PORT SAID ENGINEERING RESEARCH JOURNAL
Faculty of Engineering - Port Said University
Volume 28 No. 1 pp: 31-38

Assessment Of GNSS Positioning Techniques In EGYPT

A.A.Abdelnaeim [1,], A.I.Elhattab [2], M.H.Azzam [3], R.M.Abdelwadood [4] and A.A.ELsharkawy [5,6]*

[1] *Civil Department, Faculty of Engineering, Port-Said University, Port-Said, Egypt, email: abdelrahman.ahmed@eng.psu.edu.eg*
[2] *Civil Department, Faculty of Engineering, Port-Said University, Port-Said, Egypt, email: dr.ahmed.elhattab@eng.psu.edu.eg*
[3] *Civil Department, Faculty of Engineering, Port-Said University, Port-Said, Egypt, email: mazzam4444@gmail.com*
[4] *Civil Department, Faculty of Engineering, Port-Said University, Port-Said, Egypt, email: Rash.mosaad@eng.psu.edu.eg*
[5] *Civil Department, Faculty of Engineering, Port-Said University, Port-Said, Egypt, email: a.elsharkawy@eng.psu.edu.eg*
[6] *Civil Department, Faculty of Engineering, Horus University, New Damietta, Egypt, email: AElsharkawy@horus.edu.eg*
**Corresponding author,* *DOI: 10.21608/PSERJ.2023.240129.1267*

Received 2-10- 2023,
Revised 1-11- 2023,
Accepted 21-11- 2023

ABSTRACT

This research delves into Global Navigation Satellite Systems (GNSS) positioning accuracy, focusing on GPS, GLONASS, and their combined utility to evaluate GLONASS as an independent system in case GPS is down. The study spans three phases. First, data from stations located in Port Said, analyzed using relative positioning technique, GPS shows an average coordinate deviation of 0.32 millimeters for GPS-only scenarios, while GLONASS exhibits 1.045 millimeters for GLONASS-only scenarios. Merging both narrows this gap, especially in shorter baselines. Second, an extensive dataset over three years from eight Egyptian stations, using GPS and GLONASS as references, shows that GPS consistently provides better three-dimensional accuracy in most stations with close values. Finally, employing Precise Point Positioning (PPP) techniques, the study rigorously compares three processing software solutions (PPPH, PPP-ARISEN, PRIDE-PPPAR) with the same dataset. PRIDE-PPPAR closely aligns with BERNESE software accuracy, followed by PPP-ARISEN and PPPH. These findings suggest that GLONASS alone can be used for many applications, and open-source PPP software can be employed with acceptable accuracy.

Keywords: GNSS, GPS, GLONASS, PPP, PPPH, PPP-ARISEN, PRIDE-PPPAR, BERNESE.

1 INTRODUCTION

Global Navigation Satellite Systems (GNSS) have revolutionized the field of positioning and navigation, providing precise and accurate positioning information for a wide range of applications. In recent years, GNSS technology has gained significant importance in various sectors, including surveying, mapping, agriculture, transportation, and urban planning, among others.

In EGYPT, GNSS positioning techniques have been widely adopted for diverse applications, ranging from cadastral surveying and infrastructure development to precision agriculture and navigation systems.

GPS has become a crucial surveying system due to its ability to determine the location of points with high accuracy. It has at least 24 operational satellites and 7 spares that orbit in 6 planes with an inclination of 55° to the equator and an altitude of 20200 km. The orbital period is 12 sidereal hours [1].

GLONASS (Global Navigation Satellite System) is a positioning system developed by Russia, consisting of 24 satellites orbiting in 3 planes with an inclination of 64.8° and an altitude of 19100 km, with an orbital period of 11hr, 15min and 44sec [2].

Galileo is the European global navigation satellite system (GNSS) developed by the European Union (EU) and European Space Agency (ESA). The Galileo system consists of 26 operational satellites in medium earth orbit (MEO) and an additional 6 in-orbit spares. The satellites orbit at an altitude of 23222 km with an inclination of 56° to the equator and an orbital period of 14 hours and 56 minutes [3].

The Chinese system, (BEIDOU), has 27 satellites in MEO, 5 in GEO and 3 in IGSO, with the GEO and IGSO satellites having an altitude of 35786 km and the MEO satellites orbiting in 3 planes with an altitude of 21528 km and an inclination of 55° [4].

In urban canyons and other challenging environments, the performance of GPS can be affected due to the limited number of visible satellites, but this can be improved by combining multiple GNSS systems, thus increasing the number of visible satellites and improving accuracy [5].

Cai and Gao [6] conducted a study on precise point positioning using GPS-only and combined GPS and GLONASS processing. Results showed that the limited availability of GLONASS satellites did not significantly impact positioning accuracy. However, accuracy improved with more GLONASS satellites available. A significant improvement was observed with the combined solution compared to GPS-only.

El-Hattab, A. I. [7] GPS data initially processed with Bernese 5.0 was reprocessed using PPP. CSRS-PPP results closely matched Bernese, with centimeter-level accuracy suitable for CORS networks. This centimeter-level accuracy achieved through PPP demonstrates its suitability for municipal surveying and CORS network establishment.

Abd Rabbou and El-Rabbany [8] proposed a new precise point positioning (PPP) model that combined observations from GPS, GLONASS, GALILEO, and BEIDOU. They found that adding BEIDOU to GPS improved positioning accuracy compared to GPS-only solutions, and the combined GNSS system provided even higher accuracy.

This research will likely involve data collection from the GNSS receivers at the study stations, which track signals from GPS and GLONASS satellites. The collected data will be processed using appropriate algorithms and techniques to compute the position for each GNSS system individually, as well as for the combined solution.

Trimble Business Center (TBC) [9] is an advanced geospatial software developed by Trimble. In Trimble Business Center (TBC) software, raw GNSS data is imported and processed to generate precise positions. The software cleans, edits, and filters the data for accuracy, performs baseline processing for multiple stations, corrects errors, and achieves centimeter-level accuracy through post-processing.

In the world of Global Navigation Satellite Systems (GNSS) analysis, Bernese version 5.2 [10] stands as a vital tool. In the Bernese GNSS Software processing workflow, raw GNSS data is first entered and converted into RINEX format, which is then transformed into the Bernese-specific data format. Precise orbit files are downloaded and utilized for accurate satellite positions. Pre-processing steps include receiver clock synchronization, baseline file creation, and cycle slip screening to ensure data accuracy. The processing phase involves obtaining a clean float solution initially, resolving double-difference ambiguities for higher precision, and finally calculating the network solution using all available data.

This research paper introduces PPPH [11], a powerful MATLAB-based GNSS analysis software, offering versatility by processing data from GPS, GLONASS, GALILEO, and BEIDOU, along with customizable data combinations. PPPH stands out for its analytical and visualization tools, enabling users to assess positioning error, tropospheric zenith total delay, and satellite count.

This research paper introduces PPP-ARISEN [12], an open-source Precise Point Positioning (PPP) toolbox designed for high-precision GNSS applications. PPP-ARISEN employs the Integer Phase Clock (IPC) method with a satellite-to-satellite single difference (SSD) strategy, enabling millimeter-level accuracy in static positioning and centimeter-level accuracy in kinematic mode.

Introducing PRIDE PPP-AR [13], an open-source software tailored for GPS Precise Point Positioning Ambiguity Resolution (PPP-AR). This tool, comprising undifferenced GPS processing and single-station ambiguity resolution modules, employs a least-squares estimator to produce precise daily, sub-daily, or kinematic solutions. PRIDE PPP-AR significantly contributes to research, applications, and development in GPS post-processing PPP-AR.

In Precise Point Positioning (PPP) software processing, raw GNSS data is imported and preprocessed to ensure quality and consistency. Error sources like atmospheric delays and satellite clock errors are meticulously modeled and accounted for. The preprocessed data is then filtered to remove outliers and cycle slips, enhancing data reliability. Finally, advanced algorithms are applied to analyze the filtered data and estimate precise positions for GNSS receivers, often achieving centimeter-level accuracy.

Precise Point Positioning (PPP) and Differential Global Positioning System (DGPS) differ primarily in their correction sources and accuracy levels. PPP achieves centimeter-level accuracy by modeling various errors globally, utilizing precise satellite information, but it requires post-processing for optimal results. In contrast, DGPS relies on real-time corrections from local ground-based reference stations, offering sub-meter to decimeter-level accuracy immediately. PPP is infrastructure-independent and suitable for remote or global applications, whereas DGPS requires a network of local reference stations, making it ideal for regional or localized tasks like precision agriculture and marine navigation.

Furthermore, this research entails a comprehensive comparison of processing programs, utilizing BERNESE V.5.2 as the datum for assessing the accuracy of PPPH, PPP-ARISEN, and PRIDE-PPPAR.

2 DATA COLLECTION

This research employed data collection strategy to investigate the accuracy and performance of Global Navigation Satellite Systems (GNSS) positioning and processing software across various regions and timeframes.

The first phase involved the deployment of GNSS receivers at three key stations positioned above the Faculty of Engineering buildings in Port Said. These stations, identified as PSU1, PSU2, and PSU3, were operational over the dates of June 20th, 21st, and 22nd, 2023, utilizing LEICA GS15 receivers capable of tracking both GPS and GLONASS constellations, as illustrated in Figure 1.

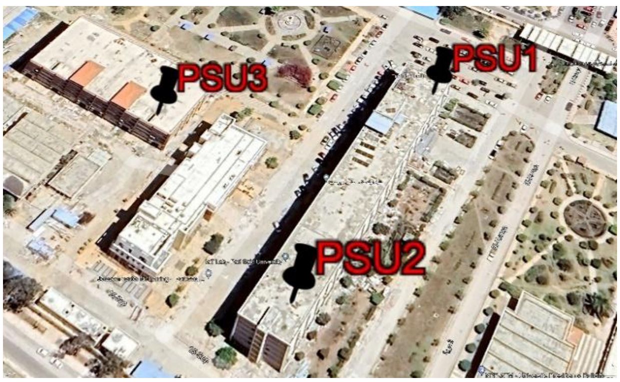

Figure (1): Distribution of the three Stations above Faculty of Engineering buildings in PORT SAID.

In the second phase, data was collected from eight strategically located stations across Egypt, provided by the Egyptian Survey Authority (ESA). These stations, named ALEX, RSHD, SAID, AYAT, ETSA, ADWH, ISNA, and ADFO, were active on May 5th in 2019, 2020, and 2021. They were equipped with GNSS receivers tracking both GPS and GLONASS constellations, as shown in Figure 2.

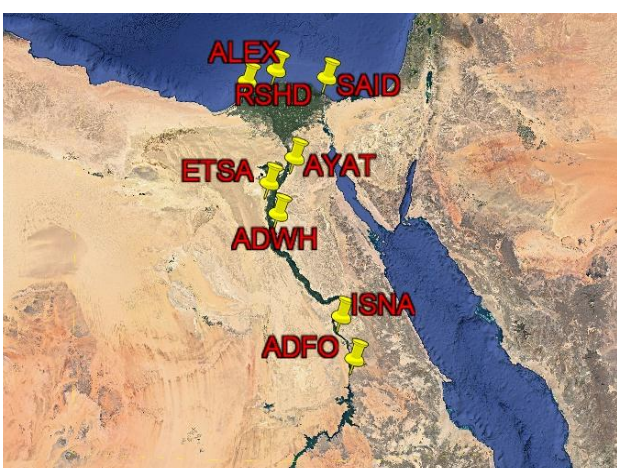

Figure (2): Distribution of the Eight Stations along EGYPT

3 DATA ANALYSIS

In the initial phase, we conducted a comprehensive analysis using data from three GNSS stations, considering three distinct scenarios: GPS only, GLONASS only, and a combined GPS and GLONASS approach. This analysis was processed by Trimble Business Center version 5.2, utilizing relative positioning techniques and using baseline solution as the solution type. This encompassed the establishment of baselines, with lengths of approximately 100 meters for PSU1-PSU2, roughly 108 meters for PSU1-PSU3, and about 90 meters for PSU2-PSU3.

Moving to the second phase, we extended our analysis to encompass observations from eight GNSS stations. Like the first phase, we explored three scenarios. The GNSS data underwent analysis and processing using Trimble Business Center version 5.2. The baselines created for this phase encompassed SAID-RSHD, spanning approximately 177 km, SAID-ALEX at about 226 km, SAID-AYAT covering around 208 km, SAID-ETSA extending over roughly 267 km, SAID-ADWH reaching approximately 321 km, SAID-ISNA at a significant distance of about 664 km, and SAID-ADFO, covering an expansive 700 km.

In the final phase, data collected from the eight strategically positioned stations across Egypt was harnessed to perform an intricate comparative analysis of three GNSS processing software solutions: PPPH, PPP-ARISEN, and PRIDE-PPPAR. The goal was to identify the most accurate GNSS processing software when used alongside BERNESE Version 5.2, with all programs using the same date and a consistent 3-degree cut-off angle.

PPP models are introduced starting from the GNSS observation presented in units of meters in (1) and (2) for the code observable Pi and phase observable Li, respectively, on frequency i. No index for the GNSS is included to improve the readability. The geometric distance between the satellite and receiver is denoted as ρ. The receiver clock error dtR and satellite clock error dtS are both multiplied by the speed of light c. dTrop and dIono denote the tropospheric and ionospheric delays. Receiver and satellite code hardware delays represented as BR and BS, respectively, are converted to the range, and ε includes random and other negligible errors. The ambiguity term of the phase observable comprises the integer term N and carrier phase hardware delays from the receiver bR and the satellite bS and is multiplied by the wavelength λi.

$$Pi = \rho + c\,(dtR - dtS) + dTrop + dIono + BR - BS + \varepsilon \qquad (1)$$

$$Li = \rho + c\,(dtR - dtS) + dTrop + dIono + (Ni + bR - bS)\,\lambda i + \varepsilon \qquad (2)$$

4 RESULTS AND DISCUSSION

Our research consists of three phases to evaluate GNSS accuracy. In the initial two phases, we employed relative positioning techniques, while the third phase involved Precise Point Positioning (PPP) techniques.

4.1 FIRST PHASE ASSESSING COORDINATE ACCURACY

The column charts below provide a visual comparison of coordinate differences (ΔE, ΔN, ΔH in millimeters) for the three stations across GPS, GLONASS, and combined GPS and GLONASS solutions.

Figure 3 illustrates the Average Departure Difference for three stations with PSU1 as the control point, utilizing GPS and GLONASS as the datum. The chart shows that when employing GPS only, it yields an error of 0 mm for PSU2 and 0.3 mm for PSU3 stations. Conversely, employing GLONASS only results in errors of 0.67 mm for PSU2 and 0.3 mm for PSU3.

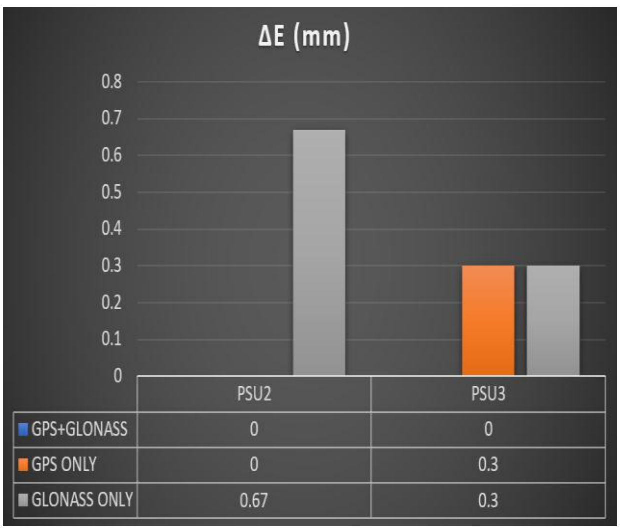

Figure (3): Average Departure Difference (ΔE) in (mm) for the three Stations above Faculty of Engineering buildings.

Figure 4 displays the Average Latitude Difference for three stations with PSU1 as the control point, utilizing GPS and GLONASS as the datum. The chart reveals that when using GPS alone, it results in an error of 0.3 mm for PSU2 and 0 mm for PSU3 stations. In contrast, employing GLONASS alone yields errors of 1.33 mm for PSU2 and 0.3 mm for PSU3. This observation emphasizes that GPS alone provides higher accuracy, resulting in smaller errors for both PSU2 and PSU3 stations in comparison to GLONASS-only scenarios.

In Figure 5, the chart presents the Average Altitude Difference for three stations with PSU1 as the control point, utilizing GPS and GLONASS as the datum. It is evident that GLONASS-only solutions exhibit the highest ΔH error, with a deviation of 3 mm in PSU2 station. Conversely, GPS-only solutions showcase the smallest error, with a difference of 0.67 mm at PSU2 station. In the case of PSU3, the results indicate that GPS-only and GLONASS-only solutions yield nearly identical errors, with a variance of approximately 0.67 mm.

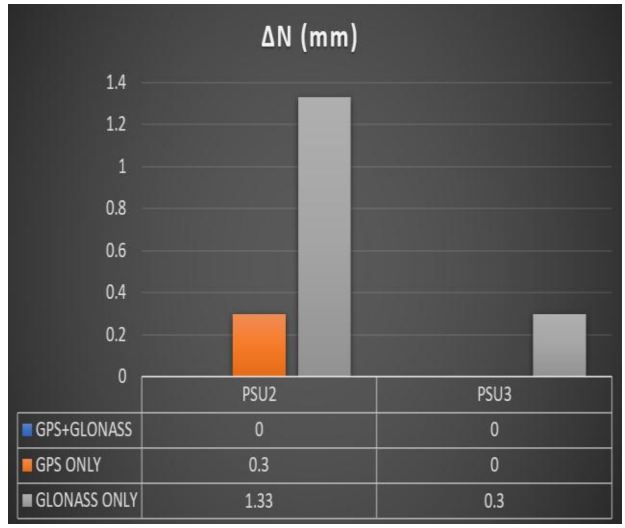

Figure (4): Average Latitude Difference (ΔN) in (mm) for the three Stations above Faculty of Engineering buildings.

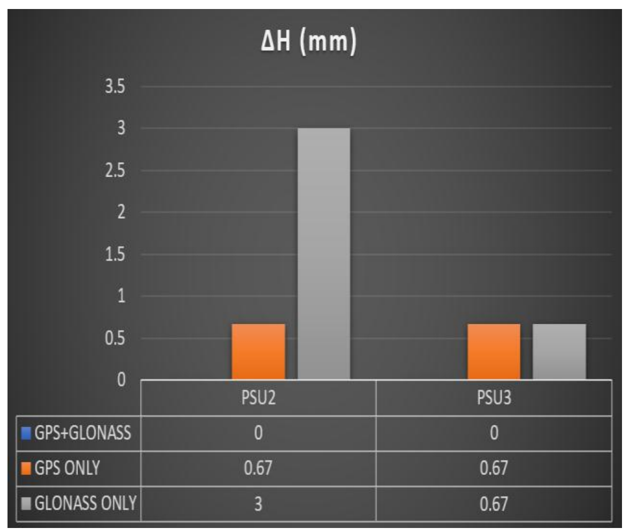

Figure (5): Average Altitude Difference (ΔH) in (mm) for the three Stations above Faculty of Engineering buildings.

4.2 SECOND PHASE ASSESSING COORDINATE ACCURACY

The tables below provide a visual comparison of coordinate differences (ΔE, ΔN, ΔH in mm) for the eight Egyptian stations in 2019, 2020, and 2021. We assess these errors across GPS, GLONASS, and combined GPS and GLONASS solutions, all with GPS and GLONASS as the reference datum. SAID station acts as our control point for this analysis.

Across the years 2019, 2020, and 2021, Table 1 shows the departure differences in mm for ESA stations. Notably, in 2019, GPS-only solutions demonstrated remarkable accuracy, with departure differences ranging from 0 to 25 mm for most stations. In contrast, GLONASS-only solutions exhibited slightly higher departure differences, ranging from 0 to 41 mm. This trend persisted in 2020, with GPS-only solutions providing departures between 0 and 12 mm, while GLONASS-only departures were notably higher, spanning 4 to 51 mm. In 2021, the same pattern emerged, with GPS-only departures between 0 and 18 mm and GLONASS-only departures from 1 to 20 mm. These findings underscore GPS's consistent accuracy advantage over GLONASS in terms of departure differences over the three years, implying its superior suitability for precise positioning applications across these stations.

Table 1. Departure Differences (ΔE) in (mm) for the ESA Stations in 2019, 2020 and 2021.

Year	Stations	RSHD	ALEX	AYAT	ETSA	ADWH	ISNA	ADFO
2019	GPS+GLONASS	0	0	0	0	0	0	0
	GPS ONLY	1	0	0	7	4	36	29
	GLONASS ONLY	7	1	8	30	27	2	55
2020	GPS+GLONASS	0	0	0	0	0	0	0
	GPS ONLY	3	1	2	6	1	61	6
	GLONASS ONLY	22	8	8	11	41	9	38
2021	GPS+GLONASS	0	0	0	0	0	0	0
	GPS ONLY	5	4	3	1	14	54	75
	GLONASS ONLY	20	21	44	11	27	32	11

Table 2 presents the Latitude Differences (ΔN) in millimeters (mm) for the ESA stations over the years 2019, 2020, and 2021. In 2019, all stations showed lower errors for GPS-only solutions compared to GLONASS-only solutions, with the highest error being 10 mm for GPS-only and 20 mm for GLONASS-only. Moving to 2020, RSHD, ALEX, ETSA, and ADWH stations demonstrated better accuracy with GPS-only solutions compared to GLONASS-only, while AYAT and ADFO stations had equal values of 3 mm and 12 mm, respectively. Surprisingly, ISNA was the only station where GLONASS-only solutions showed an advantage with a difference of 5 mm, while GPS-only solutions had a difference of 14 mm. In 2021, GPS-only solutions consistently exhibited impressive accuracy, with departure differences ranging from 1 to 6 mm for most stations. In contrast, GLONASS-only solutions, except for ISNA, displayed slightly higher departure differences, ranging from 1 to 20 mm. For ISNA station, GPS-only yielded a 6 mm difference while GLONASS-only provided a 3 mm difference. These findings underline the dominance of GPS in minimizing Latitude Differences, especially in 2021, with notable exceptions like ISNA.

Table 2. Latitude Differences (ΔN) in (mm) for the ESA stations in 2019, 2020 and 2021.

Year	Stations	RSHD	ALEX	AYAT	ETSA	ADWH	ISNA	ADFO
2019	GPS+GLONASS	0	0	0	0	0	0	0
	GPS ONLY	0	1	2	6	4	6	10
	GLONASS ONLY	1	4	8	11	9	20	17
2020	GPS+GLONASS	0	0	0	0	0	0	0
	GPS ONLY	2	2	3	2	4	14	12
	GLONASS ONLY	4	7	3	5	15	5	12
2021	GPS+GLONASS	0	0	0	0	0	0	0
	GPS ONLY	1	1	1	4	4	6	4
	GLONASS ONLY	5	1	13	12	8	3	20

Table 3. Altitude Differences (ΔH) in (mm) for the ESA stations in 2019, 2020 and 2021.

Year	Stations	RSHD	ALEX	AYAT	ETSA	ADWH	ISNA	ADFO
2019	GPS+GLONASS	0	0	0	0	0	0	0
	GPS ONLY	0	1	0	1	0	24	25
	GLONASS ONLY	2	1	4	7	4	0	41
2020	GPS+GLONASS	0	0	0	0	0	0	0
	GPS ONLY	0	1	3	6	0	12	11
	GLONASS ONLY	4	12	26	18	51	49	15
2021	GPS+GLONASS	0	0	0	0	0	0	0
	GPS ONLY	1	2	0	2	1	18	13
	GLONASS ONLY	5	1	3	8	8	3	20

In our analysis of Altitude Differences (ΔH) for the ESA stations in 2019, 2020, and 2021. Table 3 shows that in 2019, it was evident that GPS-only solutions consistently provided lower altitude difference values compared to GLONASS-only solutions across all stations, except for ISNA. ISNA's behavior was characterized by notably high error values of 36 mm for

GPS-only and 2 mm for GLONASS-only. A similar pattern persisted in 2020, with most stations favoring GPS-only solutions. However, ISNA displaying errors of 61 mm for GPS-only and 9 mm for GLONASS-only. In 2021, GPS-only solutions continued to outperform GLONASS-only solutions in most stations, with lower error values. Nevertheless, ISNA and ADFO stations once again deviated from this trend. ISNA exhibited a significant difference, with GPS-only error at 54 mm and GLONASS-only at 32 mm, while ADFO showed a considerable difference with GPS-only error at 75 mm and GLONASS-only at 11 mm.

4.3 PPP SOFTWARE EVALUATION

Table 4 displays the precise coordinates for eight strategically located stations spanning Egypt's north-to-south expanse. These coordinates were meticulously computed using BERNESE V.5.2 as the reference datum. Our calculations were based on the inclusion of three IGS stations: BSHM20705M001, DYNG12602M006, and MBAR33901M001, serving as fixed stations during processing, as illustrated in Figure 15. Additionally, we conducted a thorough comparison, assessing the results produced by three distinct processing programs: PPPH, PPP-ARISEN, and PRIDE-PPPAR. This rigorous analysis sheds light on the performance and reliability of these processing tools when paired with BERNESE V.5.2, providing valuable insights for GNSS applications across Egypt's diverse geographic regions.

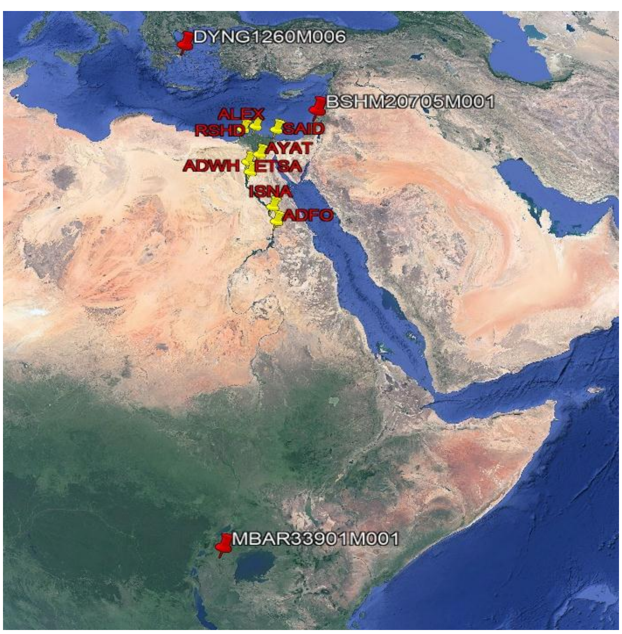

Figure (6): Distribution of the Eight Stations with IGS stations.

Table 4. The Accurate Coordinates for the Eight Stations Utilizing BERNESE V.5.2

STATIONS	BERNESE V.5.2		
	E	N	H
SAID	431061.865	3459923.206	29.917
RSHD	254864.713	3477396.801	36.864
ALEX	776759.459	3455839.165	66.832
AYAT	331161.557	3277790.792	58.828
ETSA	285914.341	3236322.477	41.665
ADWH	281853.319	3176222.761	64.629
ISNA	455494.662	2797018.443	102.45
ADFO	487942.498	2762684.428	105.958

Table 5. Coordinates Deviation Comparison in (mm) with PPP-ARISEN, PPPH, PRIDE-PPPAR

STATIONS	PPP-ARISEN			PPPH			PRIDE-PPPAR		
	ΔE	ΔN	ΔH	ΔE	ΔN	ΔH	ΔE	ΔN	ΔH
SAID	3	5	6	15	7	17	3	5	3
RSHD	2	5	12	6	6	20	1	5	7
ALEX	2	5	12	1	5	17	1	5	7
AYAT	2	4	10	1	4	12	2	4	10
ETSA	3	4	4	12	4	12	3	4	2
ADWH	2	6	13	6	5	13	2	6	8
ISNA	5	2	9	23	3	18	3	2	9
ADFO	7	5	3	4	4	2	3	4	2

Table 5 compares Coordinate Deviation (in mm) across PPP-ARISEN, PPPH, and PRIDE-PPPAR using BERNESE V.5.2 as the datum. For Departure Error (ΔE), PRIDE-PPPAR excels with 1 mm to 3 mm, followed by PPP-ARISEN (2 mm to 7 mm) and PPPH (1 mm to 23 mm). In Latitude Error (ΔN), PRIDE-PPPAR matches PPP-ARISEN in most stations except ADFO, where it achieves a 4 mm error, better than PPP-ARISEN's 5 mm. PPPH displays the highest error in several places, hitting 7 mm in SAID. In Altitude Error (ΔH), PRIDE-PPPAR stands out with errors from 2 mm to 10 mm, while PPP-ARISEN ranges from 3 mm to 13 mm, and PPPH registers errors between 2 mm and 20 mm. PRIDE-PPPAR demonstrates consistent precision across categories, highlighting its accuracy.

The results obtained from Bernese Software for the eight stations revealed average RMS errors of 2.0138 mm in (X), 1.275 mm in (Y), and 0.8325 mm in (Z) for the ellipsoidal heights, showcasing its robust performance. PRIDE-PPPAR output yielded average sigma values of 0.259 mm in (X), 0.210 mm in (Y), and 0.161 mm in (Z) across the stations, emphasizing its precision. PPP-ARISEN demonstrated remarkable accuracy with average sigma values of 0.133 mm in (X), 0.089 mm in (Y), and 0.088 mm in (Z). Additionally, PPPH exhibited average sigma values of 0.294 mm in (X), 0.352 mm in (Y), and 0.197 mm in (Z).

5 CONCLUSIONS

1) The GPS-only solution consistently demonstrates the least errors in the easting, northing, and height directions across most of stations. This solution showcases its strong performance and reliability in providing accurate positioning results.

2) The GLONASS-only solution consistently exhibits the highest errors in both easting and northing directions, as well as in height, across most of the stations we investigated. Although the differences between GPS and GLONASS are relatively small.

3) the GLONASS-only solution can be a viable alternative in cases where GPS is unavailable, as the differences in accuracy between the two systems are relatively small. This indicates the potential for using GLONASS as a backup in various applications when GPS signals are disrupted.

4) For software, our study, utilizing BERNESE V.5.2 as a datum to compare program accuracy, revealed that PRIDE-PPPAR consistently exhibited the highest accuracy, followed by PPP-ARISEN, with PPPH displaying the least accuracy. These findings underscore the significance of selecting the most precise processing software for GNSS applications, with PRIDE-PPPAR emerging as a reliable choice for achieving accurate results.

5) Open-source PPP software, specifically PRIDE-PPAR, PPP-ARISEN, and PPPH, can be utilized with acceptable accuracy. The deviations observed, ranging from 10 mm in PRIDE-PPAR to 23 mm in PPPH, compared to BERNESE software, indicate that these open-source solutions provide reliable results for precise point positioning in GNSS applications.

Acknowledgement

We extend our sincere thanks to the Egyptian Surveying Authority for generously providing the GNSS data from their CORS.

Credit Authorship Contribution Statement:

A.A.Abdelnaeim: Methodology, Writing Original Draft, Software.

A.I.ELHATTAB: Conceptualization, Review and Editing, Supervision.

M.H.AZZAM: Supervision, Review and Editing.

R.M.ABDELWADOOD: Supervision, Review and Editing.

A.A.ELSHARKAWY: Supervision, Review and Editing.

Declaration of competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

6 REFERENCES

[1] Hofmann-Wellenhof, Bernhard, Herbert Lichtenegger, and Elmar Wasle. *GNSS–global navigation satellite systems: GPS, GLONASS, Galileo, and more*. Springer Science & Business Media, 2007.

[2] Teunissen, Peter JG, and Oliver Montenbruck, eds. *Springer handbook of global navigation satellite systems*. Vol. 10. Cham, Switzerland: Springer International Publishing, 2017.

[3] Grewal, Mohinder S., Angus P. Andrews, and Chris G. Bartone. *Global navigation satellite systems, inertial navigation, and integration*. John Wiley & Sons, 2020.

[4] Rosłoniec, Stanisław. "Satellite Navigation Systems." In *Fundamentals of the Radiolocation and Radionavigation*, pp. 315-353. Cham: Springer International Publishing, 2023.

[5] Han, Houzeng, Jian Wang, Jinling Wang, and Alberto Hernandez Moraleda. "Reliable partial ambiguity resolution for single-frequency GPS/BDS and INS integration." *GPS solutions* 21 (2017): 251-264.

[6] Cai, Changsheng, and Yang Gao. "Precise point positioning using combined GPS and GLONASS observations." *Positioning* 1, no. 11 (2007).

[7] El-Hattab, A. I. "Assessment of PPP for establishment of CORS network for municipal surveying in Middle East." Survey review 46, no. 335 (2014): 97-103.

[8] Abd Rabbou, M., and A. El-Rabbany. "Performance analysis of precise point positioning using multi-constellation GNSS: GPS, GLONASS, Galileo and BeiDou." *Survey Review* 49, no. 352 (2017): 39-50.

[9] Šugar, Danijel, Boris Skopljak, and Željko Bačić. "Multi-Constellation GNSS Baseline Solutions-a Perspective from the User’s and Developer’s Point of View." In Proceedings of the FIG Congress. 2018.

[10] Dach, Rolf, and Peter Walser. "Bernese GNSS Software Version 5.2." (2015).

[11] Bahadur, Berkay, and Metin Nohutcu. "PPPH: a MATLAB-based software for multi-GNSS precise point positioning analysis." *GPS solutions* 22, no. 4 (2018): 113.

[12] Zhang, Chengfeng, Aizhi Guo, Sidao Ni, Gongwei Xiao, and Hao Xu. "PPP-ARISEN: an open-source precise point positioning software with ambiguity resolution for interdisciplinary research of seismology, geodesy and geodynamics." *GPS Solutions* 27, no. 1 (2023): 45.

[13] Geng, Jianghui, Xingyu Chen, Yuanxin Pan, Shuyin Mao, Chenghong Li, Jinning Zhou, and Kunlun Zhang. "PRIDE PPP-AR: an open-source software for GPS PPP ambiguity resolution." *GPS solutions* 23 (2019): 1-10.