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IMPROVED ACCURACY OF ELEVATIONS OBTAINED FROM RTK AND KINEMATIC DATA AND ITS IMPACT IN CALCULATING EARTHWORKS

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ABSTRACT

For many surveying applications in civil engineering, Global Navigation Satellite Systems (GNSS) are proving to be an attractive data collection and measurement technology. Real-Time kinematics (RTK) and kinematics are the most well-known observation techniques. However, the RTK and kinematics accuracy still falls short of the accuracy needed for some engineering projects, particularly those depending on the heights. This research aims to improve the accuracy of heights derived using RTK and kinematic methods data and to evaluate the using of improved heights in estimating earthworks. In the improvement process, the idea of eliminating systematic errors was used. The amount of error was first computed at a control point at the start of the task, and then the amount of this error was subtracted from the heights of the remaining points. A variety of statistical criteria and measures of quality of fit were employed to evaluate the performance of the models under study, and the outputs of the various models were then compared. The study's conclusions showed that the accuracy of heights from RTK and kinematic data had increased by 71% and 52%, respectively. Researchers or professionals that need to successfully adapt RTK and kinematic techniques to their applications might benefit from the experiences with the increased RTK and kinematic data.

KEYWORDS: Level, RTK-GNSS, Kinematic, and Earthwork volume.

الرصد المتحرك والرصد اللحظى آنيا تحسين دقة المناسيب المتحصل عليها من بيانات وتأثيرها في حساب الحفر والردم

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الملخص

بالنسبة للعديد من التطبيقات المساحية في الهندسة المدنية ، أثبتت أنظمة الملاحة العالمية عبر الأقمار الصناعية (GNSS) أنها تقنية جذابة لجمع البيانات وتكنولوجيا القياس. يعتبر علم الرصد الحركى والرصد المتحرك اللحظى آنيا فى الوقت الحالى من أكثر تقنيات الرصد شهرة. ومع ذلك لا تزال دقة الأرصاد المتحركة أقل من الدقة المطلوبة لبعض المشاريع الهندسية ، لا سيما تلك التي تعتمد على المناسيب. يهدف هذا البحث إلى تحسين دقة المناسيب المستنتجة باستخدام الرصد الحركى والرصد المتحرك اللحظى آنيا وتقييم استخدام المناسيب المحسنة في تقدير كميات الحفر والردم. في عملية التحسين تم استخدام فكرة القضاء على الأخطاء المنهجية. تم حساب مقدار الخطأ أولاً عند نقطة تحكم في بداية المهمة ، ثم تم طرح مقدار هذا الخطأ من ارتفاعات النقاط المتبقية. تم استخدام مجموعة متنوعة من المعايير الإحصائية ومقاييس جودة الملاءمة لتقييم أداء النماذج قيد الدراسة ، ثم تمت مقارنة مخرجات النماذج المختلفة. أظهرت استنتاجات الدراسة أن دقة مناسيب الرصد الحركى والرصد المتحرك اللحظى آنيا قد زادت بنسبة 52٪ و71٪ على التوالى. قد يستفيد الباحثون أو المهنيون المتخصصون الذين يحتاجون إلى تكييف الأرصاد الحركية بنجاح مع تطبيقاتهم من الخبرات مع زيادة الرصد الحركى والرصد المتحرك اللحظى آنيا.

الكلمات المفتاحية : المنسوب، الأقمار الصناعية، الرصد الحركى، الرصد المتحرك اللحظى آنيا، وكميات الحفر والردم.

1. INTRODUCTION

Earthworks are construction projects that include moving or modifying portions of the Earth's surface that contain significant quantities of soil or rock. Numerous engineering tasks, such as estimating the cutting and filling of landfills and clearing land for road engineering, drainage, and building, depend on the volume of earthworks (Pratomo, et al., 2019). The excavation and transportation of materials on such an outline are, as is well known, the most significant and expensive aspects of the works, on which gain, or loss may depend (Schofield, 2001). The moving of enormous amounts of earthwork is one of the key building procedures, and earthworks are regarded as the most expensive plan (Deakin, 2005). Data may be gathered for these projects utilizing a variety of surveying methods, including levelling, total stations, GNSS, and laser scanning (Zaia, et al., 2017).

Geodesy, cadastral surveying, land surveying, earth science, and other fields all heavily rely on global positioning satellite systems. Single Point Positioning (SPP) without correction, Differential GPS (DGPS), and Real-time Kinematic (RTK) with accuracy augmentation utilizing data from a reference station are all GNSS positioning techniques that can be used (El -Rabbany, 2006; Ragheb & Ragab, 2012). According to earlier research, RTK-GNSS is a differential positioning approach that can calculate the coordinates of unidentified locations visited by a rover receiver using the location of a reference station that a base receiver is currently utilizing as a baseline (El-Mowafy, 2000). The GNSS signals are seen simultaneously by both receivers, and a radio data link enables data to be transferred from the base to the rover, where the coordinate computation is carried out.

Numerous applications make use of GPS-RTK technology (Morales and Tsubouchi, 2007). RTK-GNSS methods reportedly save costs by up to 50%. (El-Mowafy et al., 2006; Sumpter, 1994). It was determined that the RTK saved more time than the Total Station in terms of time spent (Chekole, 2014). Contrarily, traditional surveying techniques may be time-consuming and dangerous for employees (Siebert and Teizer, 2014). RTK-GPS also has the benefit of 30 percent mapping process reduction under typical circumstances (Mensah, F. and Duncan, 2006). Additionally, the RTK-GNSS survey is efficient since it only needs one surveyor to perform it, which reduces the number of surveyors needed (Dedi Atunggal, S.P., Cahyono, B.K. and Matori, 2007). RTK is viewed as the optimum compromise between usability and accuracy as a result.

The accuracy of RTK and kinematic have been investigated in earlier publications, particularly regarding measuring point height. When comparing the RTK-GPS method to geometric levelling, Borgelt said that the elevation error was just 12 cm (Borgelt et al., 1996). GPS placement is less accurate in measuring elevation, according to Featherstone and Stewart (2001), because of how the satellites are positioned in the sky (Featherstone and Stewart, 2001). The precision of RTK is approximately centimeters, according to a different Aponte research (Aponte et al., 2009). Saghravani claimed that when compared to an automated level, the vertical accuracy of RTK-GNSS in surveying was less than 10 cm with a 95% confidence level (Saghravani, S. R., Mustapha, S., & Saghravani, 2009). In their research using RTK-GNSS to evaluate the topography, Clark and Lee observed height inaccuracies of 4 to 9 cm (Kizil and Tisor, 2011). RTK-GPS offers real-time corrections and centimeter-level precision (Xu, 2012). Today's GNSS receivers can continually give centimeter-level precision thanks to technologies like RTK, DGPS, augmented systems, etc (Manzino, A.M., Dabove, P. and Gogoi, N., 2018).

As stated by the literature, horizontal coordinates of points when using GNSS are trustable while the elevations accuracy acquired by GNSS (RTK and Kinematic) is doubtful. Therefore, the main objective of this study is to improve the elevations accuracy of GNSS data which is used in the production of earthworks based on the creation and development of two models from Level and GNSS data relationship of control point.

2. MATERIALS AND METHODS

2.1. Study area and data sources

The study area was located in October City nearby Dahshour district, Egypt. It covers an area of around 400 m by 400 m. On August 15, 2022, the observations were carried out. Figures (1) and (2) depict the research area layout, which was covered by 1437 points with spacing of roughly 10 m between each pair of successive points. The coordinates of corners of study area are shown in Table (1). The RTK-GNSS measurements took about 14 hours to be completed. A sokkia total station was used to measure the easting and northing coordinates for 1437 spot points. While the height of these 1437 sites was established using the following equipment:

- A Sokkia C330 Automatic Level has been used to measure the heights of points.
- A Sokkia Grx2 GNSS receiver has been used to collect GNSS data.
- A Sokkia CX-105 Total Station has been used to measure the easting and northing coordinates of points.

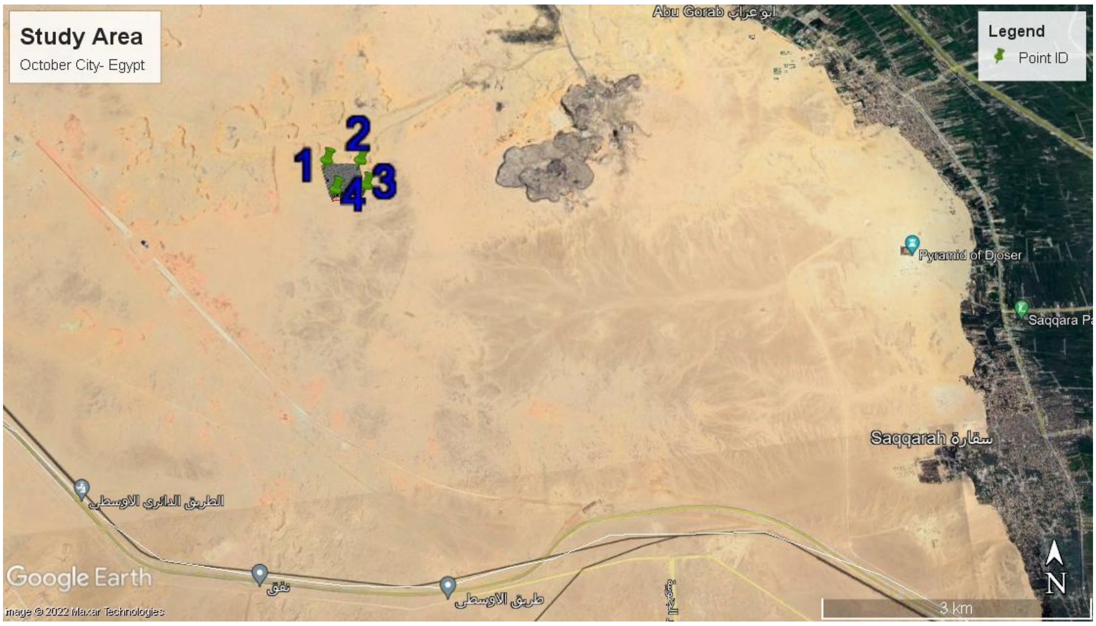
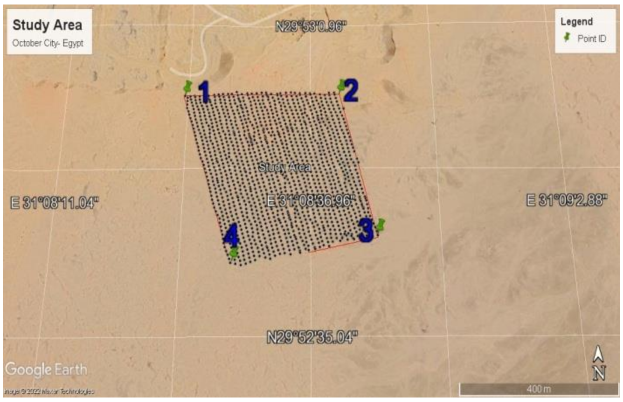


Fig. 1: Research area layout.



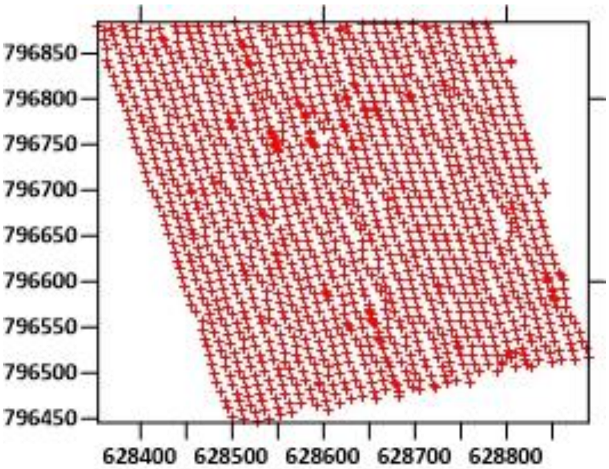


Fig.2: Distribution of 1437 points on the site.

Table 1: The coordinates of corners of study area.

Point No.	Coordinates			
	WGS 84		ETM	
	Latitude (ø)	Longitude (λ)	East (E)	North (N)
1	29° 52' 54.50"	31° 08' 22.63"	628352.95m	796878.91m
2	29° 52' 54.39"	31° 08' 40.03"	628793.60m	796879.39m
3	29° 52' 42.66"	31° 08' 43.63"	628889.57m	796515.89m
4	29° 52' 40.66"	31° 08' 29.19"	628502.29m	796441.42m

2.2. Research methodology

The research methodology to improve the accuracy of the heights obtained using RTK includes the following steps:

1- Fixing two main points in the work area (two control points, CP1 and CP2) and calculating the coordinates of these two points with high accuracy, their heights are (H_{CP1}) and (H_{CP2}).

2- A Sokkia C330 Automatic Level has been used to measure the heights of 1437points (H_{Ln}), where (n) is the number of points from 1 to 1437.

3- After that Sokkia Grx2 GNSS receiver has been used to collect GNSS data, at the beginning of work on the first control point (CP1) by the GNSS-base and the second control point (CP2) with the GNSS-rover.

4- The point height value is obtained from the rover (H_{RCP2}).

5- The difference between H_{CP2} and H_{RCP2} is calculated (ΔH_{CP2}):

$$\Delta H_{CP2} = H_{CP2} - H_{RCP2} \quad (1)$$

6- The other points in the site are be occupied by rover to calculate their heights (H_{Rn}).

7- The ΔH_{CP2} is added for all observed points with GNSS receiver, and then the improving heights (H_{In}) will be:

$$H_{In} = H_{Rn} + \Delta H_{CP2} \quad (2)$$

8- The improved heights are evaluated by comparing these heights with the heights from Automatic Level:

$$\delta H_n = H_{Ln} - H_{In} \quad (3)$$

3. RESULTS AND DISCUSSION

At first, the two control points CP1 and CP2 (located far from the study area with about 100 m) were fixed, and then they were occupied using the Sokkia Grx2 GNSS base-receiver for about two hours (static mode) and their coordinates were calculated by connecting to nearby major points. After that, the 1437 points were fixed (Figure 2) then the heights of these points were calculated using the Sokkia C330 Automatic Level. In order to evaluate the accuracy of the heights obtained from the GNSS, the 1437 points were occupied twice, once by the kinematic (Stop and go) mode and once by the RTK mode.

3.1. The heights accuracy from GNSS for the study area

The control point CP1 was occupied by the Sokkia Grx2 GNSS base-receiver while the rover-receiver was conducted by one surveyor and successfully obtained the control point CP2 and the 1437 points in the two modes, RTK and kinematic, in around 2 hours for every mode. The average values of the differences between the heights of points from Level and from GNSS in the two modes (RTK and kinematic) has been calculated, See Table 2.

Table 2: Average values of the differences (m).

	RTK (m)	Kinematic (m)
Mean	0.050	0.042
RMSE	0.052	0.048
Range	0.139	0.148
Minimum	-0.039	-0.051
Maximum	0.100	0.097

While the RMSE:

$$\text{RMSE} = \sqrt{\frac{\sum (H_L - H_{GNSS})^2}{n-1}} \quad (4)$$

3.2. Improving the accuracy of heights from RTK and kinematic data

In order to improve the accuracy of the GNSS heights in both RTK and kinematic, the differences between the height of the control point (CP2) calculated from the Sokkia C330 Automatic Level and the heights calculated from the RTK and kinematic modes for this point were calculated, and the values of these differences were -4.7 cm and -3.9 cm, respectively. After that, the values of the differences from the two modes were added to 1437 points, then the values of the improved heights of these points were calculated and compared with their heights calculated from the Level. Figure (3) summarized the results of RMSE of the differences between the heights from the level and the heights from the two RTK and kinematic before and after improving.

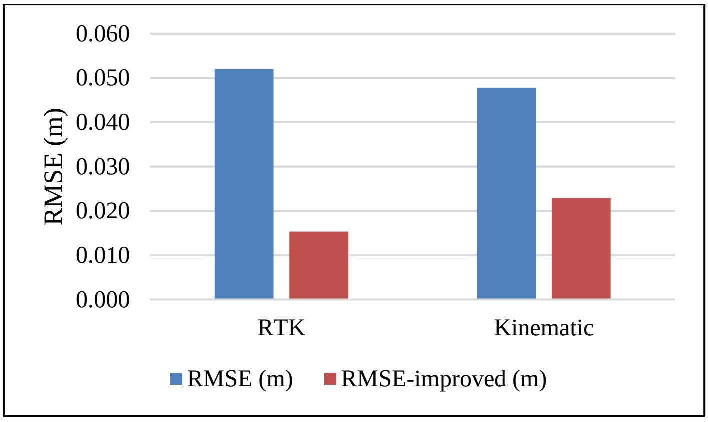


Fig. 3: RMSE values of the heights from the RTK and kinematic modes pre- and post-improving.

The figure results showed that, when adding the difference between height from level and height from the RTK and kinematic modes of the control point for the other points, the RMSE has been improved in the two modes.

To compare between the two modes, the improvement percentage in the accuracy of heights equation No. 5 was used (Awad, 2005), the results were summarized in Table 3.

$$\text{Improvement percentage} = \left|\frac{O-I}{O}\right| \% \qquad (5)$$

Where: I - RMSE value of differences of improved heights.

O - RMSE value of differences of original heights.

Table 3: Summary of improvement percentage of the RMSE

	RMSE value of original heights (O)	**RMSE value of improved heights (I)**	**Improvement of RMSE (%)**
RTK	0.052m	0.015m	71
kinematic	0.048m	0.023m	52

As shown in Table 3, the RMSE values have been improved in the RTK and kinematic modes.

3.3. Applications of improved heights from RTK and kinematic data

There are many important applications for the use of heights in various engineering works. The improved heights obtained from the RTK and kinematic data were used. The contour lines were drawn for the RTK and kinematic heights before and after the improvement and compared with the decree from the level heights using "Surfer version 17" program, see Figures 4, 5 and 6.

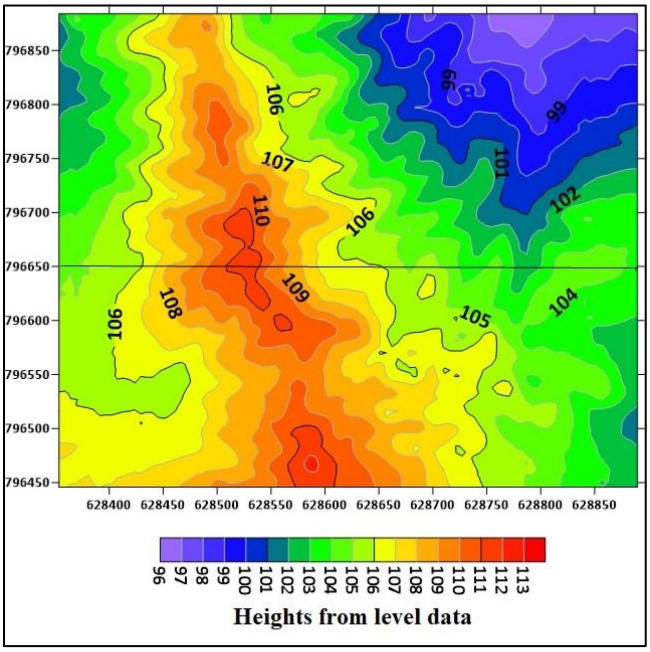


Fig. 4: Contour lines from Level data.

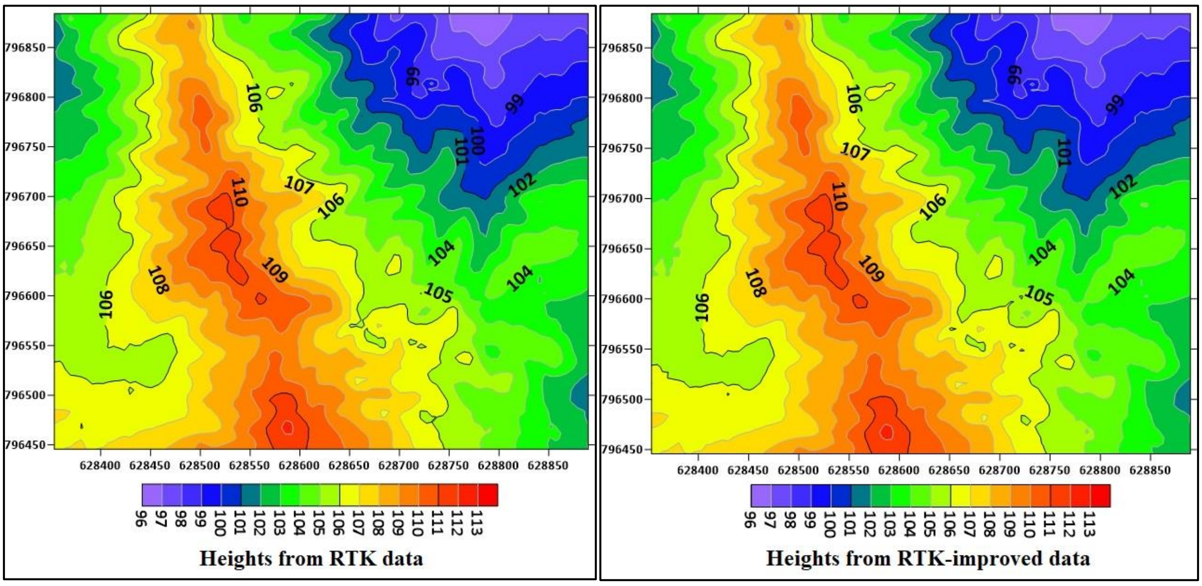


Fig. 5: Contour lines from RTK and improved RTK data.

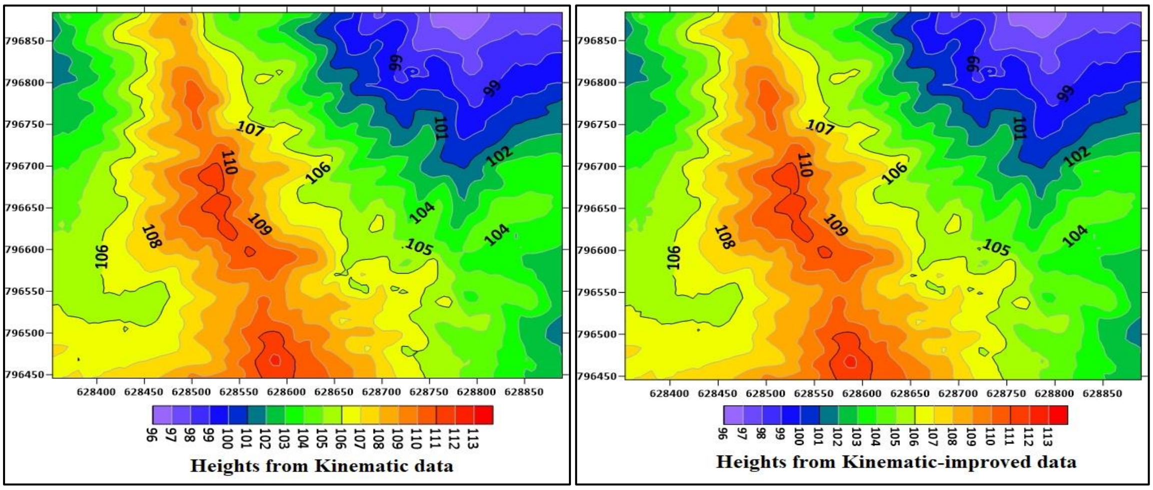


Fig. 6: Contour lines from kinematic and improved kinematic data.

Figures 4, 5, and 6 showed that there is a change in the contour lines obtained from the improved heights compared with the contour lines obtained from the original RTK and kinematic data.

Calculating the quantities of excavation and backfilling is one of the most important items of engineering projects, which depend largely on the accuracy of the calculated heights. Figure 7 shows the vertical profile of the area from Level data.

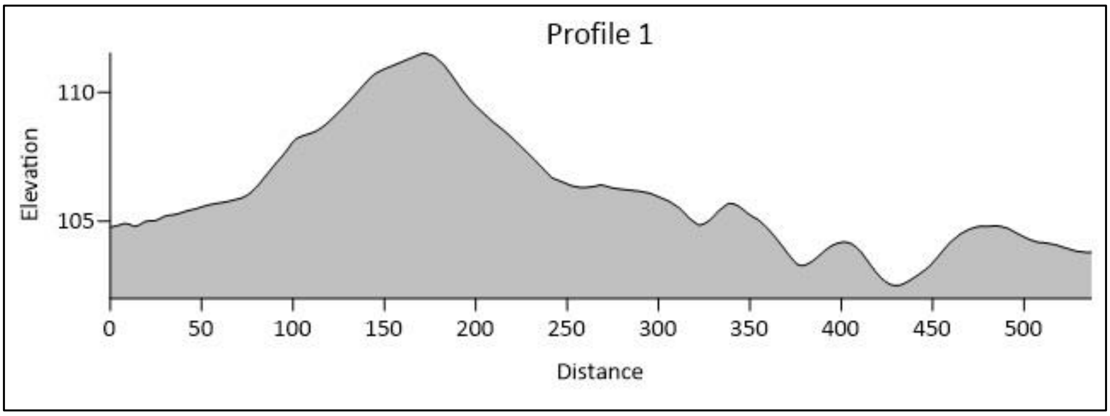


Fig. 7: Profile from Level data.

The cut quantities were calculated for the study area at level 95.00m (as an example) from the heights of level, RTK, and kinematic heights before and after the improvement. The cut quantities which were calculated using the heights of level were 2,370,570.63 m^3. The cut quantities calculations using RTK, and kinematic heights before and after the improvement are shown in Table 4, also the percentage of cut quantities relative to quantities calculated using Level are shown. The results illustrated in table 4 show the noticeable enhancement in cut quantities calculated from RTK and kinematic data before and after the improvement.

Table 4: Summary of improvement in cut quantities.

	Cut quantities (m3)		Percentage of cut quantities relative to quantities calculated using Level	
	Before improvement	After improvement	Before improvement	After improvement
RTK	2359049.53	2370091.99	99.51%	99.98%
Kinematic	2360712.69	2369875.58	99.58%	99.97%

4. CONCLUSION

Due to its simplicity of use, GNSS is an efficient and effective technology for supplying point location data in a variety of surveying applications. The purpose of this project is to improve the GNSS height data, which is one of the crucial tools for calculating the amounts of earthworks. First, a model created using Level data was compared to two models created using RTK and kinematic data. The error in the control point was then assessed and removed from the other locations to improve the accuracy of heights using RTK and kinematic data. The heights of the additional points are then computed and contrasted with the level data heights. The study's findings demonstrated a 71% and a 52% increase in the accuracy of RTK and kinematic heights, respectively. The output results of the estimated earthworks have improved as a result of this improvement. The accuracy of calculating volumes using RTK increased from 99.51% to 99.98% and using Kinematic heights increased from 99.58% to 99.97% after improvement. Further research is required to provide a better evaluation employing multiple eras, places, and circumstances.

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