

Evaluation Study of GNSS Technology and Traditional Surveying in DEM Generation and Volumes Estimation

Youssef Sh. Abd-elqader¹, Prof. DR. Essam M. Fawaz², and Dr. Ahmed M. Hamdy³

¹Master student at Department of Civil Engineer, Faculty of Engineering, Al-Azhar University, Cairo, Egypt.

²Prof. of Surveying and Geodesy, Faculty of Engineering, Al-Azhar University, Cairo, Egypt.

³Lecturer at Department of Civil Engineer, Faculty of Engineering, Al-Azhar University, Cairo, Egypt

Correspondence Author: Youssef Sh. Abd-elqader, Department of Civil Engineer, Faculty of Engineering, Al-Azhar University, Cairo, Egypt.
E-mail: yosefshaaban79@gmail.com

Received date: 22 September 2020, **Accepted date:** 28 November 2020, **Online date:** 12 December 2020

Copyright: © 2020 Youssef Sh. Abd-elqader et al, this is an open-access article distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited.

Abstract

Usage of digital surveying equipment, including Total Station (TS) and Global Navigation Satellite System (GNSS), is an essential part of the development of the human environment for so many decades. While new technologies are increasingly used, the total station remains a critical instrument for observing. A total station (TS) or total station theodolite (TST) is an electronic/optical system used for surveying and construction. Furthermore, the Global Navigation Satellite System (GNSS) is an advanced surveying system, provides reliable positioning navigation and timing services with global coverage. GNSS technology uses two main techniques for collecting observations, which are static and Kinematic techniques. The most effective method in the process of DEM generation is the GNSS Kinematic technique. Digital elevation model (DEM) is a 3D computer graphics representation of a terrain's surface; it applied to a large variety of civil engineering and military planning tasks. This paper presents a comparative study of three surveying methods; GNSS-RTK, Stop-and-go GNSS, and total station with precise leveling technique for DEM generation and earthwork volumes estimation. Findings revealed that a DEM derived by the total station has the highest precision with an RMSE error of 3.4 cm. While the RMSE of DEM generated from RTK and Stop-and-go GNSS are 5.2cm, 11.9 cm, respectively. Regarding earthwork estimation, the results show that Total Station is following very close to the accuracy of Level where the percentage of difference in volumes between Total and Level at elevations (274m, 275m, and 276m) is (4.70%, 13.43%, 2.12%) respectively

Keywords: DEM, RTK, Stop-and-go, GNSS, Total Station, Level, Earthworks.

INTRODUCTION

A Digital Elevation Model (DEM) refers to the digital representation of the topography or terrain with various accuracies for different fields of application (Farah, A. et al., 2008). DEMs had implemented for a wide range of civil engineering and military planning tasks, including Planning of transportation, analyze of communication network, Navigation, City, and region planning, Determination of radar cover area, Digital orthophoto map production, etc. (Yilmaz, I. et al., 2006).

In the process of DEM generation, many techniques and approaches with varying accuracies were used, like the photogrammetric method, airborne laser scanning, and topographic surveys (Halim, S. M. A. et al., 2019). DEM generation using radar interferometry (INSAR) is now the best possible alternative and popular medium for large and unavailable areas (Hilton, R. D. et al., 2003).

Usage of digital surveying equipment, including total station (TS) and Global Navigation Satellite System (GNSS), is a significant part of the development of the human environment for so many decades (Chekole, S. D., 2014). While new technologies used increasingly, total station—the integration of a theodolite and an Electronic Distance Meter (EDM)—remains a critical instrument for observing. A total station (TS) or total station theodolite (TST) is an electronic/optical system used for surveying and construction. It is an integrated electrical transit theodolite (EDM), designed to calculate both vertical and horizontal angles and slope distances from a certain point on the slope, and an on-board device for collecting data and measuring triangulation (Kavanagh, B. F., & Bird, S. J., 1992). Furthermore, the Global Navigation

Satellite System (GNSS) is a satellite-based radio-navigation and positioning system that provides reliable positioning navigation and timing services (Mansour, M. A., 2006). The GNSS was dramatically developed in the last decades and is used widely in scientific research and engineering applications (Gao et al., 2016). Positioning using (Global Navigation Satellite Systems [GNSS]) increases the number of satellites observed that have multiple benefits, such as enhancing accuracy and dilution (DOP) values (Cai, C., & Gao, Y., 2013). There are today four GNSS systems: 1) the American NAVSTAR GPS, 2) the Russian Globalnaya Sputnikovaya, 18 the Sistema, 3) the European (Galileo), and 4) the Chinese (BeiDou) respectively. But only GPS and GLONASS have been fully operating until 2019 (Abdallah et al., 2020).

GNSS technology provides an efficient tool for producing DEMs, particularly for developing countries due to its accuracy and cost-effectiveness (El-Mowafy, A., 2000). GNSS technology uses two main methods for collecting observations, static and Kinematic techniques. The most effective system in the process of DEM generation is the GNSS Kinematic technique.

There are three types of Kinematic survey:

- Stop-and-go GNSS.
- Continuous (kinematic) GNSS surveying.
- RTK GNSS.

In the Stop-and-go technique, the rover receiver moves between unknown points and makes a short stop at each one to collect GNSS data (El-shewy, M. A., 2016). During Kinematic surveys, the rover unit will move around the site, observing the same satellites as the base station. This kind of survey provides a high co-ordinate generation rate at the cost of less precision than static methods. The algorithms used in Kinematic surveys rely on the fact that while the rover can move around, the site should never lose lock on the satellite signal. The techniques and algorithms used in Kinematic surveys also can be used in post-processing. Real-Time Kinematic Surveys use the same methods and algorithms as Kinematic surveys with the exception that these algorithms run in real-time on the rover units. A permanent communication link between the base station and the rover is necessary for this type of survey.

According to the accuracy of these techniques, during an experimental work (Farah, A. et al., 2008) tested the accuracy of Kinematic GNSS and found it typically to be 0.03 to 0.05 meters, while the RMSE value of DEM generated by Stop-and-go GNSS and Kinematic techniques are 9.70 cm and 12.00 cm, respectively. (Edwards, S. J. et al., 2010) examined that the accuracy of using the RTK GPS technique is typically 10-20 mm in horizontal control and 15-30 mm in vertical control. Other work by (Aponte, J. et al., 2009) confirmed that the accuracy of RTK is within centimeters.

(Chekole, S. D., 2014) the thesis evaluates and compares precision, accuracy, and time expenditure of Total Station and GPS. To investigate this task, a reference network consisted of 14 control points has been measured five times with Leica 1201 Total Station and served as a reference value for comparison with RTK measurements. The reference network points were calculated five times with the GPS RTK method to compare accuracy, precision, and time expenditure with that of Total Station. The reference network points calculated with Total Station determined with 1 mm precision for both horizontal and vertical coordinates. The obtained results indicated that; when using the RTK method on the same reference network points, 9 mm in horizontal and 1.5 cm accuracy in vertical coordinates has achieved. The RTK measurements, which were measured five times, determined with a maximum standard deviation of 8 mm and 1.5 cm for horizontal and vertical coordinates. The precision of the remaining control points is below these levels.

Nowadays, GNSS is used widely in construction engineering for computing volumes, which is one part of engineering surveying. Estimating earthworks can be used almost in all kinds of constructions and infrastructures such as buildings, highways, dams, and tunnels. One of the major engineering works is earthworks estimation. Usually, estimating earthwork has to pass through two stages, gathering data and determination of figuring volumes. Data can be collected using different surveying technologies, for instance, field leveling operations, total station, Global Positioning System (GPS), and lasers scanning. These technologies have made the work easier and data collected quickly. (ZAIYA, Y. et al., 2017).

Therefore, the likelihood of this paper is to assess and compare the three techniques GNSS- RTK, Stop-and-go GNSS, and total station with level for DEM generation and earthwork volumes estimation.

TESTED AREA AND MEASUREMENTS

The area of this study locates in Madinaty City, Cairo, Egypt: an area of about 18000 square meters on Cairo-Suez road. The study area was divided into 165 points in addition to two control points (CP1, CP2). Table (1) shows the coordinates of point CP1 and CP2.

Table 1: Control points coordinates.

Point ID	East (m)	North (m)	Orthometric Height (m)
CP1	368089.773	3327762.849	278.498
CP2	368127.482	3327720.167	280.873

Three instruments were used to survey the study area as follows:

- ✓ Level SOKKIA JAPAN (C3-30/D103).
- ✓ Total Station SOKKIA (CX-105)
- ✓ GNSS (RTK & Stop-and-go) Techniques /SOKKIA GRX2 GNSS system.

Level Measurements:

Level SOKKIA JAPAN (C3-30/D103) occupied the benchmark CP2 to determine the appropriate scale for observing the field area. The data obtained by level was used as reference data in the comparison. The process of collecting observations took about 240 minutes. The precise leveling observations were performed from known high precision benchmarks based on the national vertical datum of Egypt.

Total Station Measurements:

Using Total Station SOKKIA (CX-105), the points CP1 and CP2 were linked to the Total Station network to survey the area. The observations of Total Station were obtained for 165 points to be able to compare between the Level heights and Total Station heights. The period to collect data for the 165 points was about 150 minutes.

GNSS Measurements

GNSS RTK Technique:

To collect information by RTK-GPS: the SOKKIA GRX2 GNSS system was used. The reference receiver occupied the benchmark CP2 during the collecting observations process. To ensure centimeter-level accuracy: the bar executed an initialization process for 20 minutes. The distances between the survey points were from 9m to 11m. The time occupied by the observer during collecting observations for the chosen 165 points was about 120 minutes. Every single point takes between 5-10 seconds. The value of PDOP was between 2 - 3.50. The number of tracked GPS satellites was 15 satellites.

GNSS Stop-and-go Technique:

During the collecting observations process -using the Stop-and-go technique/ SOKKIA GRX2 GNSS system - the reference receiver sited on CP2 point. For 10 minutes, the bar exceeded an initialization process. The time occupied by the observer during collecting observations for the 165 points was about 180 minutes. In the rover receiver, the recording time was 15 seconds. The value of PDOP was between 1.5–2.5, and the number of tracked GNSS satellites was 15 satellites.



Figure 1: Study area on Google Earth

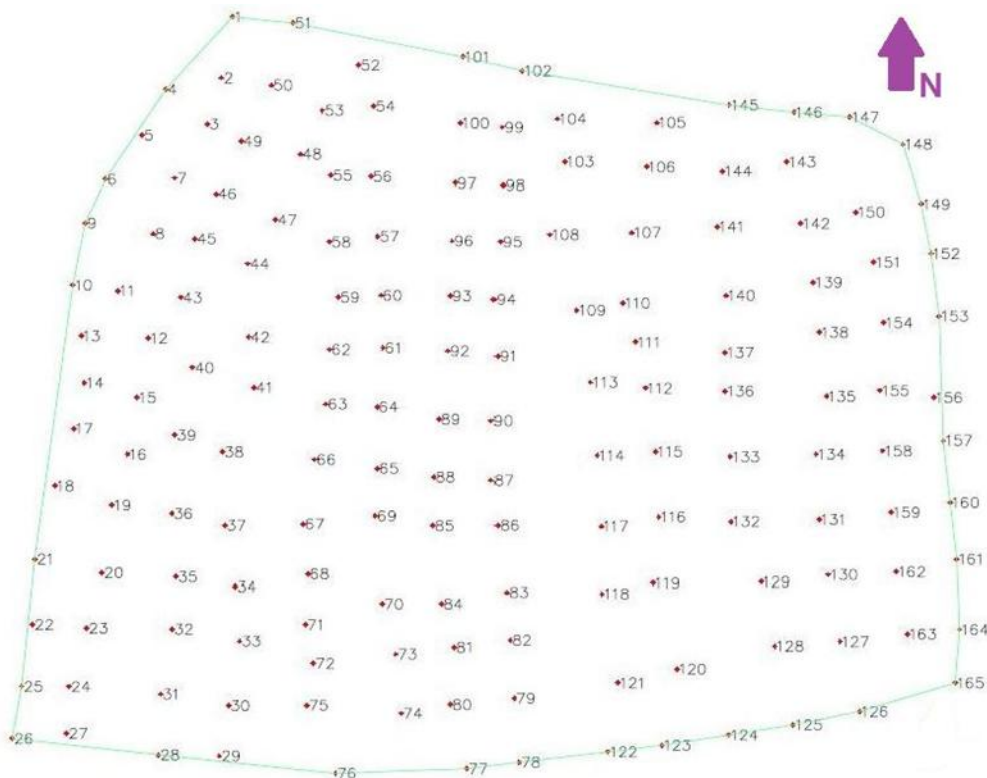


Figure 2: Plan of the study area.

EVALUATION OF ELEVATIONS FROM DIFFERENT METHODS:

The elevations of the 165 points computed using three different instruments; Level, Total station, and GNSS (RTK & Stop-and-go). The obtained heights from RTK, Stop-and-go, and Total station are compared to the obtained elevations via a precise leveling technique to show the differences. Table (2) shows some statistical analysis.

RMSE computed using the following formula: (Abdallah, A., 2009)

$$RMSE = \sqrt{\frac{1}{n} \sum_{i=1}^n (v')^2} \quad (1)$$

Where:

RMSE is the Root Mean Square Error.

v' = $(M - Mo)$ the residual error of observation.

M is any measurement.

Mo is the true value of measurement.

n numbers of measurements

Table 2: Obtained differences in elevation profiles from the different methods

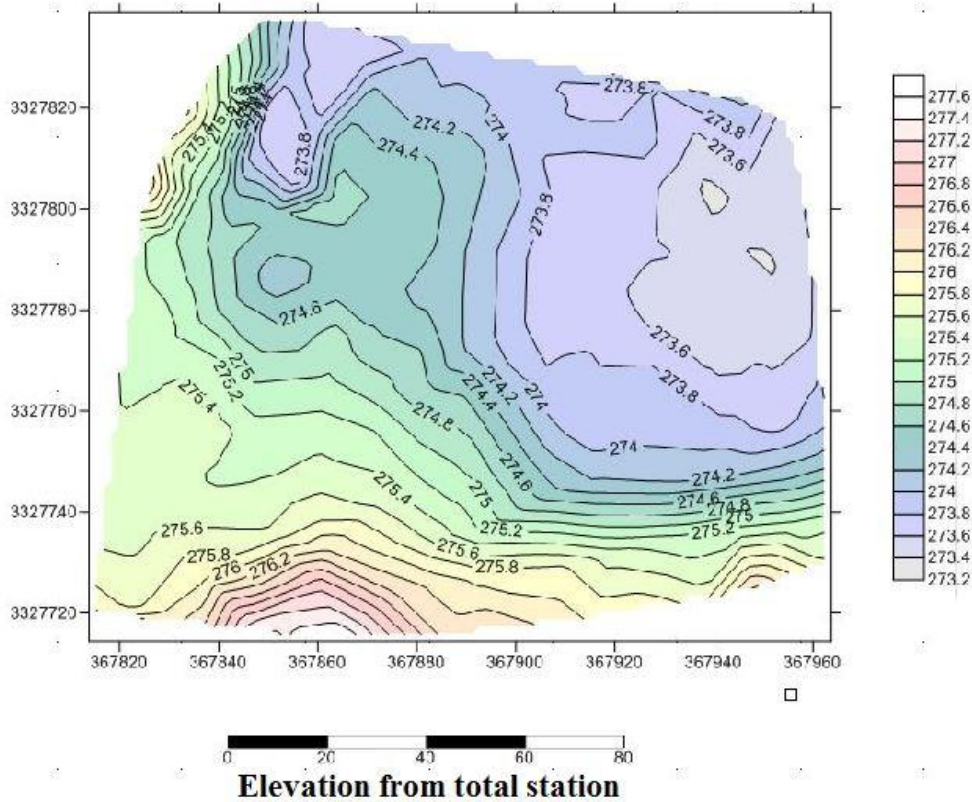
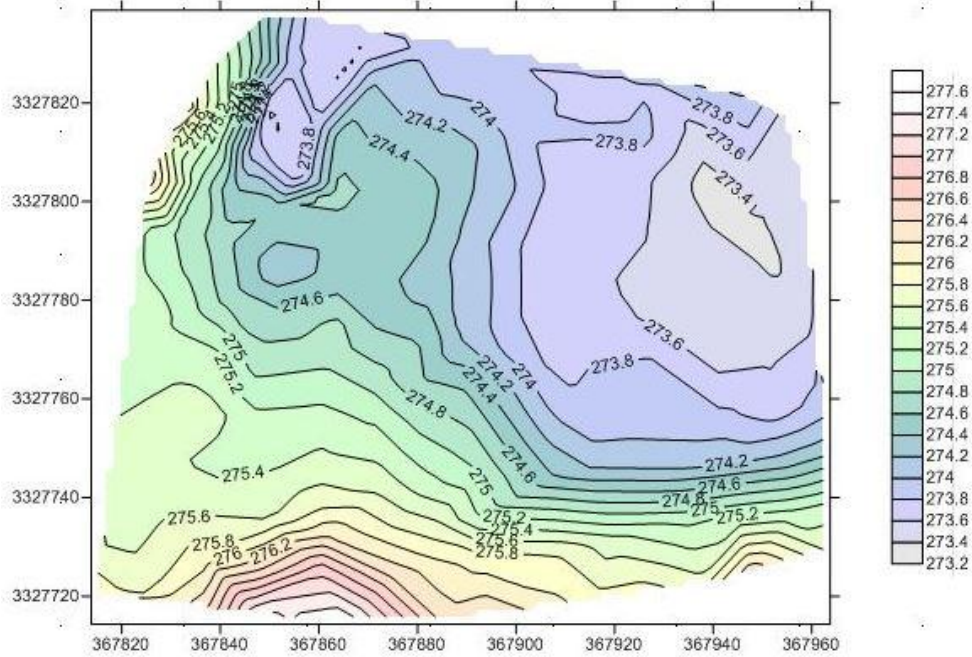
Technique	Max. height difference (cm)	Min. height difference (cm)	Mean(cm)	RMSE height difference (cm)
Total	7.4	-9.4	2.87	3.4
RTK	10	-3.9	4.95	5.2
Stop-and-go	32	-5.1	8.2	11.9

From table (2), we can notice that:

- The RMSE value of the RTK technique (5.2cm) is smaller than the Stop-and-go GNSS technique (11.9cm), while the total station presents the smallest RMSE value (3.4 cm).
- The maximum value of difference for the RTK (10 cm) is smaller than the Stop-and-go technique (32cm), while the Total Station presents the smallest maximum value of the difference (7.4 cm).
- The minimum value of difference for the Stop-and-go technique (-5.1 cm) is smaller than the RTK technique (-3.9 cm), while Total Station presents the smallest minimum value of the difference (-9.4 cm).

EVALUATING CONTOUR MAPS FROM DIFFERENT METHODS:

Four contour maps were created using surfer 10 package and Civil 3D as follow in Fig. (3)



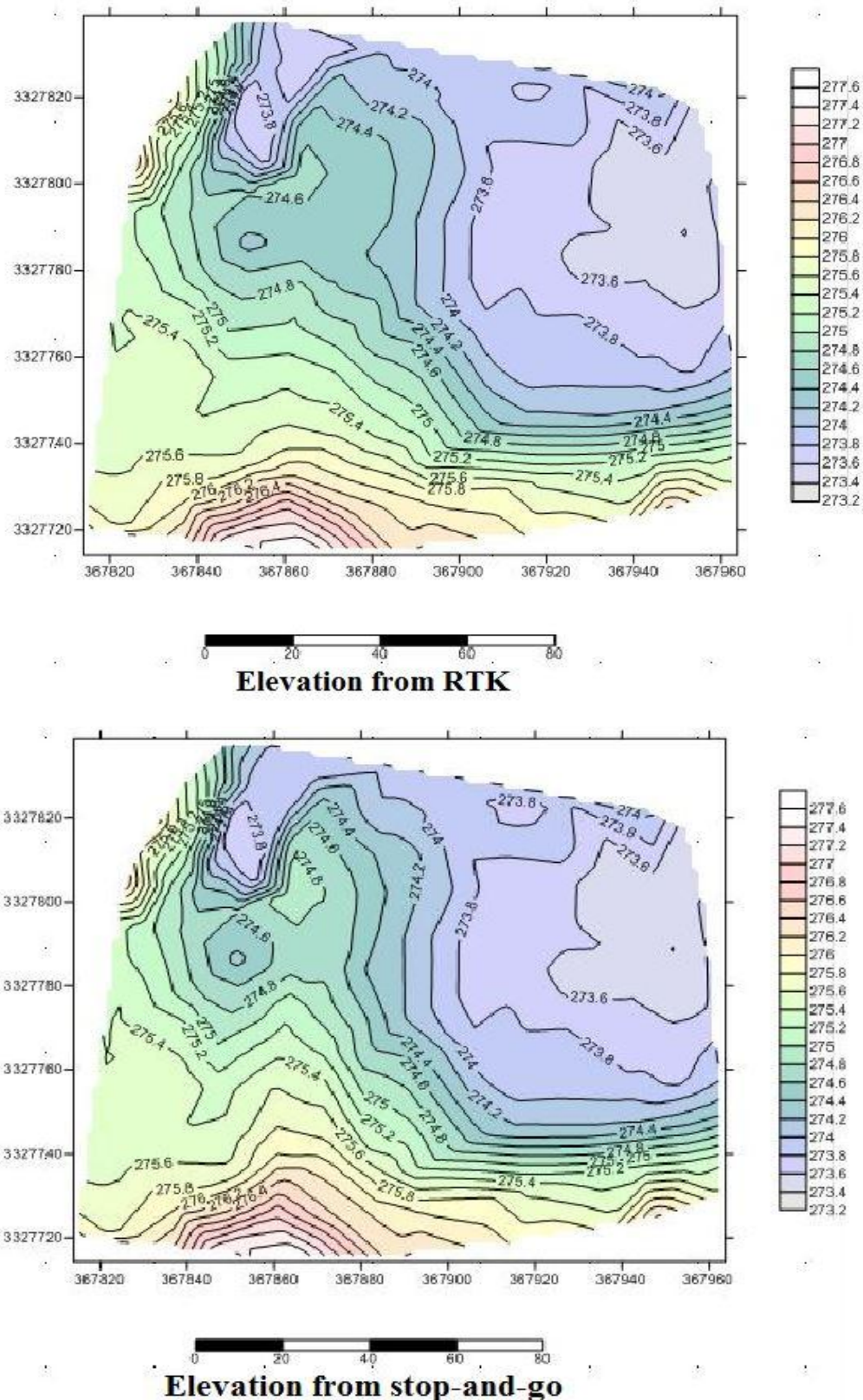


Figure 3: Contour lines from Level, Total station, RTK and Stop-and-go techniques.

EVALUATE THE EARTHWORK FROM DIFFERENT METHODS:

Using CIVIL 3D software, the fill and cut volumes for the tested area computed at levels 274 m, 275 m, and 276 m. Table (3) shows cut and fill Volumes estimated by the three different methods in comparison with Level.

Table 3: Volumes of Earthworks.

Elevation	Volumes	Level	Total Station	RTK	Stop-and-go
274 m	Cut m ³	11143.245	11453.173	11671.001	12159.134
	Fill m ³	1548.429	1407.655	1293.376	1282.518
	Net m ³	9594.816	10045.518	10377.625	10876.616
275 m	Cut m ³	3489.496	3777.818	3777.818	4018.469
	Fill m ³	9319.101	8824.615	8824.615	8566.276
	Net m ³	-5829.606	-5046.797	-5046.796	-4547.806
276 m	Cut m ³	489.335	527.390	547.205	587.682
	Fill m ³	21743.363	21330.716	21018.424	20559.910
	Net m ³	-21254.028	-20803.326	-20471.219	-19972.228

The percentage of the difference in earthwork (cut and fill) is as follow: (Awad, O. M., 2005)

$$\Delta cf = \left\| \frac{cf1 - cf2}{cf1} \right\| \% \quad (2)$$

Where;

Δcf : the percentage difference in earthwork volume.

cf1: the net volume for Level survey.

cf2: the net volume for the other techniques

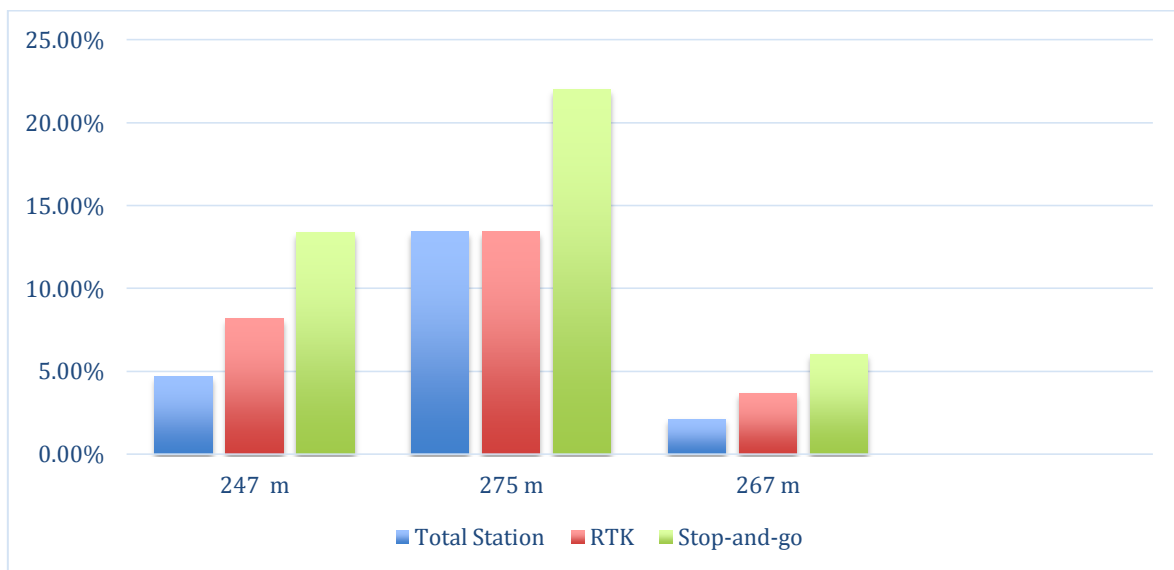


Figure 4: The percentage of the difference in earthwork (cut and fill).

From the percentage of the cut and fill volumes, the arrangement of observation methods is as follow: Level (274 m), Total Station (274 m), Stop-and-go (274 m), RTK (274 m), Level (275 m), Total Station (275 m), Stop-and-go (275 m), RTK (275 m), Level (276 m), Total Station (276 m), Stop-and-go (276 m), and RTK (276).

RESULTS:

In this study, the GNSS techniques (Stop-and-go & RTK) and Total Station were used to generate DEM for the study area and then compared with the DEM generated using a precise leveling technique. Then, the collected data used for determining the height accuracy and estimating earthwork volumes. First, regarding the height accuracy, the results show that the Total station follows the behavior of level very closely with differences in height component from (-3.9 cm to 10 cm). The RTK GNSS technique presents a good precision as well in following the level behavior: with differences in height component from (-9.4cm to 7.4cm). On the other hand, the Stop-and-go technique gives the lowest accuracy in height with differences from (-5.1 cm to 32 cm). The value of RMSE of DEMs derived by total station, RTK-GNSS, Stop-and-go GNSS is (3.4 cm, 5.2 cm, 11.9 cm) respectively.

Second, the three methods -total station, GNSS Stop-and-go, GNSS-RTK- were used for carrying out the measurements for figuring volumes. The main aim was to compare the accuracy of the three techniques with trusted data (Level). The results show

that the percentage of difference in volumes between total and Level at elevations (274m, 275m, and 276m) is (4.70%, 13.43%, 2.12%), respectively. This result means that the total station is following very close to the accuracy of the Level. The GNSS-RTK gives good precision as well, while the percentage of difference in volumes between GNSS-RTK and Level at elevations (274m, 275m, and 276m) is (8.16%, 13.43%, 3.68%) respectively. On the other hand, Stop-and-go GNSS gives the less precision with a percentage of difference in volumes in comparison with the Level at elevations (274m, 275m, 276m) of (13.36%, 21.99%, 6.03%), respectively.

CONCLUSION:

This paper aimed to assess the accuracy of the three surveying methods; GNSS (RTK& Stop-and-go) and Total station for DEM generation and earthwork estimation. The result of the experiment indicated that; Total station gives the best accuracy either in height measurement or in earthwork volumes estimation. DEMs derived by the total station has the highest precision with an RMSE error of 3.4 cm, and the percentage of difference in volumes between Total and Level at elevations (274m, 275m, and 276m) is (4.70%, 13.43%, 2.12%), respectively. On the other hand, the RMSE of DEM generated from RTK and Stop-and-go GNSS is 5.2cm, and 11.9 cm: this result indicated that the accuracy of GNSS-RTK comes in the second place, while the Stop-and-go GNSS gives the lowest accuracy.

REFERENCES:

- Abdallah, A., Saifeldin, A., Abomariam, A., & Ali, R. (2020). Efficiency of using GNSS-PPP for digital elevation model (DEM) production. *Artificial Satellites*, 55(1), 17-28. <https://doi.org/10.2478/arsa-2020-0002>
- Abdallah, A. T. M. (2009). Accuracy assessment study of using GPS for surveying applications in south Egypt: Master of science thesis/Ashraf Talaat Mohammad Abdallah.
- Aponte, J., Meng, X., Hill, C., Moore, T., Burbidge, M., & Dodson, A. (2009). Quality assessment of a network-based RTK GPS service in the UK. *Journal of Applied Geodesy*, 3(1), 25-34. <https://doi.org/10.1515/JAG.2009.003>
- Awad, O. M. (2005). Analyzing The effect of Geomorphologic Patterns of The Accuracy of DEMs (Doctoral dissertation, M. Sc. thesis, Aswan Faculty of Engineering, South Valley University, Egypt).
- Cai, C., & Gao, Y. (2013). Modeling and assessment of combined GPS/GLONASS precise point positioning. *GPS solutions*, 17(2), 223-236. DOI 10.1007/s10291-012-0273-9
- Chekole, S. D. (2014). Surveying with GPS, total station and terrestrial laser scanner: a comparative study., M.Sc. Thesis in Geodesy No. 3131, School of Architecture and the Built Environment, Royal Institute of Technology (KTH) Stockholm, Sweden, 55 pages.
- El-Mowafy, A. (2000). Performance analysis of the RTK technique in an urban environment. *Australian surveyor*, 45(1), 47-54. <https://doi.org/10.1080/00050353.2000.10558803>
- El-shewy, M. A. (2016). Comparison between Traditional Surveying Measurements and GPS Observations. (Unpublished master's thesis). Al-Azhar University.
- Edwards, S. J., Clarke, P. J., Penna, N. T., & Goebell, S. (2010). An examination of network RTK GPS services in Great Britain. *Survey Review*, 42(316), 107-121. <https://doi.org/10.1179/003962610X12572516251529>
- Farah, A., Talaat, A., & Farrag, F. (2008). Accuracy assessment of digital elevation models using GPS. *Artificial Satellites*, 43(4), 151-161. <https://doi.org/10.2478/v10018-009-0014-7>
- Gao, Z., Shen, W., Zhang, H., Niu, X., & Ge, M. (2016). Real-time Kinematic positioning of INS tightly aided multi-GNSS ionospheric constrained PPP. *Scientific reports*, 6(1), 1-16. <https://doi.org/10.1038/srep30488>
- Halim, S. M. A., Green, M. F. P. S., Narashid, R. H., & Din, A. H. M. (2019, August). Accuracy Assessment of TanDEM-X 90 m Digital Elevation Model In East of Malaysia Using GNSS/Levelling. In 2019 IEEE 10th Control and System Graduate Research Colloquium (ICSGRC) (pp. 88-93). IEEE. DOI: 10.1109/ICSGRC.2019.8837059
- Hilton, R. D., Featherstone, W. E., Berry, P. A. M., Johnson, C. P. D., & Kirby, J. F. (2003). Comparison of digital elevation models over Australia and external validation using ERS-1 satellite radar altimetry. *Australian Journal of Earth Sciences*, 50(2), 157-168. <https://doi.org/10.1046/j.1440-0952.2003.00982.x>
- Kavanagh, B. F., & Bird, S. J. (1992). *Surveying: Principles and applications* (No. 526.9 K21s). New Jersey, US: Prentice-Hall.
- Mansour, M. A. (2006). Evaluation of GPS Accuracy For Mapping and Engineering Applications. (Unpublished master's thesis). South Valley University.
- Yılmaz, I., Tiryakioglu, I., Taktak, F., & Uysal, M. (2006, January). Using RTK GPS Method in Creation of Digital Terrain Models". In International conference on cartography and GIS. Borovets, Bulgaria.
- ZAIA, Y. Y., ADAM, S. M., & GILYANA, S. M. (2017). A comparison of RTK-GPS vertical component with precise digital level for estimating volumes. *Journal of Duhok University*, 374-380. <https://doi.org/10.26682/sjuod.2017.20.1.34>