Performance Analysis of the Permanent and a Regional GNSS Networks in Egypt

R. E. Sleem[a], M. A. Abdelfatah[a], A. E. Mousa[b], G. S. El-Fiky[a,c]

Abstract— Recently, GPS has become the most significant used survey system. The GPS performance is affected by the number of tracked satellites, so its performance is degraded in limited sky regions. Thus, one of the good solutions is adding other GNSS satellites and make combined solutions between GNSS systems to increase the number of satellites.

In this study, there are two networks; the permanent and a regional networks. In the permanent network, a comparative study using GPS, GLONASS and combined GPS with GLONASS has been implemented to investigate the possible benefit of combined solution. Data processing has been performed with different values of elevation cut-off angles. The regional network has been processed using different cases of combined satellite systems. These systems are GPS, GLONASS and BEIDOU.

For the permanent network, in the condition of open sky view, the average coordinate errors for GPS, GLONASS and combined solution are respectively 16.5, 25.0 and 36.0 mm. The solutions by using GPS only are more accurate than other cases and there are no clear improvements from combined GPS and GLONASS. The significance of combined solution arise when the elevation cut-off angle was set to 40° and higher which represent the extremely limited sky view such as urban canyons.

For the regional network, the results indicated that combined GPS with BEIDOU is the best case because it achieved the smallest closure error with 19.50 mm. GPS only is better than GLONASS only, BEIDOU only, combined solution between GPS and GLONASS and combined GPS with GLONASS and BEIDOU.

Index Terms— Performance, Analysis, GNSS, GPS, GLONASS, BEIDOU, Permanent Network.

1 Introduction

In the last years, GPS which is used for getting the position of any point accurately has become the most significant survey system. The nominal constellation of 24 GPS satellites and 7 spare units orbit in six orbital planes and the inclination angle of the orbital planes is 55° to the equator with an altitude of 20200 km and with 12 sidereal hours as an orbit period [1].

GLONASS (Global Navigation Satellite System) is a positioning satellite system developed by the Russian Federation. In recent years, the performance of GLONASS system has been improved after the constellation of 24 operational satellites is completely operated [2]. GLONASS system consists of 24 satellites that orbit in three circular orbital planes with an inclination of 64.8° to the equator with altitude of 19100 km and a period of 11hr, 15min and 44sec [1].

The Chinese system (BEIDOU) consists of 27 satellites in medium earth orbit (MEO), 5 satellites in geostationary orbit (GEO) and 3 satellites in geosynchronous orbit (IGSO). The GEO and IGSO satellites have an altitude of 35786 km. The 27 MEO satellites orbit in three orbital planes with an altitude of 21528 km and an inclination angle of 55° to the equator [3].

The performance of GPS is affected by the number of tracked satellites, so the positioning performance of GPS is degraded in limited sky regions or in urban canyons because of the limited number of tracked satellites [4]. Thus, one of the good solutions is increasing the number of visible satellites by adding other GNSS satellites and make a combined solutions between GNSS systems. There are many advantages of increasing the number of concurrent visible satellites, such as improving the performance and accuracy especially in the case of urban canyons or in real time positioning and the great number of tracked satellites help to eliminate the weak signals or the inaccurate satellites [5]. In the environment of urban canyons, narrow regions and tall buildings block most of satellites' signals so the number of visible satellites is decreased as shown in figure (1) [6].

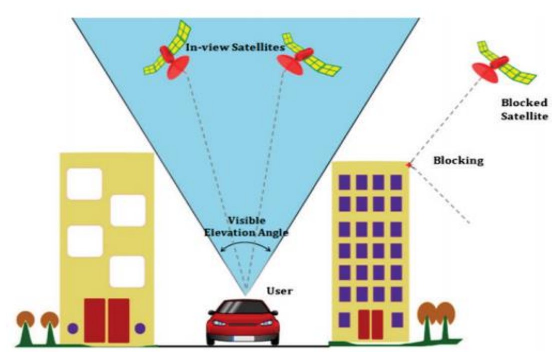

Fig. (1): Satellite Blocking in Urban Canyons.

A possible solution to overcome the problem of satellite blocking is to combine the GPS observations with other navigation systems such as the Russian system (GLONASS), the Chinese system (BEIDOU) and the European system (GALILEO) [6]. The integration of GLONASS, Galileo or BEIDOU systems to GPS constellation can increase the number of tracked satellites and can enhance the positioning dilution of precision (PDOP) values [2].

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To process integrated GNSS observations, many problems arise from the difference in reference frames, time systems and frequency systems (signal structures) utilized in different GNSS systems [7]. The reference frames of GPS, GLONASS and BEIDOU are respectively World Geodetic System 1984 (WGS-84), Parametry Zemli 1990 (PZ-90) and China Geodetic Coordinate System 2000 (CGCS2000) [1]. The reference frame of GLONASS and BEIDOU are transformed to the GPS reference frame. The GLONASS and BEIDOU time systems are unified to GPS time system [8]. GPS and BEIDOU satellites use CDMA principle (Code Division Multiple Access), while GLONASS satellites use FDMA technique (Frequency Division Multiple Access) to distinguish between the different satellite signals [1].

Alcay et al [9] presented a comparative study of network processing between GPS only and combined GPS with GLONASS. The results have confirmed that the results of GPS and combined GPS with GLONASS are consistent and have insignificant difference. The results of GLONASS only are inaccurate compared with GPS and combined solution.

Alcay and Yigit [2] presented a study that compares GPS with integrated GPS and GLONASS solutions under different conditions of sky view and different observation periods. The results have indicated that in the case of open sky view, there is insignificant difference between GPS and integrated solutions. It also has confirmed that in the case of limited sky view regions and short observation periods, the integrated solution is required to obtain high performance for positioning compared with the solution of GPS only.

Maciuk [5] performed a comparison between GPS, GLONASS and combined solution with precise point positioning technique under different sky visibility conditions. The results indicated that there is no significant improvement in the solutions of GPS only and combined solution. It confirmed that adding GLONASS to GPS observations didn't have a noticeable improvement in positioning accuracy and this integration caused deterioration in accuracy in some cases. The results also indicated that the solution of GLONASS only had the biggest errors and is not recommended for precise works.

In the present study, two types of networks; the permanent and a regional networks have been studied to investigate the possible benefit from using combined solutions. For the permanent network, a comparative study of network processing using GPS only, GLONASS only and combined GPS with GLONASS has been implemented to investigate the advantages and disadvantages of combined solution. The network consists of six stations from National Research Institute of Astronomy and Geophesics (NRIAG). Theses stations equipped with GNSS receivers that track GPS and GLONASS satellites. Data processing has been performed with different values of elevation cut-off angles (3°, 10°, 20°, 30°, 40°, 50° and 60°).

A regional network in Egypt consists of three stations equipped with GNSS receivers which track GPS, GLONASS and BEIDOU satellites. This network has been processed using different cases of satellite systems. These different cases are GPS, GLONASS, BEIDOU, combined GPS with GLONASS, combined GPS with BEIDOU, combined GLONASS with BEIDOU and combined GPS with GLONASS and BEIDOU.

2 Data Collection

Firstly, six stations from NRIAG Permanent Network; MARSA ALAM, AL-ARISH, ASWAN, AL-MANSOURA, MARSA MATROH and PORT SAID. These stations were used over 57 separate days in 2014 equipped with GNSS receivers that track GPS and GLONASS constellations see (Fig. 2).

Fig. (2): Distribution of the Permanent Network Stations in Egypt.

The data collected for this network covered from north to south locations of Egypt all over different seasons of the year 2014. The coordinates of the permanent network stations were given with high accuracy as shown in table (1) [10].

Secondly, a regional network which consists of three GNSS stations; AL-ASHER, AL-SHOBAK and ZAGAZIG has been processed by using different cases of satellite systems for 4 days in 2019. These stations equipped with GNSS receivers that track GPS, GLONASS and BEIDOU constellations see (Fig. 3).

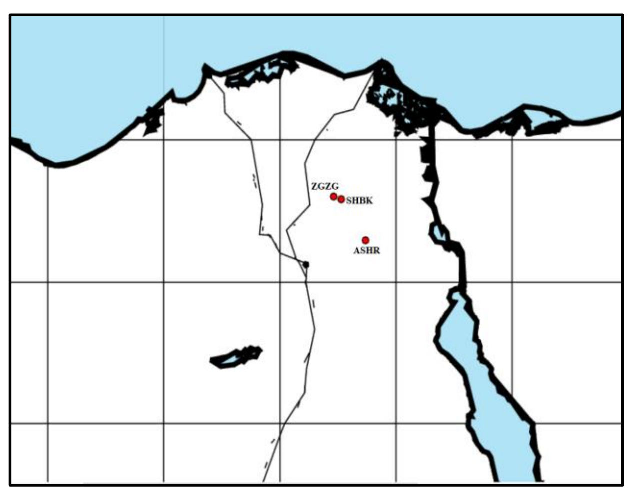

Fig. (3): Distribution of the Regional Network Stations in Egypt.

TABLE 1
THE ACCURATE COORDINATES OF THE PERMANENT NETWORK STATIONS.

STATION	LATITUDE (Φ_{ref}) (DEG.)	LONGITUDE (λ_{ref}) (DEG.)	HEIGHT (h_{ref}) (m)
ALAM	25.0669448	34.8777575	48.86922
ARSH	31.1074930	33.6169133	27.39627
ASWN	23.9707806	32.8483729	215.50721
MNSR	31.0410273	31.3526049	39.57551
MTRH	31.3457307	27.2305357	58.68772
SAID	31.2456955	32.3143399	41.96260

3 DATA ANALYSIS

For the permanent network, the observations of the six GNSS stations have been analyzed with the three cases; GPS only, GLONASS only and combined GPS and GLONASS. Bernese GPS Software Version 5.0 is used for analyzing and processing the GNSS network data [11]. The same steps and conditions have been implemented identically for GPS, GLONASS and Combined GPS and GLONASS. The created baselines are MNSR-ALAM [~748 km], MNSR-ARSH [~217 km], MNSR-ASWN [~800 km], MNSR-MTRH [~395 km] and MNSR-SAID [~95 km].

For the regional network, the observations of three GNSS stations have been analyzed with different cases of satellite systems. Compass solution version 1.8.8 is the used software for data processing [12]. The created baselines are SHBK-ZGZG [~6.50 km], ZGZG-ASHR [~43.00 km] and ASHR-SHBK [~38.00 km].

4 RESULTS AND DISCUSSION

Firstly, in the permanent network, Bernese GPS software version 5.0 is the used software for observation data analysis. Results have been compared with the accurate values of the network stations' coordinates as in table (1). The results have been evaluated by coordinate error evaluation, two sample t-test and F-test at elevation cut-off angle (E = 3°) for the three cases; GPS, GLONASS and combined GPS and GLONASS. The solutions of GPS, GLONASS and combined GPS and GLONASS have been compared at different sky view conditions to investigate the significance of combined GPS and GLONASS. These different conditions were represented by the different values of elevation cut-off angles (3°, 10°, 20°, 30°, 40°, 50° and 60°).

Secondly, the regional network has been processed by using compass solution software version 1.8.8 and different cases have been assessed. The results have been assessed by closure error, two sample t-test and F-test.

4.1 COORDINATE ERROR EVALUATION

The bar charts below illustrate the comparison between GPS, GLONASS and combined GPS and GLONASS network solutions in coordinate errors for the six stations. The coordinate errors here are represented by altitude coordinate error (Δh), latitude coordinate error (ΔN) and departure coordinate error (ΔE) in millimeters.

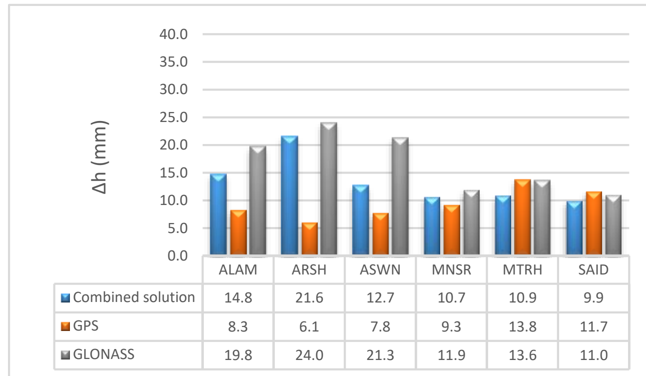

Fig. (4): Altitude Coordinate Error (Δh) in (mm) for Different Network Stations.

The bar chart in figure (4) shows that altitude coordinate errors (Δh) computed by using GPS only is smaller than errors from other cases for all stations except MTRH and SAID. The minimum coordinate errors (Δh) are 6.1, 9.9 and 11.0 mm for GPS, combined solution and GLONASS respectively. Whereas the maximum coordinate errors (Δh) are 13.8, 21.6 and 24.0 mm for GPS, combined solution and GLONASS respectively. Combined GPS and GLONASS is more accurate than GLONASS in altitude coordinate error (Δh) but is larger than GPS only. GPS achieved the smallest error (Δh) at AL-ARISH and the largest error (Δh) at MTRH.

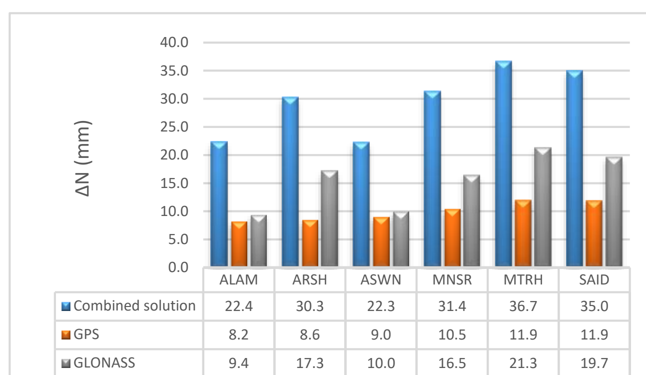

Fig. (5): Latitude Coordinate Error (ΔN) in (mm) for Different Network Stations.

In figure (5), the chart shows that GPS only achieved latitude coordinate error (ΔN) smaller than GLONASS only or combined GPS and GLONASS at the six stations which have different locations in Egypt. For GPS only, the minimum (ΔN) error is 8.2 mm at ALAM and the maximum (ΔN) error is 11.9 mm at MTRH and SAID. For GLONASS only, the minimum and maximum (ΔN) errors are 9.4 mm at ALAM and 21.3 mm at MTRH respectively. The case of combined GPS and GLONASS is the worst case in (ΔN) coordinate error which achieved 22.3 mm as the minimum error at ASWN and the maximum error is 36.7 mm at MTRH.

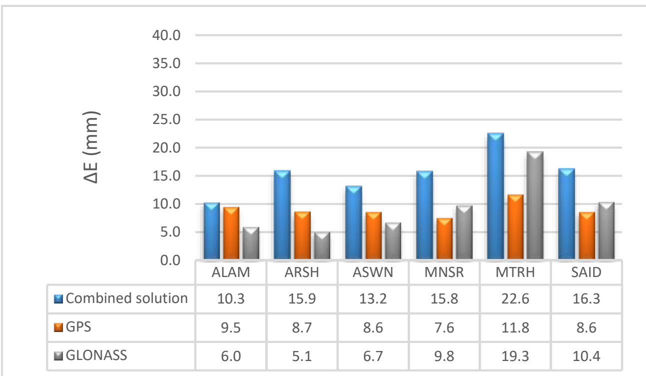

Fig. (6): Departure Coordinate Error (ΔE) in (mm) for Different Network Stations.

The chart above in figure (6) shows that GPS only is better than GLONASS only and combined GPS and GLONASS in departure coordinate error (ΔE) at stations MNSR, MTRH and SAID. GLONASS only is better than GPS and combined GPS and GLONASS at stations ALAM, ARSH and ASWN. GLONASS minimum (ΔE) error is 5.1 mm at AL-ARISH and maximum (ΔE) error is 19.3 mm at MTRH with 14.2 mm difference between the maximum and minimum errors. It is shown that combined solution achieved the largest (ΔE) coordinate error with 22.6 mm at MTRH and achieved 10.3 mm as minimum error at ALAM. In the case of GPS only, the minimum error is 7.6 mm at MNSR and the maximum error is 11.8 mm at MTRH. The difference between the maximum and minimum (ΔE) errors are 4.2, 14.2 and 12.3 mm for GPS, GLONASS and combined GPS and GLONASS respectively.

4.2 Test of Hypothesis for Two Sample Means (t-test)

The two sample t-test has been performed on the results of 57 days of year 2014 for all network stations. In this test, the two sample means are compared. The two hypotheses; null hypothesis, H_0, and alternative hypothesis, H_a, are stipulated as follows [13]:

$$H_0: \mu_1 = \mu_2 \tag{1}$$

$$H_a: \mu_1 \neq \mu_2 \tag{2}$$

The test statistic is:

$$t = \frac{\mu_1 - \mu_2}{\sqrt{\frac{S_1^2}{N_1} + \frac{S_2^2}{N_2}}} \tag{3}$$

The null hypothesis is rejected in the region:

$$|t| > t_{\alpha/2} \tag{4}$$

Where μ_1 and μ_2 are the means of the samples, S_1^2 and S_2^2 are the sample variances, N1 and N2 are the sample sizes and $t_{\alpha/2}$ is the tabulated t-value at confidence level 95% [14].

Table (2) shows the values of t-test for the three parameters; altitude (h), latitude (Φ) and longitude (λ). T-test here is implemented for three cases; GPS with combined GPS and GLONASS, GLONASS with combined GPS and GLONASS and GPS with GLONASS. The tabulated value of t is 1.96 at confidence level 95%. The values of t-test smaller than the tabulated value are accepted and greater than the tabulated value are rejected.

In the case of GPS with combined solution, the computed t-test values for the two components; latitude (Φ) and longitude (λ) are more than the tabulated t-value so that, the null hypotheses can be rejected at confidence level 95%. Thus, the two sample means of the two cases; GPS and Combined solution are different for latitude (Φ) and longitude (λ) at 0.05 significance level. For altitude (h), the computed t-values for stations; MNSR, MTRH and SAID are less than the tabulated t-value so, the null hypotheses can't be rejected at 0.05 significance level. For other stations, the null hypotheses can be rejected at confidence level 95% because the computed t-values for altitude (h) are more than the tabulated t-value.

In the case of GLONASS with Combined solution, the computed t-values for altitude (h) for stations; ARSH, MNSR and SAID are less than the tabulated t-value so, the null hypotheses can't be rejected at 0.05 significance level. For other stations, the null hypotheses can be rejected at confidence level 95%. The computed values of t-test for the two components; latitude (Φ) and longitude (λ) are greater than the tabulated t-value at all stations. Therefore, the null hypotheses can be rejected at confidence level 95%. Thus, the two sample means of the two cases; GLONASS and Combined solution are different for latitude (Φ) and longitude (λ) at 0.05 significance level.

In the case of GPS with GLONASS, the computed t-test values for altitude (h) for stations; MTRH and SAID are less than the tabulated t-value. In other words, for the two stations, GPS solution has the same mean of GLONASS solution at 0.05 significance level. For other stations, the computed t-values for altitude (h) are more than the tabulated t-value so, the null hypotheses can be rejected at confidence level 95%. For latitude (Φ), the computed t-test for stations; ALAM and ASWN are less than the tabulated t-value. In other words, the sample mean of GPS solution has the same sample mean of GLONASS solution at 0.05 significance level. For other stations, the computed t-values for latitude (Φ) are more than the tabulated t-value so, the null hypotheses can be rejected at confidence level 95%. For longitude (λ), the computed t-test for all stations except SAID are more than the tabulated t-value and the null hypotheses can be

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rejected for these stations at confidence level 95%. For SAID, the null hypotheses can't be rejected at confidence level 95%. Thus, GPS solution has the same sample mean of GLONASS solution for SAID at 0.05 significance level.

It's clear that most cases of the test indicate that different solutions give different means. This mean that GPS generally gives the best results as shown in the previous section (coordinate error evaluation).

TABLE 2
T-TEST FOR DIFFERENT CASES AND DIFFERENT NETWORK STATIONS

Station	Parameter	Case					
		GPS with Combined solution		GLONASS with Combined solution		GPS with GLONASS	
		t-test	Status	t-test	Status	t-test	Status
ALAM	h	6.40	rejected	4.05	rejected	11.80	rejected
	Φ	10.52	rejected	9.71	rejected	0.76	accepted
	λ	2.12	rejected	3.78	rejected	5.21	rejected
ARSH	h	8.09	rejected	1.05	accepted	12.42	rejected
	Φ	9.93	rejected	4.85	rejected	5.82	rejected
	λ	3.51	rejected	6.34	rejected	3.32	rejected
ASWN	h	4.91	rejected	6.50	rejected	12.60	rejected
	Φ	9.72	rejected	9.08	rejected	0.52	accepted
	λ	4.15	rejected	6.64	rejected	2.50	rejected
MNSR	h	1.44	accepted	0.96	accepted	2.81	rejected
	Φ	13.60	rejected	9.17	rejected	5.27	rejected
	λ	7.92	rejected	5.24	rejected	2.81	rejected
MTRH	h	1.91	accepted	2.16	rejected	0.13	accepted
	Φ	13.88	rejected	8.80	rejected	6.65	rejected
	λ	7.75	rejected	2.12	rejected	6.63	rejected
SAID	h	0.98	accepted	1.10	accepted	0.09	accepted
	Φ	15.27	rejected	9.26	rejected	6.77	rejected
	λ	6.63	rejected	4.85	rejected	1.91	accepted

4.3 Test of Hypothesis for the Ratio of Two Population Variances (F-test)

The F-test has been implemented on the results of the processed data of year 2014 for all network stations. F-test distribution compares the variances of two samples. The null hypothesis, H_0, and alternative hypothesis, H_a, have been performed for this test [13].

$$H_0: \frac{S_1^2}{S_2^2} = 1 \quad (5)$$

$$H_a: \frac{S_1^2}{S_2^2} \neq 1 \quad (6)$$

The test statistic is:

$$F = \frac{S_1^2}{S_2^2}, \qquad (S_1^2 > S_2^2) \quad (7)$$

The null hypothesis is rejected where:

$$F > F_{\alpha/2} \quad (8)$$

Where S_1^2 is the larger sample variance, S_2^2 is the smaller sample variance and F is test statistic value [15].

Table (3) is showing the values of F-test for the three parameters; altitude (h), latitude (Φ) and longitude (λ). F-test here is implemented for three cases; GPS with combined solution, GLONASS with combined solution and GPS with GLONASS. The tabulated F-value at confidence level 95% is 1.71. The F-test values smaller than tabulated value are accepted and greater than the tabulated value are rejected.

In the case of GPS with combined solution, for altitude (h), the computed F-test for all stations except MTRH and SAID are more than the tabulated F-value, so the null hypotheses can be rejected for all stations except MTRH and SAID. This means that the variances of GPS and combined solution are different for all stations except MTRH and SAID at confidence level 95%. For latitude (Φ), the values of F-test are more than the tabulated value, so the variances of the two samples; GPS and Combined solution are different at 0.05 significance level. For longitude (λ), the computed F-test for stations; ALAM, ARSH and ASWN are less than the tabulated F-value, so the null hypotheses can't be rejected at confidence level 95%. For other stations, the variances of GPS and Combined solution are different at 0.05 significance level.

In the case of GLONASS with Combined solution, for altitude (h), the computed F-test for all stations except SAID are less than the tabulated F-value, so the null hypotheses can't be rejected for all stations except SAID. This means that the variances of GLONASS and Combined solution are the same for all stations except SAID at confidence level 95%. For latitude (Φ), the null hypotheses can be rejected for all stations except ARSH. In other words, the variances of GLONASS and Combined solution are different for all stations except ARSH at confidence level 95%. For longitude (λ), the computed F-test for all stations except SAID are more than the tabulated F-value. In other words, the variances of GLONASS and Combined solution are different for all stations except SAID at confidence level 95%.

In the case of GPS with GLONASS, for altitude (h) and longitude (λ), the computed F-test for stations; ALAM, ARSH and ASWN are more than the tabulated F-value, so the null hypotheses can be rejected for these stations at confidence level 95%. This means that the variances of GPS and GLONASS are different for these stations at 0.05 significance level. For other stations, the null hypotheses can't be rejected and the variances of GPS and GLONASS are the same at 0.05 significance level. For latitude (Φ), the null hypotheses can be rejected for all stations except ARISH at confidence level 95%. In other words, the variances of the two samples; GPS and GLONASS are different at

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0.05 significance level for all stations except AL-ARISH.

TABLE 3
F-TEST FOR DIFFERENT CASES AND DIFFERENT NETWORK STATIONS

Station	Parameter	Case					
		GPS with Combined solution		GLONASS with Combined solution		GPS with GLONASS	
		F-test	Status	F-test	Status	F-test	Status
ALAM	h	3.82	rejected	1.10	accepted	3.48	rejected
	Φ	4.67	rejected	3.39	rejected	1.38	accepted
	λ	1.10	accepted	2.01	rejected	1.83	rejected
ARSH	h	8.49	rejected	1.51	accepted	4.33	rejected
	Φ	5.98	rejected	1.52	accepted	3.01	rejected
	λ	1.49	accepted	5.63	rejected	2.58	rejected
ASWN	h	3.40	rejected	1.14	accepted	3.89	rejected
	Φ	4.67	rejected	3.38	rejected	1.38	accepted
	λ	1.64	accepted	2.88	rejected	1.76	rejected
MNSR	h	2.33	rejected	1.45	accepted	1.60	accepted
	Φ	3.31	rejected	2.29	rejected	1.44	accepted
	λ	2.59	rejected	1.74	rejected	1.49	accepted
MTRH	h	1.24	accepted	1.70	accepted	1.37	accepted
	Φ	2.36	rejected	2.41	rejected	1.02	accepted
	λ	1.93	rejected	1.77	rejected	1.09	accepted
SAID	h	1.47	accepted	1.80	rejected	1.22	accepted
	Φ	2.84	rejected	1.91	rejected	1.49	accepted
	λ	2.03	rejected	1.70	accepted	1.19	accepted

4.4 Elevation Cut-off Angle Evaluation

All cases; GPS, GLONASS and combined solution were compared at different values of elevation cut-off angles which represent different conditions of sky view. The elevation cut-off angles were set to 3°, 10°, 20°, 30°, 40°, 50° and 60° which were compared vertically and horizontally for the three cases. The following charts are showing the comparison between the different values of elevation cut-off angles in degrees on the horizontal axis and the coordinate errors of the network in millimeters on the vertical axis. Coordinate errors here are represented vertically and horizontally.

The bar chart in figure (7) shows the average vertical coordinate error in millimeters for different values of elevation cut-off angles. Different sky view conditions were represented by different values of elevation cut-off angles. GPS only achieved the smallest vertical coordinate errors for elevation cut-off angles less than 40°. GLONASS only achieved the largest errors for all values of elevation cut-off angles. For elevation cut-off angles more than 40°, combined GPS and GLONASS achieved vertical coordinate errors less than GPS only and GLONASS only, this show that combined GPS and GLONASS is the best case for the condition of extremely limited sky view and narrow urban places. For the condition of open sky view, GPS only is better than other cases in vertical coordinates

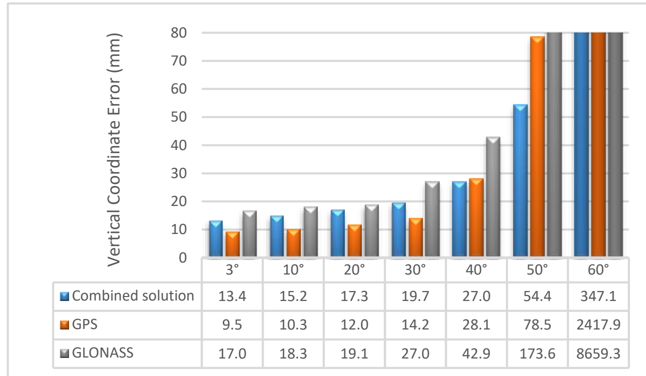

Fig. (7): Average Vertical Coordinate Error in (mm) for Different Elevation Cut-off Angles.

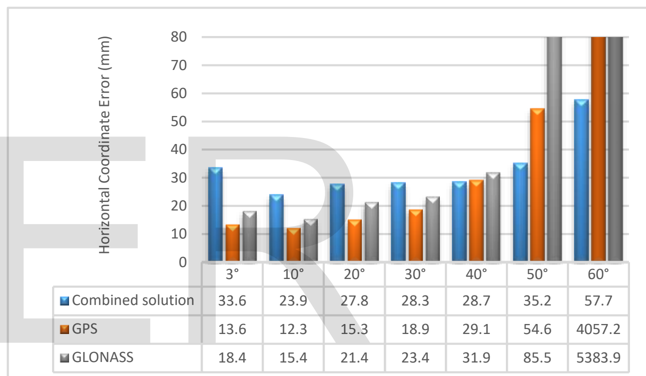

Fig. (8): Average Horizontal Coordinate Error in (mm) for Different Elevation Cut-off Angles.

In figure (8), the bar chart shows the average horizontal coordinate errors in millimeters for different values of elevation cut-off angles. In the case of combined GPS and GLONASS, horizontal coordinate errors are larger than other cases for elevation cut-off angles less than 40°. The performance of combined GPS and GLONASS improved when the elevation cut-off angle is 40° and higher. The performance of GPS only is better than combined GPS and GLONASS for elevation cut-off angles less than 40°. For the condition of extremely limited sky view that is represented by elevation cut-off angle equal 40° and more, the performance of horizontal component of GPS and GLONASS improved.

4.5 Regional Network closure error

A regional network in Egypt consists of three stations; AL-ASHER, AL-SHOBAK and ZAGAZIG equipped with GNSS receivers that track GPS, GLONASS and BEIDOU satellites. The data of four days in April 2019 were collected. Compass solution version 1.8.8 is the used software for analyzing the observation data. All cases; GPS, GLONASS, BEIDOU, combined GPS with GLONASS, combined GPS with BEIDOU, combined GLONASS with BEIDOU and combined GPS with GLONASS and BEIDOU are compared here by loop closure error in millimeters. The following bar chart shows the loop closure error in millimeters on the vertical axis and different cases on the horizontal axis.

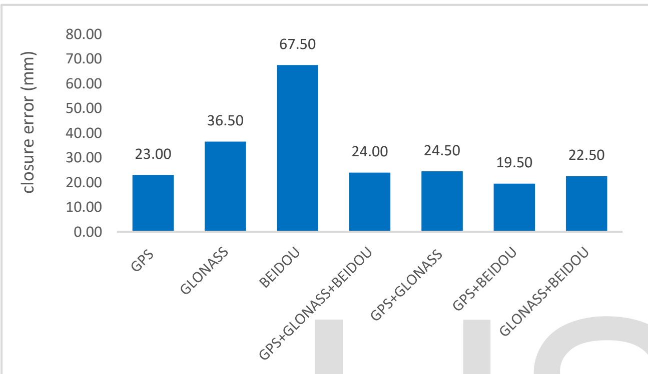

Fig. (9): Loop Closure Error in (mm) for Different Cases.

The bar chart in figure (9) shows the loop closure errors in millimeters for different cases. The minimum closure error is 19.50 mm in the case of combined GPS with BEIDOU and the maximum error is 67.50 mm in the case of BEIDOU only. GPS only achieved 23.00 mm as closure error and it is better than GLONASS only, BEIDOU only, combined GPS with GLONASS and combined GPS with GLONASS and BEIDOU. The closure error in the case of GLONASS only, BEIDOU only and combined GLONASS with BEIDOU is respectively 36.50, 67.50 and 22.50 mm. combined solution between GLONASS and BEIDOU achieved a closure error smaller than GLONASS only and BEIDOU only because of increasing the number of tracked satellites in the case of combined solution.

4.6 Regional Network tests (t-test and F-test)

The t-test and F-test have been implemented on the results of processed data of year 2019. Table (4) is showing the values of t and F for all cases. The tabulated t-value and F-value at confidence level 95% are 2.44 and 15.44 respectively.

For t-test, all cases except six cases can be accepted at 0.05 significance level as shown in table (4) because the computed t-values for most cases are less than the tabulated t-value. This means that most cases have the same means and no significant differences at confidence level 95%.

For F-test, table (4) indicated that the computed F-values for all cases except five cases are less than the tabulated F-value, so most cases can't be rejected at 0.05 significance level. This means that most cases have the same variances and no significant differences at confidence level 95%.

TABLE 4
T-TEST AND F-TEST FOR DIFFERENT CASES OF REGIONAL NETWORK

Case	Test			
	t-test		F-test	
	t-test	Status	F-test	Status
GPS with GLONASS	2.14	accepted	8.07	accepted
GPS with BEIDOU	2.98	rejected	48.57	rejected
GPS with combined GPS+GLONASS+BEIDOU	0.31	accepted	1.18	accepted
GPS with combined GPS+GLONASS	0.39	accepted	2.44	accepted
GPS with combined GPS+BEIDOU	0.92	accepted	1.74	accepted
GPS with combined GLONASS+BEIDOU	0.11	accepted	3.18	accepted
GLONASS with BEIDOU	1.94	accepted	6.02	accepted
GLONASS with combined GPS+GLONASS+BEIDOU	1.96	accepted	6.86	accepted
GLONASS with combined GPS+GLONASS	1.76	accepted	3.31	accepted
GLONASS with combined GPS+BEIDOU	2.54	rejected	4.64	accepted
GLONASS with combined GLONASS+BEIDOU	1.99	accepted	2.54	accepted
BEIDOU with combined GPS+GLONASS+BEIDOU	2.91	rejected	41.26	rejected
BEIDOU with combined GPS+BEIDOU	3.18	rejected	27.91	rejected
BEIDOU with combined GLONASS+BEIDOU	2.95	rejected	15.29	rejected
BEIDOU with combined GPS+GLONASS	2.84	rejected	19.94	rejected
Combined GPS+GLONASS with combined GPS+GLONASS+BEIDOU	0.13	accepted	2.07	accepted
Combined GPS+GLONASS with combined GPS +BEIDOU	1.10	accepted	1.40	accepted
Combined GPS+ BEIDOU with combined GLONASS+BEIDOU	0.59	accepted	1.83	accepted

5 Conclusion

Firstly, for the permanent network, in the condition of open sky view (E = 3°), all tests indicated that there is no necessity for augmenting GLONASS with GPS observations because there are enough number of tracked satellites. The average (Δh) coordinate errors are 9.5, 17.0 and 13.4 mm for GPS, GLONASS and combined solution respectively. The average (ΔN) coordinate errors for GPS, GLONASS and combined solution are 10.0, 15.7 and 29.7 mm, respectively. GPS, GLONASS and combined solution achieved 9.1, 9.6 and 15.7 mm respectively as average (ΔE) coordinate errors. The solutions by using GPS only are more accurate than other cases and there are no clear improvements from combined GPS with GLONASS observations. The above results may be attributed to the differences in reference frames, time systems and frequency systems between different GNSS systems.

The results of most cases of t-test and F-test give different solutions and the null hypotheses can be rejected. But GPS only gives the best results as shown in the section of (coordinate error evaluation).

In the extremely limited sky view condition, which simulate urban regions and narrow canyons (E ≥ 40°), GPS only and GLONASS only constellations confront many problems because of the shortage in the number of visible satellites. Integrating GLONASS to GPS observations is one of the best solutions to overcome these problems. The solution of combined GPS and GLONASS is more accurate than other solutions at elevation cut-off angle (E = 40°) with 27.0 and 28.7 mm as coordinate errors in the vertical and horizontal components respectively. The elevation cut-off angle (E ≥ 40°) represent limited sky view condition. At elevation cut-off angle (E = 40°), the vertical coordinate errors for GPS only and GLONASS only are 28.1 and 42.9 mm respectively. Whereas, the horizontal coordinate errors for GPS only and GLONASS only are 29.1 and 31.9 mm respectively. At elevation cut-off angle (E = 50°), the vertical coordinate errors for GPS, GLONASS and combined GPS with GLONASS are 78.5, 173.6 and 54.4 mm respectively. Whereas, the horizontal coordinate errors for GPS, GLONASS and combined GPS with GLONASS are respectively 54.6, 85.5 and 35.2 mm.

In summary, the results of the permanent network have indicated that GPS only is the best solution for open sky condition because of the differences in reference frames, time systems and frequency systems between different GNSS systems. It also indicated that combined GPS with GLONASS is the best solution for urban canyons and narrow regions. This because of the shortage in the number of visible satellites for individual systems.

Secondly, for the regional network, the results have indicated that combined GPS with BEIDOU is the best case because it achieved a closure error smaller than other cases with 19.5 mm. GPS only achieved 23.0 mm as a closure error. The closure errors in the case of GLONASS, BEIDOU and combined GLONASS with BEIDOU are 36.50, 67.50 and 22.50 mm, respectively. GPS is better than GLONASS, BEIDOU, combined solution between GPS with GLONASS and combined GPS, GLONASS and BEIDOU. Combined GLONASS with BEIDOU achieved a closure error smaller than GLONASS only and BEIDOU only because of increasing the number of tracked satellites in the case of combined solution.

References

[1] Hofmann-Wellenhof B., Lichtenegger H., and Walse E., "GNSS Global Navigation Satellite Systems, GPS, Glonass, Galileo & more", Springer Wien, New York (2008).

[2] Alcay S., and Yigit C. O., "Network based performance of GPS-only and combined GPS/GLONASS positioning under different sky view conditions". Acta geodaetica et geophysica (2017), 52(3), 345-356.

[3] IAC, Information and Analysis Center for Positioning, Navigation and Timing Glonass Offical (2019). Accessed March, 2019. Website, https://www.glonass-iac.ru/en/guide/index.php.

[4] Al-Shaery A., Lim S., and Rizos C., "Assessment of network-based positioning performance using GPS alone versus GPS and GLONASS Combined". In 24th International Technical Meeting of the Satellite Division of the Institute of Navigation (2011), pp. 2341-2349.

[5] Maciuk K. "GPS-only, GLONASS-only and Combined GPS+ GLONASS Absolute Positioning under Different Sky View Conditions". Tehnički vjesnik (2018), 25(3), 933-939.

[6] Tabatabaei A., Mosavi M. R., Khavari A., and Shahhoseini H. S., "Reliable urban canyon navigation solution in GPS and GLONASS integrated receiver using improved fuzzy weighted least-square method". Wireless Personal Communications (2017), 94(4), 3181-3196.

[7] Wang J., and Wang J., "Comparing long baseline results from GPS and GPS/GLONASS". InCombinedInt. Symp. & Exhibition on Geoinformation & GNSS, Johor Bahru, Malaysia (2007), pp. 5-7.

[8] Jingnan, Z. Y. L. "Combined GPS/GLONASS Data Processing". Science (Quarterly), V. 5, Issue 4 (2002), p 32-36.

[9] Alcay S., Inal C., Yigit C. O., and Yetkin M., "Comparing GLONASS-only with GPS-only and hybrid positioning in various length of baselines". Acta Geodaetica et Geophysica Hungarica (2012), 47(1), 1-12.

[10] Saleh M., and Becker M., "A new velocity field from the analysis of the Egyptian Permanent GPS Network (EPGN)". Arabian Journal of Geosciences (2014), 7(11), 4665-4682.

[11] Dach R., Hugentobler U., Fridez P., and Meindl M., "User manual of the Bernese GPS software version 5.0". Astronomical Institute, University of Bern (2007), pp. 640.

[12] COMNAV, (2018). Accessed April, 2019. Website, http://comnavtech.com/productsdetail.asp?id=25&sw=1366&sh=768.

[13] Ghilani, C. D. "Adjustment computations: spatial data analysis". John Wiley & Sons. 6th, edition (2017), pp. 720, ISBN: 978-1-119-38598-1.

[14] Moore D. S., and Kirkland S., "The basic practice of statistics". (Vol. 2). New York: WH Freeman (2007).

[15] Kanji, G. K. "100 statistical tests". SAGE Publications Ltd; 3rd edition, 256 pages, ISBN-10: 9788178297316 (2006).