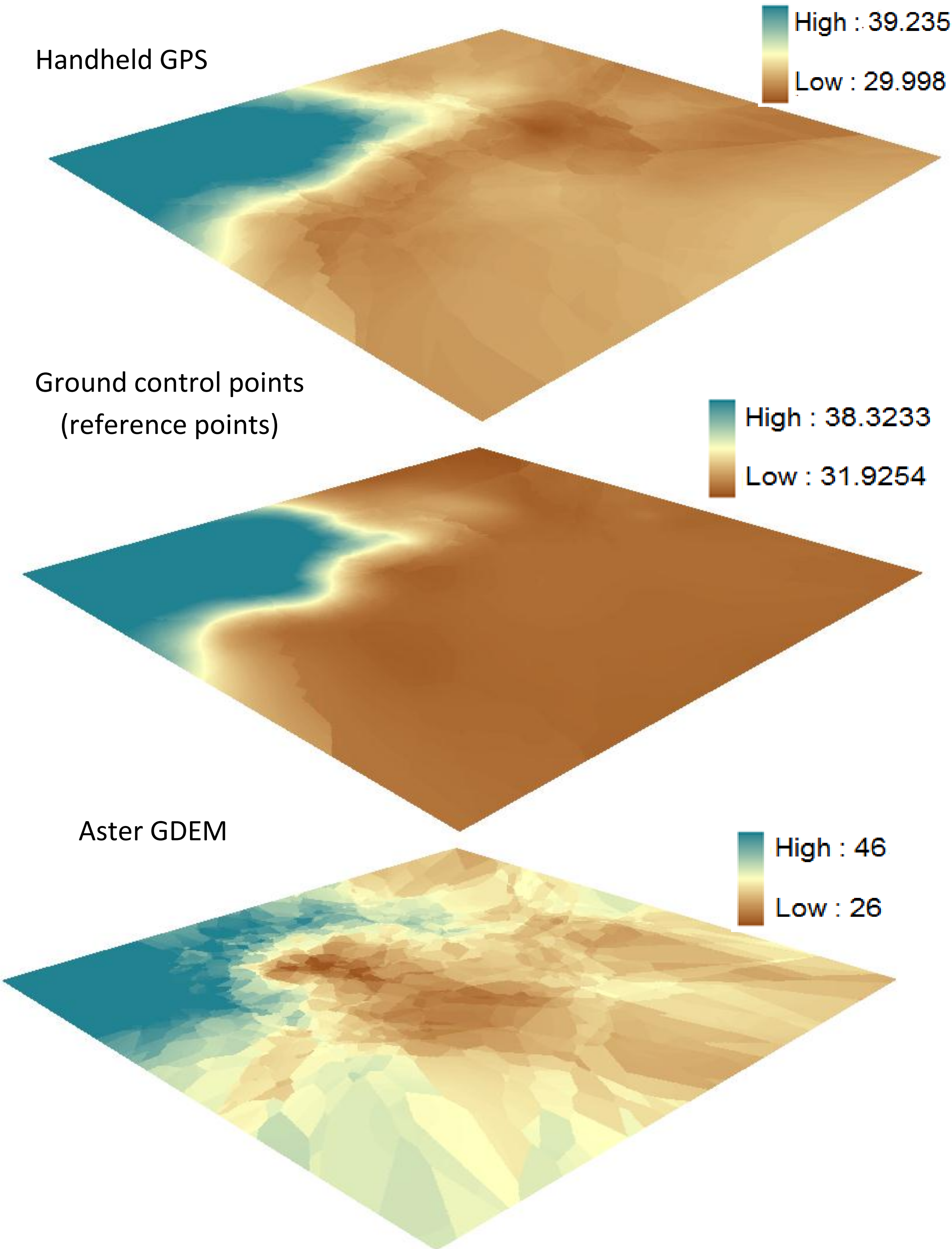

Figure 5. Created DEM using each of handheld GPS, ground control points and Aster GDEM.

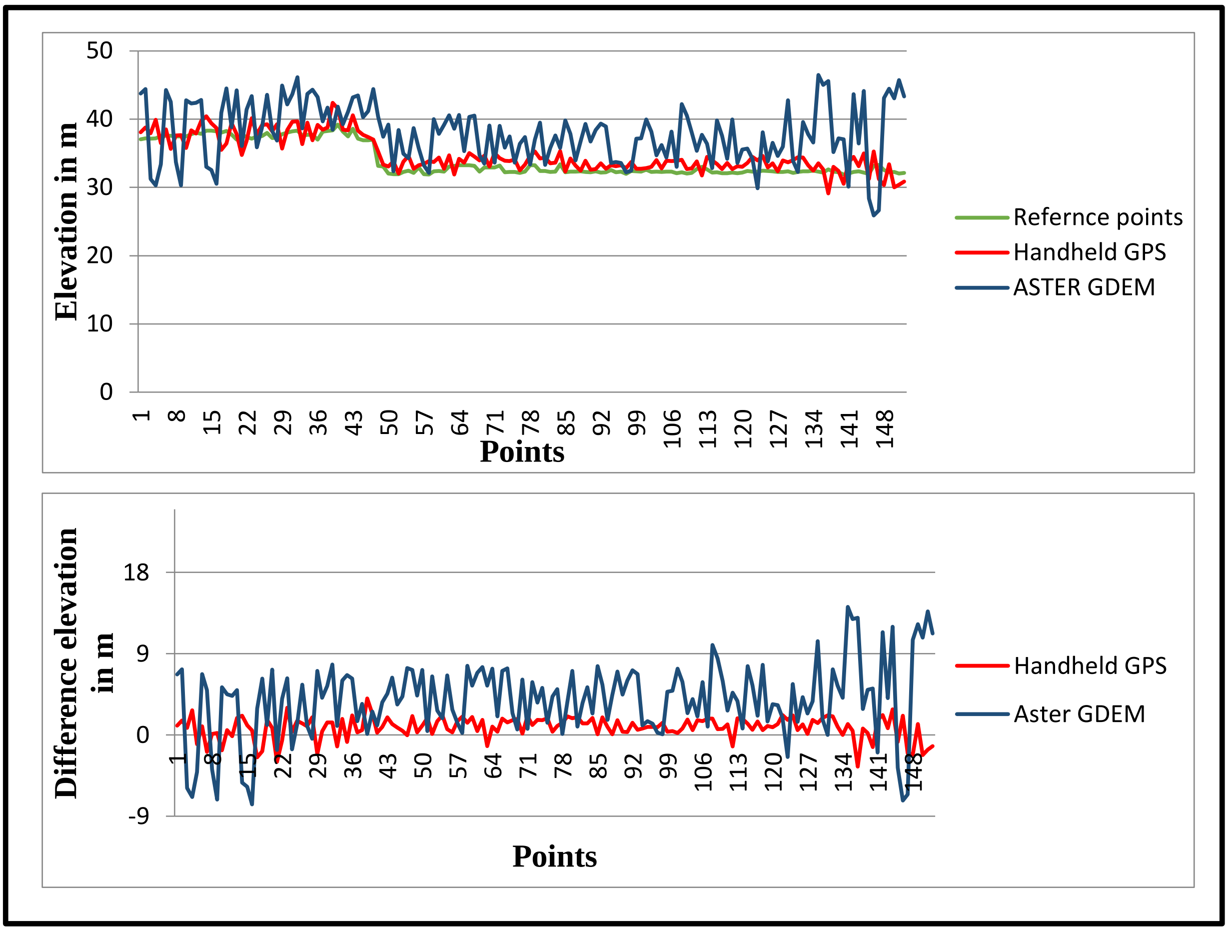

Figure 6. Comparison of elevation and difference elevation for the resulting DEMs.