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A Methodology for Checking the Validity of an Existing Contour Map Using RTK-GPS and GIS

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Abstract: This paper presents a methodology for checking the validity of the height information of an existing contour map using RTK-GPS measurements and GIS analysis. In particular, 3D profiles were measured in the field by RTK-GPS. The same 3D profiles were extracted from a scanned and geo-referenced contour map using GIS. The height information from the two data sets of 3D profiles were compared in the absolute and relative sense. This comparison reveals two aspects about the two data sets. First, the two data sets from the RTK-GPS measurements and the existing maps are very similar in terms of shape, which suggest that both of them they capture the same underlying trend of the topography. Second, the maximum relative *RMSE* is $\pm$ 0.939 m in the first 3D profile that goes from the west to the east. The relative *RMSE* is a very important measure since it does not depend on the changes that may happened to the vertical datum (benchmark). These two findings leave us with two options. First, to accept the existing contour map; and this acceptance should be judged in light of the overall requirements and the design criteria of the project. For example, a global compensation can be made to accommodate the maximum variation in the topographic surface for an irrigation project. This compensation does not give any information about the local variation of the topography that may impact, for instance, a pivot irrigation design. Second, to redo the survey work. Indeed, both options are associated with obvious and hidden risks that may not be trivial during the design stage of the project. The first option can be accepted on the basis of a global compensation parameters that will be obtained from the comparison tests. And the second option will come with an instantaneous financial burden.

***Keywords**: Existing Contour Map; Validation; RTK-GPS; GIS*.

1. INTRODUCTION

Validation of existing topographic data and contour maps is a common practice in survey work [1]. Real-Time-Kinematic Differential GPS (RTK-DGPS or RTK-GPS) is a rapid surveying technology for precise 3D topographic mapping that can be used to generate the contour maps and height information for engineering and agricultural projects [2]. A typical use of RTK-GPS for topographic mapping gives an accuracy of $\pm$2 cm in the horizontal coordinates and $\pm$3 cm in the vertical coordinates, which can satisfy the practical needs and demands of several types of projects. The overall objective of this paper is to layout practical guidelines and a cost-effective methodology for the validation of the height values of an existing contour map.

In this work, RTK-GPS was used to verify the correctness and the consistency of an existing contour map that was obtained from a previous survey. The notion of correctness is mainly related to the idea of absolute comparison; and the consistency is related to the idea of relative comparison. Both notions capture different aspects of the compared data sets.

The existing topographic map belongs to a location that is known as Area 1 in this project. Area 1 covers an area of 20,000 Feddans.

This paper is organized as follows. Section two gives the general outlines of the approach that was used to develop the proposed methodology. Section three presents the elements of the proposed methodology. Section four outlines the description of the data sets that were used for the validation process. Section five provides the discussion for the results and analysis. Section six concludes the paper and offers some recommendations.

2. PROPOSED APPROACH FOR CHECKING

The checking approach for this work is based on measuring several 3D profiles in Area 1 using RTK-GPS. The measured profiles by RTK-GPS will be compared with their counterparts from the existing contour map; and conclusions will be drawn from the results of this comparison. This type of comparison will be called the absolute check. As indicated

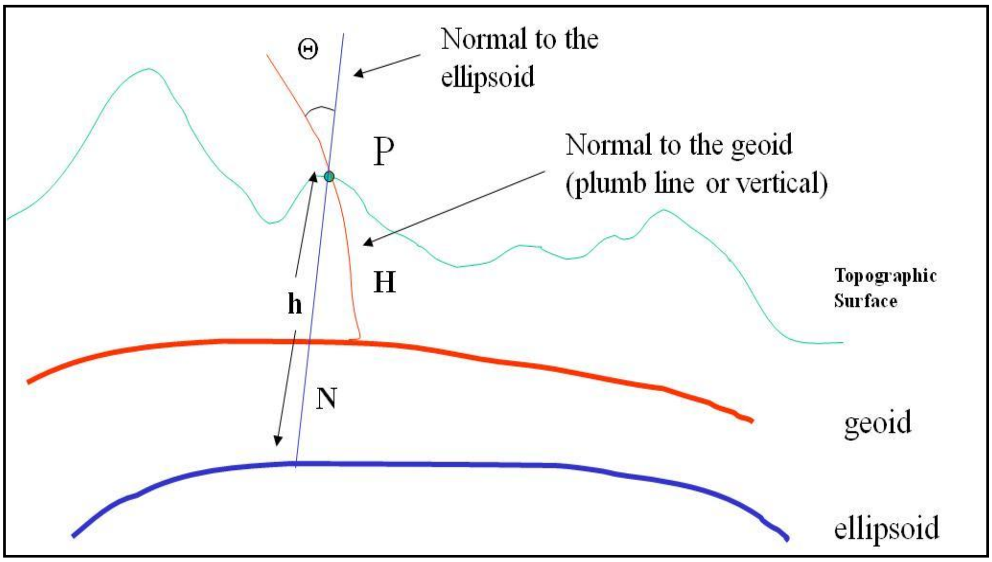

Fig. 1. Geoid-Ellipsoid relationship

in the paper's version of the contour map, the height information is based on the Mean-Sea-Level (MSL). In other words, they are orthometric heights (H). As is well known, the height information of GPS is based on a mathematical figure of the Earth or the ellipsoidal heights [3]. The distance between the ellipsoidal height and the orthometric height is called the geoid separation (N) (see Fig. 1). Therefore, the height information of the RTK-GPS (h) measurements should related to an existing benchmark to account for the geoid separation problem. This is an approximate solution for the geoid separation problem in this particular project, but it is good enough for this type of application since practical findings confirms that its accuracy is within a range of few centimetres.

To build more confidence in the validation process, a second checking approach was developed that considers the typical problems that may be induced by the vertical reference datum (benchmark) such as the settlement of the physical monument of the benchmark and the interpolation issues of the contour lines and the measured profiles by RTK-GPS. This approach was called the relative check. In light of these problems, absolute and relative comparisons will be conducted since they provide complementary understanding of the underlying similarities and differences between the two data sets.

The absolute comparison will be based on a direct subtraction between the elevation values from the two data sets (RTK-GPS profiles & existing map). As stated, the absolute comparison gives implicit information about the physical stability of the benchmarks and the hidden assumptions that were made during their establishment and measurements. On the other hand, the relative comparison consists of two steps. First, the relative height difference between each pair of points in each data set will be computed. Second, the height difference that belong to the same pair of points or line segment in both data sets will be computed. The relative comparison will neutralize the effects of the vertical datum (benchmark) in terms of physical stability and gives more convincing idea about the validity of the existing contour map in some sort of a local reference system. In both comparisons, the Root-Mean-Square Error (RMSE)

will be used as an indicator for the overall accuracy between the two data sets. It should be noted that one of the critical parameter that governs the accuracy of the contour map is the grid size or the spatial resolution of measurement. The grid size or the terrain sampling governs the level of topographic details or information that controls the overall accuracy of the contour map as well as the comparison with different sources of data. In flat terrain a large grid size can be used; and in a highly undulated terrain a smaller one should be used. In all grid sizes, the golden principles of surveying measurement should be considered, which states that "measurements should be taken at the changes of the terrain slope".

3. METHODOLOGY

The proposed approach in the previous section is detailed by the following methodology:

a. Convert the exiting paper's map for Area 1 into digital format by scanning. A very high resolution setting was used during the scanning process to avoid any confusion during the data extraction by the GIS software.
b. Geo-referensing of the scanned map in ArcGIS 10.2 using the given ground coordinates of its corner points.
c. Setting of the base-station of the RTK-GPS over a known benchmark. This setting will automatically account for the geoid separation problem in the vicinity of the project area.
d. Measurement of 3D profiles in the field using RTK-GPS.
e. Overlay the 3D profiles that were obtained from the RTK-GPS measurements on the top of the scanned contour map using ArcGIS. Practically, this overlay creates a set of intersection's points between the 3D profiles from the RTK-GPS and the contour lines.
f. Measure the height information from the contour lines that were shown in the scanned map at the intersection points with the RTK-GPS profiles. This step generates a list or a table of coordinates that have the 2D coordinates

(Easting, Northing) and the height information from the contour map and the RTK-GPS.

g. Compare the height information that will be measured from the RTK-GPS with their counterparts that will be obtained from the previous step. As stated, absolute and relative comparisons will be conducted. In the absolute comparison, the elevation values from the RTK-GPS, which will be related to the existing benchmark, will be subtracted from their counterparts that will be obtained from the existing map (see Equation 1). The RMSE for the absolute comparison will be computed by equation 2. Equations 3 to 6 explain the computational procedure of the relative comparison.

$$\Delta Elevation_i = Elevation_{RTK-GPS} - Elevation_{Existing\_map} \quad (1)$$

$\Delta Elevation_i$: Difference in elevation between two points.

$$RMSE_{Absolute} = \sqrt{\frac{\sum_{i=1}^{i=n} (\Delta Elevation_i)^2}{n}} \quad (2)$$

$$\Delta H\_RTK-GPS_{i+1\&i} = Elevation_{i+1} - Elevation_i \quad (3)$$

$\Delta H\_RTK-GPS_{i+1\&i}$: Difference in elevation between two points in the same data set (RTK-GPS).

$$\Delta H\_Existing-Maps_{i+1\&i} = Elevation_{i+1} - Elevation_i \quad (4)$$

$\Delta H\_Existing-Maps_{i+1\&i}$: Difference in elevation between two points in the same data set (map).

$$\Delta H_j = \Delta H\_RTK-GPS_j - \Delta H\_Existing-Maps_j \quad (5)$$

ΔH_j : The difference between Equations (3) and (4).

$$RMSE_{Relative} = \sqrt{\frac{\sum_{j=1}^{j=n} (\Delta H_j)^2}{n}} \quad (6)$$

4. DATA SETS FOR VALIDATION

Fig. 2 shows part of the scanned map for Area 1 that was used for the validation process in this project. This part of the map covers an area of 40.32 km^2 or 9596 Feddans. This area represents about 50% of the total area of the project under investigation. The red points in Figure 2 belong to the first 3D profile and their values from the RTK-GPS and the existing maps were shown in Table 1. The green points in Figure 2 belong to the second 3D profile and their values from the RTK-GPS and the existing maps were shown in Table 2. The length of the first profile is 6.35 km and the second one is 6.33 km. The elevation values from the existing maps in Tables 1 and 2 were measured very closely, by GIS digitization, at the intersection of the contour lines with the 3D points from the RTK-GPS profiles in order to avoid unnecessary interpolation between the contour lines and the measured profiles.

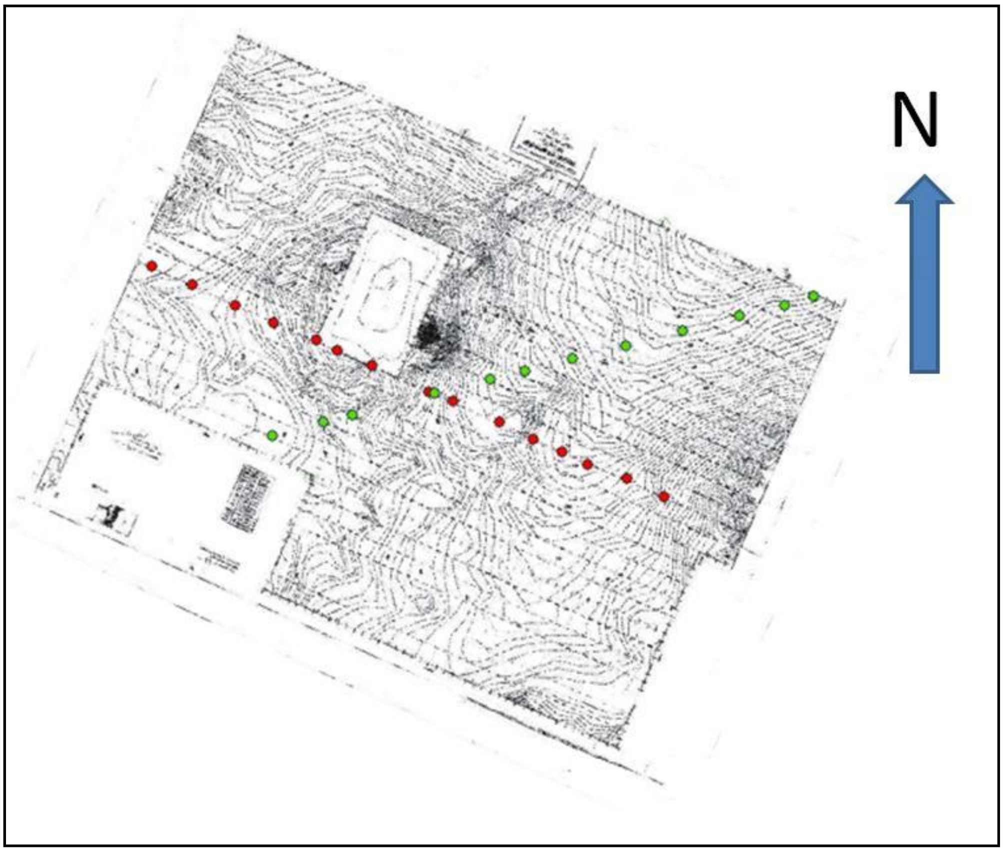

Fig. 2. The red and green points show the location of points along 3D profiles in Area 1

Table 1. 3D points for the first profile

Point Id	Northing (m)	Easting (m)	Elevation(RTK-GPS): (m)	Elevation (Existing Map): (m)
206	1940579.800	574062.615	382.429	382.358
215	1940365.145	574525.512	383.876	383.408
224	1940134.811	575013.998	384.654	384.352
232	1939940.324	575445.924	385.633	385.292
241	1939746.336	575928.677	388.289	388.617
246	1939628.962	576162.655	389.568	390.684
254	1939460.016	576553.506	387.323	386.627
267	1939151.907	577205.248	382.715	381.261
272	1939042.549	577471.603	381.381	380.690
282	1938805.939	577997.279	379.975	380.774
290	1938618.187	578381.572	378.774	377.808
296	1938469.831	578712.901	377.545	376.959
302	1938331.270	579000.314	377.482	376.981
310	1938162.778	579446.211	378.054	378.062
318	1937959.292	579861.486	379.936	378.988

Table 2. 3D points for the second profile

Point Id	Northing (m)	Easting (m)	Elevation(RTK-GPS): (m)	Elevation(Existing Map): (m)
632	1938658.189	575425.553	384.157	383.884
621	1938807.625	576013.854	385.114	385.643
615	1938892.099	576338.132	386.261	386.074
597	1939143.596	577270.822	382.325	382.107
372	1939292.963	577889.566	379.702	379.268
580	1939391.089	578294.979	378.791	377.890
571	1939527.375	578819.751	376.880	376.345
560	1939674.436	579429.666	374.958	374.109
548	1939848.648	580069.099	373.815	373.420
536	1940011.813	580711.718	373.731	373.471
526	1940138.785	581231.674	374.488	373.709
494	1940246.914	581548.240	374.061	373.354

5. RESULTS AND DISCUSSION

Figs 3 and 4 show the plot of the elevation values from the RTK-GPS and their counterparts from the existing map. Both figures show a very high degree of similarity in terms of shape and indeed with very observable deviations in both of them. In fact, for some part of the two shape are very similar as well as very close to each other. **Figs 5 and 6** show the plot of deviations from the two profiles. Both deviation values were fitted to the equation of the straight line to give a quantitative measure for the degree of regularity in the deviations. Very low R^2 value (0.0532) was obtained for the first 3D profile, which suggests that these deviations are not systematic and cannot be explained by one linear transformational model to account for the discrepancies between the two data sets. Although the R^2 for the second 3D profile (0.3679) is relatively high, it cannot be used to suggest any regularity in the deviations for the second 3D profile. The RMSE for the absolute and relative comparisons for the first 3D profile are ± 0.723 m and ± 0.939 m respectively. The first value (± 0.723 m) suggests a datum problem and the second one (± 0.939 m) suggests an irregularity problem between the two data sets. Similarly, The RMSE for the absolute and relative comparisons for the second 3D profile are ± 0.561 m and ± 0.424 m respectively. Both values offer similar suggestions as explained for the first profile, but with a less degree of irregularity as indicated by a larger value of R^2.

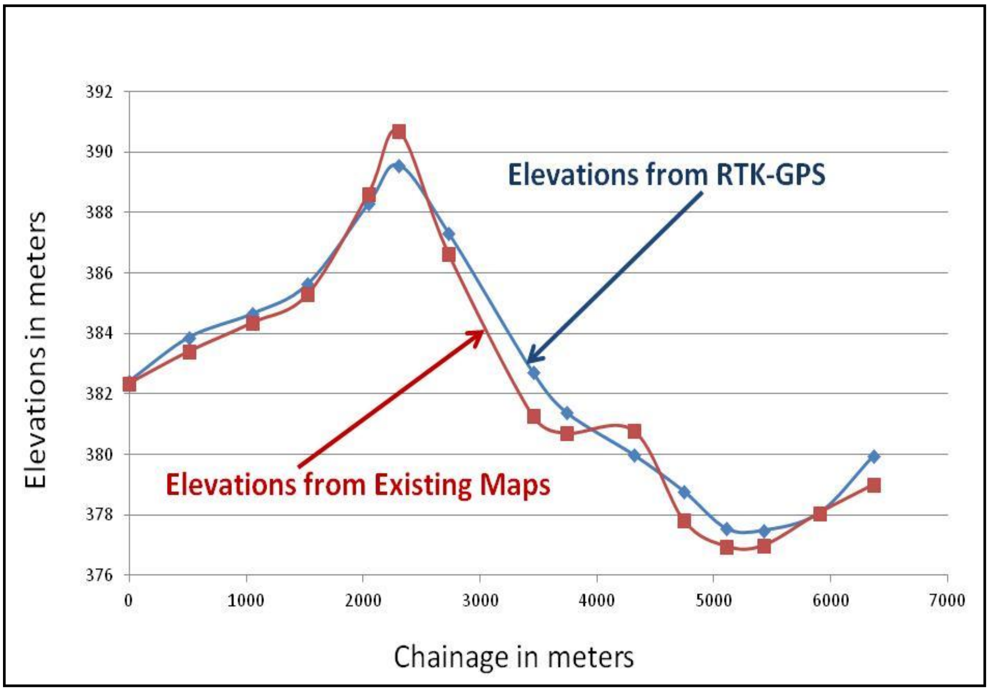

Fig. 3. Plot of the first 3D profile (red color in Fig 1)

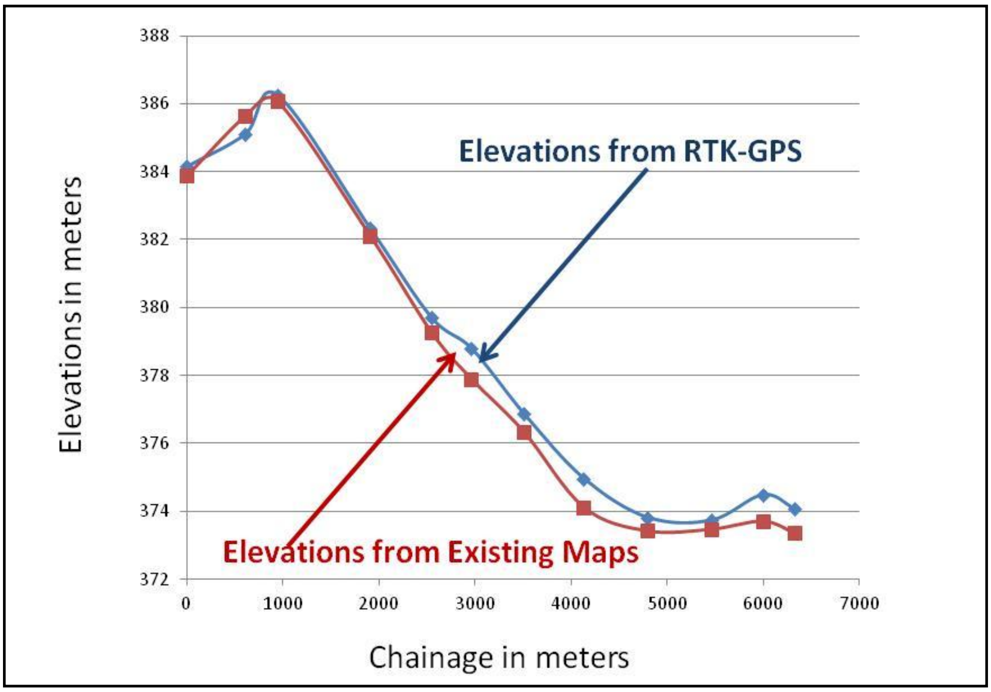

Fig. 4. Plot of the second 3D profile (green color in Fig. 1)

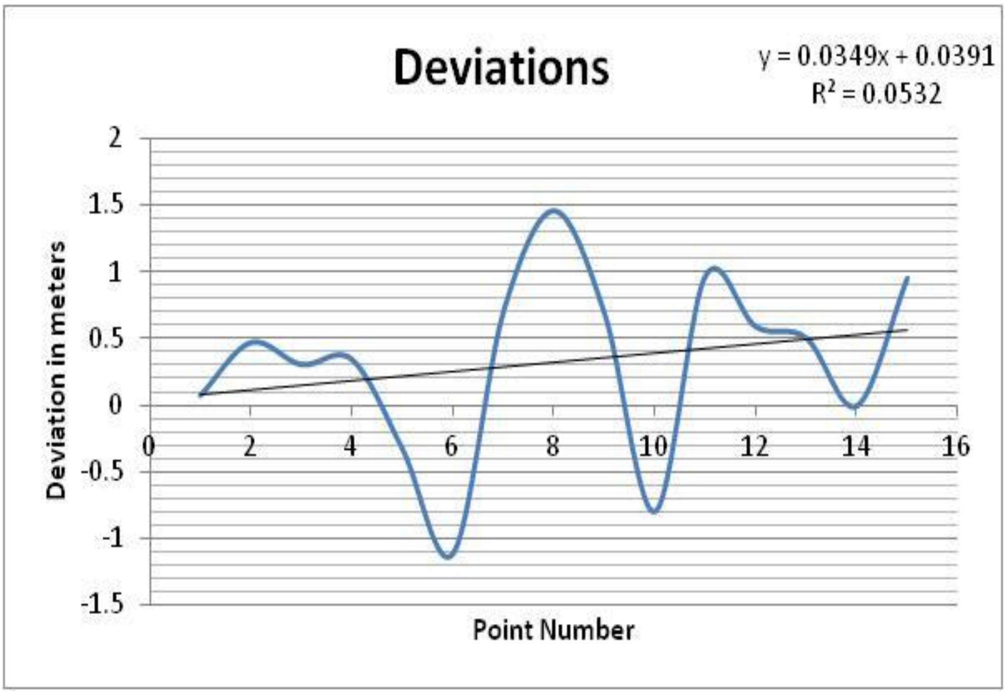

Fig. 5. Deviation values between the RTK-GPS elevations and their counterparts from the existing maps for the first 3D profile.

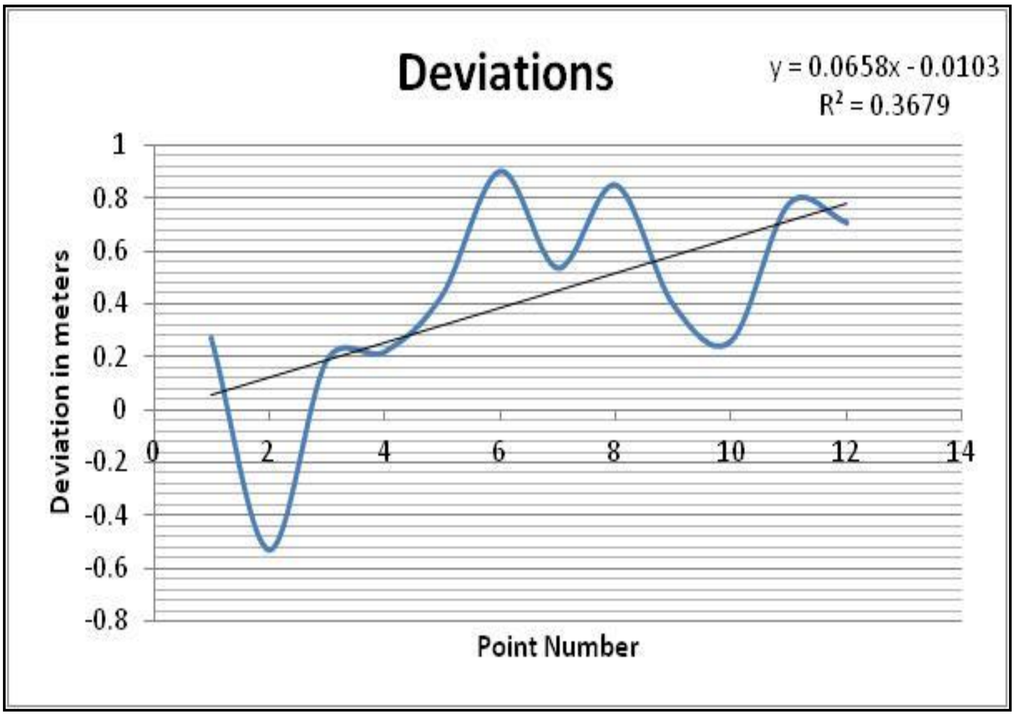

Fig. 6. Deviation values between the RTK-GPS elevations and their counterparts from the existing maps for the second 3D profile

6. CONCLUSIONS

The overall objective of this paper is to present a set of practical guidelines and a cost-effective methodology to validate the results of an existing contour map. The main findings of this work are two aspects. First, the two data sets from the RTK-GPS and the existing map are very similar in terms of shape. Second, the maximum relative RMSE is $\pm$ 0.939 m in the first profile that goes from the west to the east. These findings leave us with two options. First, to accept the existing contour map; and this acceptance should be judged in light of the overall requirements and design criteria of the project. Global compensation can be made by raising the water head of the booster station and/or the pump station. This option does not give information about the local variation of the topography. Second, to redo the survey work for Area 1. The developed methodology has a wide range of applications such as checking the existing contour maps for irrigation projects, storm-water drainage system, and routes evaluation.

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