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Accuracy and Applicability of GNSS PPP for GNSS Surveys: A Case Study in the Nile Delta, Egypt

Gomaa M. Dawod*, Ahmed M. Amin and Hoda F. Mohamed
Survey Research Institute, National Water Research Center, Giza, Egypt

ABSTRACT : *The Due to its technical and economical merits, the Precise Point Positioning (PPP) approach of Global Navigation Satellite Systems (GNSS) has been utilized for a wide range of surveying and geodetic applications in recent years. However, its accuracy and applicability are significantly limited by the occupation time. This paper investigates the relationship between accuracy and static occupation time of PPP in Egypt as a case study. Based on the available GPS+GLONASS datasets, accomplished results showed that precision of few centimeters in both latitude and longitude could be obtained by occupation of more than half an hour. In addition, a sub-centimeter accuracy requires occupation of two hours at least. From an accuracy point of view, two-centimeters accuracy is attained with four hours of static occupation. It can be concluded that civil engineering applications require occupations varying from 1 to 4 hours according to the required accuracy. Furthermore, an occupation of half an hour or less should be assigned only for reconnaissance and small-scale mapping activities. The current study's conclusions should be taken into account in surveying, mapping, and civil engineering applications in Egypt.*

KEYWORDS *GNSS, PPP, Occupation Time, Accuracy, Applicability, Egypt.*

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I. INTRODUCTION

PPP has become a powerful widely-used positioning technique utilizing satellite-based GNSS for a wide range of applications. With the PPP technique, GNSS satellites' observations collected by a single receiver, without the need of a nearby base or reference station, are used to determine its 3D coordinates. In nowadays, PPP is regarded as a dominant solution where precise positioning and navigation are required in remote locations, where reference station infrastructure is not available. From an economic perspective, PPP is a cost-effective method since it works with a single GNSS receiver in the static or kinematic mode.

The most important feature of the GNSS PPP technique is its utilization of precise satellite orbits and satellite clock corrections from either commercial or public service. Traditionally, PPP was applied as a relative GNSS processing technique where one/or more station from the International GNSS Services (IGS) network are downloaded along with the precise orbits and clocks. The baseline between such a station and the observed one was, then, being post-processed to compute the precise coordinates of the occupied station. In the last few years, absolute PPP was introduced by collecting and utilizing precise satellites orbits and clocks to estimate the coordinates of the occupied station directly without ting to the IGS network. Such processing could be post-processing or real-time. The occupation time or GNSS session plays a critical role in the anticipated accuracy of the PPP solution. For example, Abdallah and Schwieger [1] found that a centimeter accuracy of 3D coordinates could be obtained after 4 hours of static occupation. Similarly, Harima et al. [2] found that ten centimeter horizontal accuracy could be achieved when the static occupation time equals half an hour. Moreover, a two-centimeter level of accuracy has been reported in Egypt based on two-hour static occupation [3].

PPP has been utilized for several geodetic and environmental applications. For example, Bahadur and Nohutcu [4] showed that PPP could provide a positioning solution appropriate for establishing geodetic control points in Turkey. Vazquez-Ontiveros et al [5] have utilized PPP for monitoring structural health of bridges. The utilization of PPP processing of smartphones has been recently investigated particularly in urban environments [6]. Also, Rabah et al. [7] have proposed the utilization of PPP for establishing a Continuously Operating Reference Station (CORS) network in Kuwait. Recently, PPP is proposed to be utilized with smartphones where it could reach sub-meter errors in static mode of a few minutes occupation time [8].

This paper aims to investigate the accuracy and applicability of GNSS PPP (particularly GPS+GLONASS) in GNSS surveys in Egypt as a case study. Three scenarios have been investigated, namely short occupation (1 to 60 minutes), medium occupation (1 to 6 hours), and long occupation (6 to 24 hours). Accomplished results in both 3D and 2D cases have been analyzed.

II. METHEDOLOGY

The basic mathematical models of the PPP approach for both pseudorange and carrier phase are [9]:

$$L_i^k - \rho_i^k - c(\Delta t_i - \Delta t^k) - \alpha_i^k T_i + I_i^k - \lambda B_i^k - \varepsilon = 0 \quad (1)$$

$$P_i^k - \rho_i^k - c(\Delta t_i - \Delta t^k) - \alpha_i^k T_i + I_i^k - c(b^k + b_i) - \varepsilon = 0 \quad (2)$$

where,

L_i^k, P_i^k : undifferenced carrier phase and code observations (meters),
ρ_i^k : geometric distance between satellite and receiver,
B_i^k : carrier phase bias,
N_i^k, δN_i^k : integer carrier phase ambiguity and non-zero initial fractional phase,
Δt_i, Δt^k : receiver and satellite clock offset,
T_i : troposheric total zenith delay,
α_i^k : troposheric mapping function,
I_i^k : slant ionospheric delay,
b_i, b^k, d_i, d^k : receiver and satellite code and phase hardware delays,
λ : corresponding carrier wavelength,
c : speed of light, and
ε : random error or residual.

PPP technique provides accuracy in the range of centimeter-to-decimeter level depending on the occupation time of static GNSS surveys [10]. Many online GNSS processing services are applying the absolute PPP technique for fast processing and precise output. Such services include the free post-processing Canadian Spatial Reference System PPP (CSR-PPP) [11] and the non-free real-time Trimble RTX. For example, Trimble RTX could provide 2 centimeters horizontal accuracy and 5 centimeters vertical accuracy having collected static GNSS observations for at least 15 minutes [12]. Other online processing services, such as the Australian AUSPOS and the American OPUS, still utilized the relative PPP approach.

III. STUDY AREA AND AVAILABLE DATA

The study area is located in the north of Egypt covering Port Said, Alexandria and Cairo cities (Fig. 1). It is bounded by latitudes 29.9° N and 31.6° N and longitudes 29.7° E and 32.3° E. The utilized dataset comprises three GNSS stations, just as a case study, belong to the CORS network established and operated by the Egyptian Survey Authority (ESA). Those stations are located in Port Said. Alexandria, and Cairo cities. A 24-hours raw GNSS dataset in the Receiver Independent Exchange Format (RINEX) has been obtained for each station. The data has been observed, with a 30-second interval, on January 23rd, 2019 and include data from only GPS and GLONASS systems as the installed receivers only track those satellites signals. The processing has been carried out using the Trimble TBC v. 5.2. It uses precise satellite orbit, clock and bias corrections derived from a global GNSS network to compute accurate user positions worldwide.

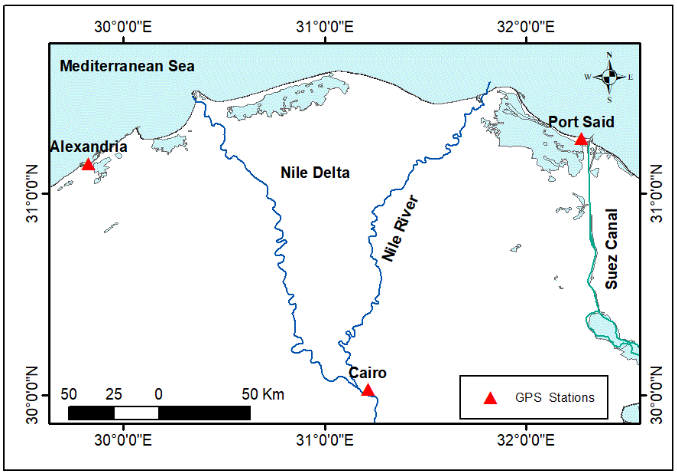

Fig. 1: The Study Area

IV. PROCESSING AND RESULTS

To investigate the applicability of the PPP approach, each observation file has been cut into several small files each represents a special scenario of occupation session. Those scenarios could be divided into three main cases: short occupation (1, 2, 5, 15, 30, and 60 minutes), medium occupation (1, 2, 3, 4, 5, and 6 hours), and long occupation (12, 18, and 24 hours). All raw RINEX files have been processed by the Trmibal TBS v. 5.2 (that utilizes equations 1 and 2) and the attained results have been analyzed in the three major scenarios. Both geodetic and Universal Transfers Mercator (UTM) zone 35 coordinates have been investigated relative to the World Geodetic System 1984 (WGS84) datum. Based on the date of collected data, the International Terrestrial Reference Frame (ITRF) of 2014 epoch 2019.1 has been the datum of the output. Statistical indicators for precision and accuracy have been determined. Based on the results of each station, the average indicators of each scenario have been computed, and presented herein, instead of dealing with three different GNSS stations.

The first scenario presents short GNSS occupation sessions ranging from one minute to sixty minutes. The precision of each case is expressed by the standard deviation indicator. Table 1 and Figure 2 present the average precision of each occupation time. It can be noticed that the standard deviations of occupations of lengths 1-5 minutes are greater than one meter. The occupation of 15 minutes produces precision of less than a meter, while precision of few centimeters could be obtained from sessions of lengths equal to or greater than half an hour.

Table 1: Precision of GPS+GLONASS Short Occupation Times

Occupation (minutes)	Standard Deviation of the Average (m)		
	Latitude	Longitude	Height
1	±2.452	±3.271	±5.098
2	±1.527	±2.479	±3.250
5	±0.784	±0.837	±1.468
15	±0.172	±0.365	±0.535
30	±0.019	±0.017	±0.063
60	±0.011	±0.011	±0.036

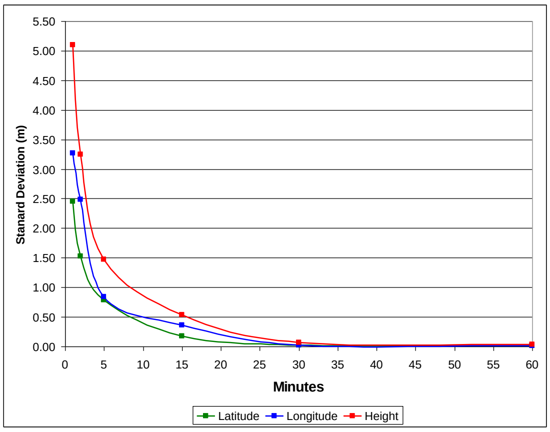

Fig. 2: Precision of GPS+GLONASS Short Occupation Times

The second investigated scenario represent medium occupation sessions varying between 1 and 6 hours. Similarly, Table 2 and Figure 3 present the average precision of each occupation time in such a case. It can be seen that the precision of occupation of 2 hours is less than a centimeter for both latitude and longitude, but the height's precision is still greater than 2 centimeters. In addition, it can be realized that longer occupation times significantly enhance the precision of the height more than the precision of both latitude and longitude. For instance, the precision of height at the 6-hour scenario is almost 157% and 71% better than those of the 1-hour and 2-hours cases respectively.

Table 2: Precision of GPS+GLONASS Medium Occupation Times

Occupation (hours)	Standard Deviation of the Average (m)		
	Latitude	Longitude	Height
1	±0.011	±0.011	±0.036
2	±0.007	±0.008	±0.024
3	±0.005	±0.006	±0.019
4	±0.004	±0.005	±0.017
5	±0.004	±0.004	±0.015
6	±0.003	±0.004	±0.014

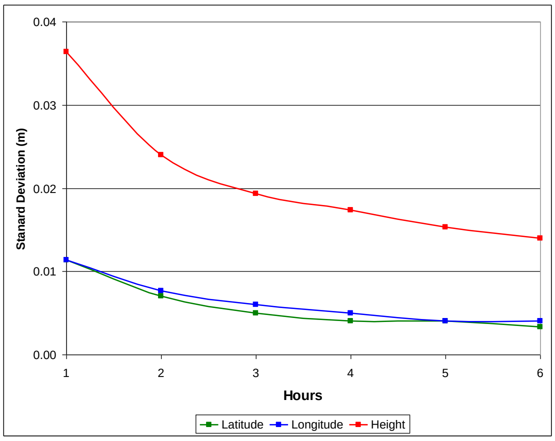

Fig. 3: Precision of Medium GPS+GLONASS Occupation Times

Table 3 and Figure 4 demonstrate the attained results of the third case for long occupation sessions varying between 12 and 24 hours. It can be noticed that the precision of occupation of 18 and 24 hours produce precision of two millimeters in both latitude and longitude and eight millimeters for the height. Also, it can be seen that the 24-hour session produces precision similar to the 24-hour one. Based on available data, it might say that 18 hours of GNSS occupation is optimum to achieve few-millimeters precision for precise geodetic GNSS activities.

Table 3: Precision of GPS+GLONASS Long Occupation Times

Occupation (hours)	Standard Deviation of the Average (m)		
	Latitude	Longitude	Height
12	±0.003	±0.003	±0.010
18	±0.002	±0.002	±0.008
24	±0.002	±0.002	±0.008

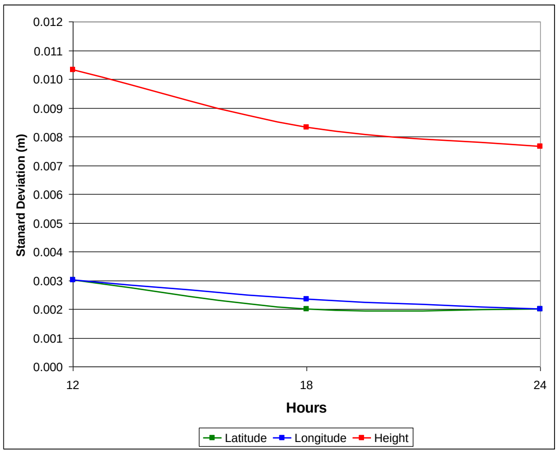

Fig. 4: Precision of GPS+GLONASS Long Occupation Times

Next, the study tries to investigate the accuracy of the GNSS PPP rater than its precision. In this regard, it is known that estimating the accuracy of measurements requires the knowledge of true values. The study considers the 24-hour coordinates of each GNSS station as a possible candidate for the true coordinates. Consequently, comparing the 24-hours coordinates to the results of each scenario might be considered as an accuracy estimation.

Table 4, and Figures 5, 6, and 7 present the attained results in terms of accuracy indicators. Several significant remarks could be drawn. First, it can be realized that the accuracy of occupation times less than 15 minutes are in the order of few decimeters, which is not appropriate for GNSS surveying applications. Next, it can be seen that the accuracy of few centimeters could be obtained when the occupation time is more than a quarter an hour. Starting from 1-hour of occupation, an accuracy of 2-centimeters becomes feasible. The level few-millimeters accuracy could be achieved in latitude and longitude when the occupation time is more than three hours. Additionally, the longer the occupation time the more increase of height accuracy. On the other hand, the errors in height estimation have been decreased by more than two orders of magnitude at the 18-hours occupation compared to the 4-hours results. Generally, it can be concluded that surveying-grade GNSS activities, with accuracy of 5 centimeters, require an occupation time of more than 15 minutes. However, 24-hours occupations still needed for accurate geodetic GNSS applications such as the establishment of control points and monitoring crustal deformation. Similar results have been reported by Abou Galala et al. [13].

Table 4: Accuracy of GPS+GLONASS Short, Medium, and Long Occupation Times

Occupation (minutes)	Average Absolute Errors (m)		
	Latitude	Longitude	Height
1	-0.119	0.462	0.362
2	-0.051	0.347	0.502
5	-0.091	0.240	0.303
15	0.045	-0.041	-0.050
30	0.030	0.000	0.006
60	0.021	0.001	0.005
Occupation (hours)	Average Absolute Errors (m)		
	Latitude	Longitude	Height
1	0.021	0.001	0.005
2	0.015	0.000	0.004
3	0.015	0.000	0.002
4	0.015	-0.001	0.000
5	0.013	-0.001	0.001
6	0.011	-0.001	0.001
Occupation (hours)	Average Absolute Errors (m)		
	Latitude	Longitude	Height
12	0.006	-0.002	0.002
18	0.004	-0.001	0.001

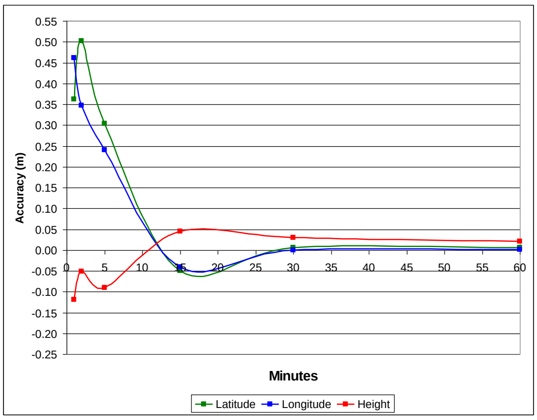

Fig. 5: Accuracy of GPS+GLONASS Short Occupation Times

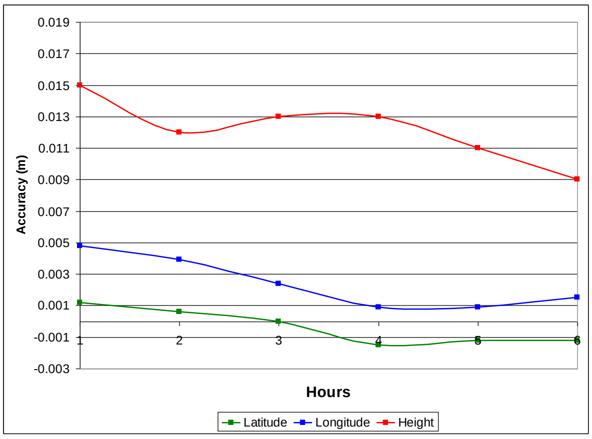

Fig. 6: Accuracy of GPS+GLONASS Medium Occupation Times

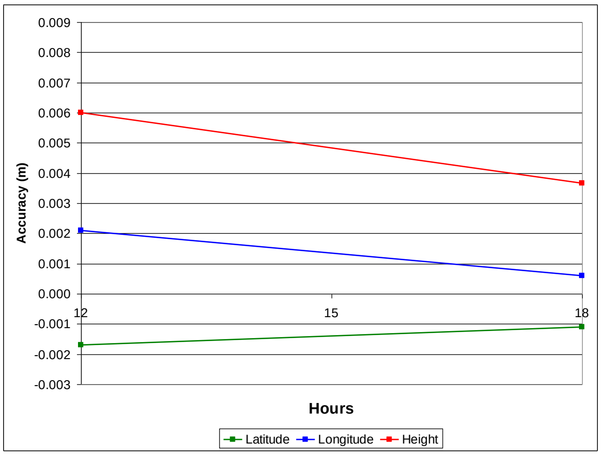

Fig. 7: Accuracy of GPS+GLONASS Long Occupation Times

The second analysis step concerns the estimation of projected coordinates' accuracy, particularly the UTM coordinates, for mapping applications at each scenario of GNSS occupation time. Table 5 and Figures 8, 9, and 10 present the accomplished findings. It can be seen that the sub-decimeter level of accuracy is achieved after a 15-minute occupation, while the sub-centimeter level is attained with 30-minutes or more of occupation time. Also, the millimeter level of accuracy is obtained with an occupation time of 3 hours and more.

Table 5: Accuracy of GPS+GLONASS Short, Medium, and Long Occupation Times for the UTM Coordinates

Occupation (minutes)	Average Absolute Errors (m)	
	North	East
1	0.478	0.321
2	0.358	0.445
5	0.248	0.266
15	-0.042	-0.044
30	0.000	0.004
60	0.000	0.004
Occupation (hours)	Average Absolute Errors (m)	
	North	East
1	0.000	0.004
2	0.001	0.003
3	0.000	0.001
4	-0.001	0.000
5	-0.001	0.000
6	-0.001	0.001

Occupation (hours)	Average Absolute Errors (m)	
	North	East
12	-0.001	0.001
18	0.000	0.000

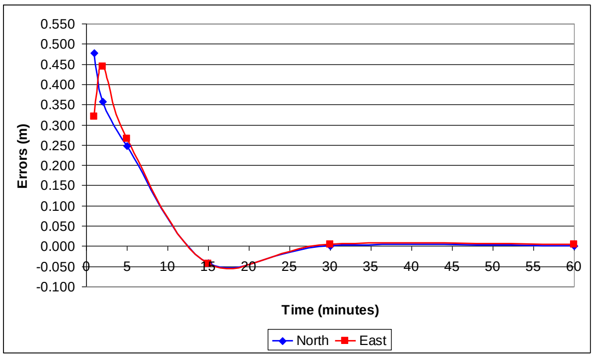

Fig. 8: Accuracy of GPS+GLONASS Short Occupation Times for the UTM Coordinates

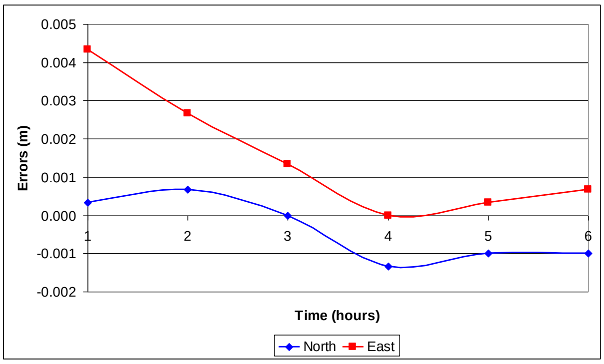

Fig. 9: Accuracy of GPS+GLONASS Medium Occupation Times for the UTM Coordinates

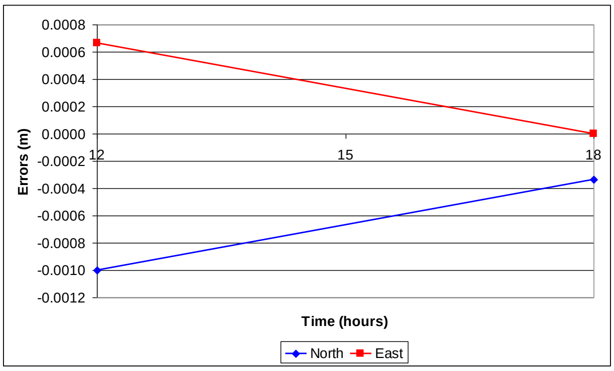

Fig. 10: Accuracy of GPS+GLONASS Long Occupation Times for the UTM Coordinates

The 3D estimates of both precision and accuracy have been computed and presented in Table 6. From this table, few final remarks could conclude the findings of the current research study. From a precision point of view, it is a must to have a GNSS occupation time of more than 15 minutes to achieve the sub-meter level. Thus, occupation times of few minutes should be avoided in GNSS surveying and mapping activities. For surveying applications require sub-decimeter precision, occupation of 15 minutes or more. If the required precision is less than five centimeters, the time of occupation should be at least one hour. A one-centimeter precision could be achieved when the occupation time is at least 12 hours. Similar results have been reported by Abou-Galala et al. [14].

Table 6: 3D Accuracy and Precision of GPS+GLONASS Short, Medium, and Long Occupation Times

Occupation (minutes)	3D Accuracy (m)	3D Precision (m)
1	0.599	±6.535
2	0.612	±4.364
5	0.397	±1.863
15	0.078	±0.670
30	0.030	±0.068
60	0.021	±0.040
Occupation (hours)	3D Accuracy (m)	3D Precision (m)
1	0.021	±0.040
2	0.016	±0.026
3	0.015	±0.021
4	0.015	±0.018
5	0.013	±0.016
6	0.011	±0.015
Occupation (hours)	3D Accuracy (m)	3D Precision (m)
12	0.007	±0.011
18	0.004	±0.009
24	NA	±0.008

According to the Egyptian surveying standards [15], it can be concluded that first-order geodetic networks require occupation of at least 4 hours. In addition second and third-order networks need static occupation of at least 1 and 0.5 hours respectively. Deformation and crustal monitoring geodetic applications require the highest precision and accuracy. Thus, a 24-hour occupation is appropriate for such high-precision activities. For civil engineering works, it is obvious that the precision of static GNSS occupation of less than half an hour could only be suitable for reconnaissance and small-scale mapping. Other engineering activities would require occupation ranging from 1 to 4 hours based on the required precision limits for each project.

V. Conclusions

The accuracy of the GNSS PPP technique depends on several factors, but the occupation time is the most critical one. Based on 24-hour GNSS datasets at Alexandria, Port Said, and Cairo, the accuracy and applicability of PPP (mainly GPS+GLONASS) in Egypt have been investigated. The analysis has been carried out for short, medium, and long occupation times.

Regarding the precision of 3D geodetic coordinates, attained results showed that the standard deviations of occupations of lengths 1-5 minutes are greater than one meter, while precision of few centimeters could be obtained from sessions of lengths equal to or greater than half an hour. For medium occupation, it has been noticed that the precision of occupation of 2 hours is less than a centimeter for both latitude and longitude, but the height's precision is still greater than 2 centimeters. Furthermore, it has been realized that longer occupation times significantly enhance the precision of the height more than the precision of both latitude and longitude. Based on available data, it might say that 18 hours of GNSS occupation is optimum to achieve few-millimeters precision for precise geodetic GNSS activities. From an accuracy perspective, it is noticed that at least 1-hour of occupation produce accuracy of 2-centimeters, while the level few-millimeters accuracy could be achieved in latitude and longitude when the occupation time is more than three hours.

It has been concluded that first-order geodetic network requires occupation of at least 4 hours, and second and third-order networks need static occupation of at least 1 and 0.5 hours respectively. Moreover, a 24-hour occupation would be appropriate for high-precision activities. For civil engineering works, it is clear that the precision of static GNSS occupation of less than half an hour could only be suitable for reconnaissance and small-scale mapping. Other engineering activities would require occupation ranging from 1 to 4 hours based on the required precision limits for each project. The concluded remarks of the current study should be considered in surveying, mapping, and civil engineering applications in Egypt.

REFERENCES

[1]. Abdallah, A. and Schwieger, V.: The effect of convergence time on the static- PPP solution, Presented at the 2nd International workshop on “Integration of Point- and Area-wise Geodetic Monitoring for Structures and Natural Objects”, March 23-24, Stuttgart, Germany (2015).

[2]. Harima, K., Choy. S., Rizos, C. , and Satoshi, K.: Performance of real-time precise point positioning in New Zealand, Presented at the FIG Working Week 2016, May 2–6, New Zealand (2016).
[3]. El Manaily, E., Abd Rabbou, M., El-Shazly, A. and Baraka, M.: Evaluation of quad-constellation GNSS precise point positioning in Egypt, Artificial Satellites, Vol. 52, No. 1, pp. 9-18 (2017).
[4]. Bahadur, B. and Nohutcu, M.: Multi-GNSS PPP: An alternative positioning technique for establishing ground control points, International Journal of Environment and Geoinformatics, 7(1): 88-92. https://doi.org/10.30897/ijegeo.710304 (2020)
[5]. Vazquez-Ontiveros, J., Vazquez-Becerra, G., Quintana, J., Carrion, F., Guzman-Acevedo, M. and Gaxiola-Camacho, R. Implementation of PPP-GNSS measurement technology in the probabilistic SHM of bridge structures, Measurements, https://doi.org/10.1016/j.measurement.2020.108677 (2020)
[6]. Shinghal, G. and Bisnath, S.: Conditioning and PPP processing of smartphone GNSS measurements in realistic environments, Satellite Navigation, 2:10, https://doi.org/10.1186/s43020-021-00042-2 (2021)
[7]. Rabah, M. Zedan, Z. Ghanem, E., Awad, A. and Sherif, S.: Study the feasibility of using PPP for establishing CORS network, Arabian Journal of GeoSciences, 9: 613, DOI: 10.1007/s12517-016-2647-8 (2016).
[8]. Wang, L., Li, Z., Wang, N. and Wang, Z.: Real-time GNSS precise point positioning for low-cost smart devices, GPS Solutions, 25:69, DOI: 10.1007/s10291-021-01106-1 (2021).
[9]. Hofmann-Wellenhof, B., Lichtenegger, H. and Wasle, E.: GNSS: Global Navigation Satellite Systems. GPS, GLONASS, Galileo and more, Springer Wien, New York, USA (2008).
[10]. Choy, S. and Harima, K.: Satellite delivery of high-accuracy GNSS precise point positioning service: an overview for Australia, Journal of Spatial Science, DOI: 10.1080/14498596.2018.1427155 (2018).
[11]. CSR-PPP (Canadian Spatial Reference System Precise Point Positioning): https://webapp.geod.nrcan.gc.ca/geod/tools-outils/ppp.php, Accessed Jun 4 (.2021).
[12]. Trimble Navigation: Center Point RTX, https://positioningservices.trimble.com/services/rtx/centerpoint-rtx/, Accessed Jun 1 (. 2021).
[13]. Abou Galala, M., Rabah, M. and Zidan, Z.: Assessment of the accuracy and convergence period of precise point positioning, Mansoura Enginnerring Joyrnal, 41(2): C1-C5 (2016).
[14]. Abou-Galala, M., Rabah, M., Kaloop, M., and Zidan, Z.: Assessment of the accuracy and convergence period of precise point positioning, Alexandria Engineering Journal, No. 57, pp. 1721-1726 (2018).
[15]. ESA (Egyptian Surveying Authority): Technical specifications for surveying and mapping works, Part 1: Surveying specifications, A technical report, ESA, Giza, Egypt (2020).

Gomaa M. Dawod, et. al. "Accuracy and Applicability of GNSS PPP for GNSS Surveys: A Case Study in the Nile Delta, Egypt."*American Journal of Engineering Research (AJER)*, vol. 11(05), 2022, pp. 10-18.