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The effect of GLONASS on position accuracy in CORS-TR measurements at different baseline distances

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Keywords
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ABSTRACT
GLONASS system; It has become the second system operating on a global scale after the GPS system in the world, after completing the satellite constellation and using it at full capacity as of 8 December 2011. Due to the increasing need for high accuracy and precision real-time location information, CORS networks have become widespread in the world. In Turkey, it was established as CORS-TR and opened for use in December 2008. Comprehensive studies investigating the effects of Network-Based RTK techniques (VRS, FKP, and MAC) in the CORS-TR network are very limited due to the fact that the GLONASS system has been used at full capacity recently. In this paper, it is aimed to determine the effect of measurements derived from the Network-Based RTK techniques in the CORS-TR network of the GLONASS system on the location accuracy, and thus to make a business plan according to the accuracy and precision requirements of all civil and military users. For this purpose, simultaneous measurements were made with 6 GNSS receiver devices of the same brand and model. A total of 308,908 epoch data (northing value, easting value, and ellipsoidal height: projection coordinates (ITRF96 Datum, 2005.00 Reference Epoch)) were collected at one-second intervals in each technique and for seven days of measurements. As a result of the evaluation and analysis of the data sets obtained with the measurements; It has been observed that the GLONASS system has a positive effect on position accuracy, but in some cases, it also has disruptive effects. It has been observed that the most important contribution is to increase the number of visible satellites and to enable measurements with GLONASS satellites in cases where GPS satellites alone are not sufficient, especially in areas where the satellite elevation angle is narrowed, such as city centers, and forest areas.

1. INTRODUCTION

GPS, which started to be used by the US Department of Defense for military purposes since the 1970s, has been used for civilians since June 28, 1983, and today it is used in many areas such as geodetic and cadastral measurements, GIS, navigation, as well as map production. In parallel with the advancement of technology, the usage areas of global positioning systems are increasing day by day. Thirty-one satellites of the GPS are in operation as of July 2021 (Kahveci and Yıldız 2017; Gündüz 2013; Kalaycı 2003; GPS Official Webpage 2021).

The first system that can be called a rival to the USA's GPS was the GLONASS system developed by the Russian Federation. Later, studies on geolocation systems such as the Galileo by the European Union and Compass-BeiDou by China were started. With the emergence of the idea of creating reference networks that make constant and continuous observation, CORS systems have been established in the world and in Turkey. CORS systems, which have examples in countries such as the USA, Germany, and Japan in the world, were implemented in Turkey by the CORS-TR Project in 2008 by Istanbul Kultur University, General

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Directorate of Land Registry and Cadastre and General Directorate of Mapping (General Command of Mapping), (Tusat 2018; Qasim and Tusat 2018; Kahveci and Yıldız 2017).

In this paper; the GLONASS system, CORS-TR system, and Network-Based RTK techniques are explained. At the same time, the effect of GLONASS was investigated by performing a test application. Measurements were made with 6 GNSS receiver devices with the same brand, model, and software using only GPS and GPS+GLONASS systems and three Network-Based RTK techniques in the CORS-TR network (Devices; 1. Device GPS-VRS technique, 2. Device GPS-FKP technique, 3. Device GPS-MAC technique, 4. Device GPS+GLONASS-VRS technique, 5. Device GPS+GLONASS-FKP technique and 6. Device GPS+GLONASS-MAC technique). The results obtained by analyzing the effect of GLONASS on position accuracy in CORS-TR measurements, accuracy comparison between Network-Based RTK techniques (VRS, FKP, and MAC), and the effect of baseline distance on position accuracy were explained.

2. METHOD

As a method in this paper; GLONASS system, CORS-TR system, and Network-Based RTK techniques (VRS, FKP, and MAC) are briefly explained. Then, the test/application study conducted to determine the effect of GLONASS on the CORS-TR network and the analysis and evaluation of the obtained data are explained in this section.

2.1. GLONASS System

The GLONASS system is a project started for the response to the USA's GPS in the early 1970s to increase the accuracy of ballistic missiles of the Soviet Military Forces in real-time positioning, speed detection, and targeting as a program under the Russian Federation Armed Forces Space Forces Command. The GLONASS system, which is similar to the GPS in many ways, was officially announced in 1983 and started to serve in the military field on September 24, 1993, with 12 operational satellites. It reached its full operational capacity in 1995 with the completion of the number of satellites to 24. With the deterioration of the Russian economy toward the end of the 1990s, investments in the GLONASS system stopped, the modernization of satellites could not be realized, and therefore the number of operational satellites decreased to 7 satellites in 2001. Since 2001, Russia has increased its investments to operate the system again and made it operational on a global scale by completing the number of satellites to 24 in 2011 (İçen 2018; Kahveci and Yıldız 2017; Revnivykh et al. 2017; Gündüz 2013; Mekik 2010).

The GLONASS system consists of three main components: space segment, control segment, and user segment. The space segment of the GLONASS system, whose first satellite was put into orbit on October 12, 1982; although it is planned to consist of 21 + 3 backup satellites, the number of existing satellites is as of July 2021, 23 of which are operational, one is temporarily withdrawn for maintenance (in orbit), and 2 are in the testing phase. It consists of a total of 26 MEO (Medium Earth Orbit) satellites (İçen 2018; Revnivykh et al. 2017; GLONASS Official Webpage 2021). The GLONASS time system is UTC (SU) and this time system is maintained by the National Metrology Institute of the Russian Federation and there is a three-hour difference from UTC. The geodetic datum of the system PZ-90 (Parametry Zemli 1990 or Parameters of the Earth 1990) is the terrestrial reference system and is used as the reference system of ephemeris information (Kahveci and Yıldız 2017; Revnivykh et al. 2017; Pektaş 2010; Yalçın 2007).

The control segment of the GLONASS system; It consists of a system control center (SCC), two central clock facilities (CC), and monitoring and command stations (TT&C) scattered across the territory of Russia (and the former Soviet Union states). The task of these stations is to ensure the efficient operation of satellites, to calculate satellite orbits with data collected from satellites, and to calculate satellite clock corrections (İçen 2018; Revnivykh et al. 2017; Stoyanova et al. 2017; Kahveci and Yıldız 2017). The user segment consists of GNSS receiver devices and users that can collect data broadcast by GLONASS satellites and evaluate them for different purposes. (Stoyanova et al. 2017; ESA Official Webpage 2021). In the GLONASS system, effects such as the deliberate reduction of selective availability (SA), which was removed in the GPS on May 1, 2000, are not applied (Revnivykh et al. 2017).

Comparison of parameters of GLONASS and GPS systems is given in Table 1.

2.2. CORS-TR System

Continuously Operating GNSS Stations Network and National Datum Transformation Project under the execution of TUBITAK's 1007 project code, Istanbul Kultur University, with the General Directorate of Mapping and the General Directorate of Land Registry and Cadastre, It started on May 8, 2006, and became operational after its completion as of December 2008. Operation of the CORS-TR system and calculation of correction parameters are carried out in control and analysis centers. The data collected from all stations are transferred to data centers via ADSL and GPRS/EDGE, where correction parameters are calculated and presented to all users. RTK correction data are in RTCM communication format and are sent to rovers with the help of one or more GSM, GPRS, NTRIP tools (Tusat 2018; Öğütcü and Kalayci 2016; Yıldırım et al. 2011; Cingöz et al. 2009; CORS-TR Application Report 2006; CORS-TR Official Webpage 2021a).

Table 1. Similarities and differences between GLONASS and GPS systems (Kahveci and Yıldız 2017; GLONASS Official Webpage 2021; ESA Official Webpage 2021)

Technical Specifications	GLONASS	GPS
Basic Number of Satellites	21 main+ 3 reserve	21 main+ 3 reserve
Available Number of Satellites	23	31
Number of Orbital Planes	3	6
Orbital Plane Inclination	64.8º	55º
Orbit Radius (km)	25.510	26.560
Base Clock Frequency (MHz)	5.0	10.23
Signal Separation Technique	FDMA + CDMA	CDMA
Carrier Frequencies: L1 (MHz)	1602.0 - 1615.5	1575.42
L2 (MHz)	1246.0 - 1256.5	1227.60
Navigation Message Time (min)	2.5	12.5
Satellite Ephemeris Information	Coordinates and derivatives in the geocentric Cartesian coordinate system	Kepler orbital elements and disruptive effects
Time Reference System	UTC (SU)	UTC (USNO)
Geodetic Datum	PZ-90	WGS84

2.3. Network-Based RTK Techniques

Various interpolation techniques are used to calculate the correction data calculated from CORS stations within the network according to the location of the GNSS receiver. Three main methods have been determined as Network-Based RTK techniques. These are named as Virtual Reference Station (VRS), Flat Plane Correction Parameter (FKP, German Flächen Korrektur Parameter), and Master Auxiliary Concept (MAC) (Yılmaz 2020; Öğütcü 2018; Öğütcü 2017; Cina et al. 2015; Wübbena et al. 2001; Euler et al. 2001; Vollath et al. 2000).

The VRS technique is one of the first Network-Based RTK techniques developed by Trimble for commercial purposes and first proposed by Vollath et al. (2000). It is the most common method used because it is compatible with existing software on GNSS receiver devices and does not require changes in the software, and this is the biggest advantage of the method. However, a major disadvantage of this method is the existence of a constraint on the number of users relative to the capacity of the central processing unit, as the VRS observations are customized for each user. The basic principle of the VRS technique is that it uses a virtual reference station that uses virtual observation data instead of a real physical reference station. In the VRS technique, the accuracy achieved using the classical RTK method (with a single reference station) is ensured by creating a virtual point that is not established and invisible to the eye. Correction data valid for the GNSS receiver are calculated by interpolation from multiple reference station data in the worksite. Thus, some systematic errors (ionospheric, tropospheric, orbital, etc.) in the measurements of the GNSS receiver are minimized. To apply the VRS technique, the GNSS receiver must receive data from at least 3 reference stations (at least 5 required for the CORS-TR system) within the CORS network, and the GNSS receiver must support two-way communication (Yılmaz 2020; Öğütcü 2017; Kahveci 2017; El-Mowafy 2012; Janssen 2009; Hu et al. 2003; Landau et al. 2002; Vollath et al. 2000).

The FKP technique is one of the first Network-Based RTK methods developed by the SAPOS group (Germany) in the mid-1990s. The basic principle of this technique is to transfer the field correction parameter information calculated from the reference stations to the rover GNSS receivers. The name FKP, plane correction parameters, comes from here. Information in the network (reference station) is interpolated for the user through a polynomial surface, calculated with linear parameters to model tropospheric, ionospheric, and orbital errors. This technique is based on linear interpolation. The distance between the reference stations and the GNSS receiver is used for weighting in the interpolation process. Plane correction parameters in the form of north-south and east-west are created for the GNSS receiver according to the modeled area. To create the FKP plane, the GNSS receiver must remain in at least 3 reference stations. Frequency-dependent and frequency-independent correction parameters represent the linear correlation of north-south and east-west errors for each reference station (Yüksel 2015; Öğütcü 2014; Wübbena and Bagge 2006; Higuchi et al. 2004; Wübbena et al. 2001).

The most serious problem encountered in Network-Based RTK applications is that a common format cannot be used in practice. Since the correction data of VRS and FKP techniques are modeled, they are not in a common format in RTCM standards and belong to the manufacturer. Euler et al. (2001) developed the MAC technique, which is a different approach compared to other Network-Based RTK techniques in terms of transferring and using correction data to eliminate these problems. The basic principle of this technique is to send error information regarding the CORS network and observations to the GNSS receivers as a whole. The more information the GNSS receiver for the network receives, the more likely the GNSS receiver is to accurately determine its location. In the MAC method, a master reference station and all raw metering data in its "RTCM V3.1 Message 1004" format and the reduced data of other auxiliaries (minimum 5 auxiliary reference stations) reference stations are used together. In the MAC technique, phase distances between reference stations and satellites are reduced to a common ambiguity level. Thus, in modeling the network, the solution of the phase unknowns is minimized and the remaining ionosphere, troposphere, and satellite orbital errors are modeled with high accuracy (Öğütcü 2017; Kahveci 2017; Yüksel 2015; Cina et al. 2015; Brown et al. 2006; Euler et al. 2001).

The features of Network-Based RTK techniques are briefly described above. Techniques have common and different aspects with respect to each other. These can be briefly explained as follows. Since the correction data are modeled in VRS and FKP techniques, it is not in accordance with RTCM standards and is specific to the manufacturer, while in the MAC technique, it is in accordance with RTCM standards and is the international standard. In the VRS technique, since more than a certain number of concurrent users cause the system to lock, there is a concurrent user restriction, while there is no such restriction in other techniques. While bidirectional communication is mandatory in the VRS technique, other techniques can be used with both bidirectional and unidirectional communication. While at least three reference stations are required in VRS and FKP techniques, 6 reference stations are required, including one master five auxiliaries in the MAC technique (Öğütcü 2017; Kahveci 2017; Öğütcü 2014; Brown et al. 2006; Euler et al. 2001; Vollath et al. 2000).

3. EXPERIMENTAL STUDY

KAMN and BEYS stations in the CORS-TR network were selected for the test study. The reasons for choosing these stations are that the locations of the stations have not been changed since the first establishment and that the land structure from the KAMN station to the BEYS direction is suitable for measuring in the desired km. Control measurements were made between CIHA and AKSR stations outside of this baseline.

The study was carried out as follows: between the KAMN and BEYS stations shown in figure 1 (baseline distance 141.1 km), the KAMN point being the main reference station (the station where correction data is received) with the same brand, model, and software 6 GNSS receiver devices (Devices; 1. Device GPS-VRS technique, 2. Device GPS-FKP technique, 3. Device GPS-MAC technique, 4. Device GPS+GLONASS-VRS technique, 5. Device GPS+GLONASS-FKP technique and 6. Device GPS+GLONASS-MAC technique), simultaneously using both only GPS and GPS+GLONASS satellites at the 5th, 10th, 20th, 40th, and 55th km (Figure 2) on a special platform designed (Figure 3) measurements were made for 2 + 2 hours, the satellite elevation cut-off angle was 10° and 30°, and the epoch interval was 1 second (Figure 4). By making all measurements simultaneously, it is aimed that the errors (atmospheric and orbital errors, etc.) affecting GNSS measurements are at the same level in static and Network-Based RTK measurements. The reason for measuring at different satellite elevation cut-off angles is to determine the effect of GLONASS in built-up areas such as city centers and forested areas where satellite signals are blocked. However, since the effect of GLONASS was investigated in the CORS-TR system, all measurements, GPS, and GLONASS systems were active (open) and other satellite systems were passively (closed). While network-based RTK measurements were made, only fixed solutions were recorded, but unsolved ambiguity data (float) were not recorded. For this reason, the collected data (epoch numbers) differed among the solutions. With the control points, 308,908 epoch data measurements were made at seven test points and in all three techniques. Measurements were made on 02 - August 08, 2019, between 07:00 - 17:00, first Network-Based RTK measurements and then static measurements. As control measurements, two points were determined apart from the baseline where the main measurements were made. First, between the CIHA and AKSR stations (baseline distance 98.8 km), the measurements were made at 20. km from the CIHA station and the second at 43. km from the AKSR station.

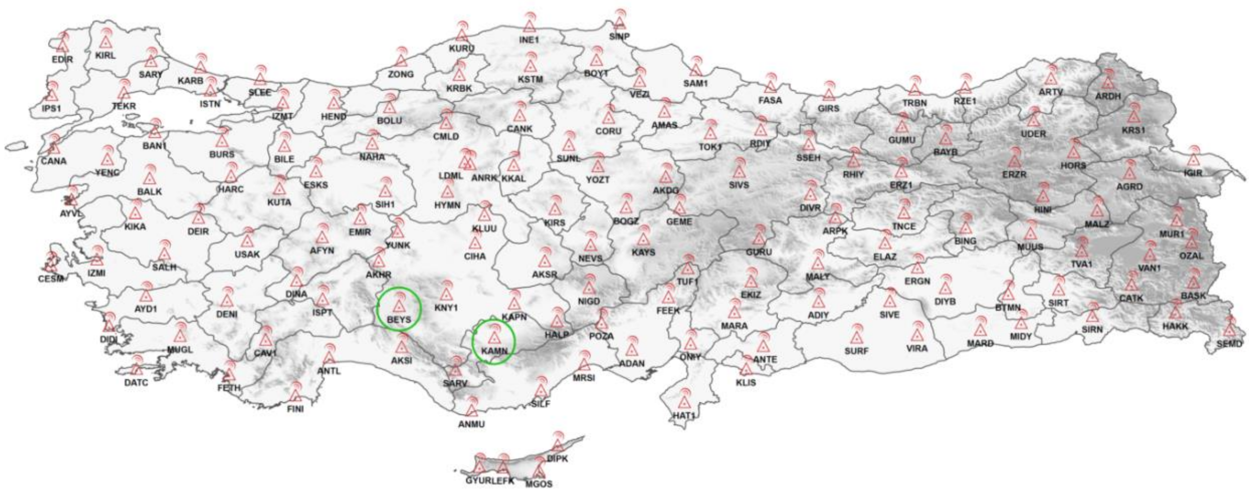

Figure 1. CORS-TR station points (CORS-TR Official Webpage 2021b)

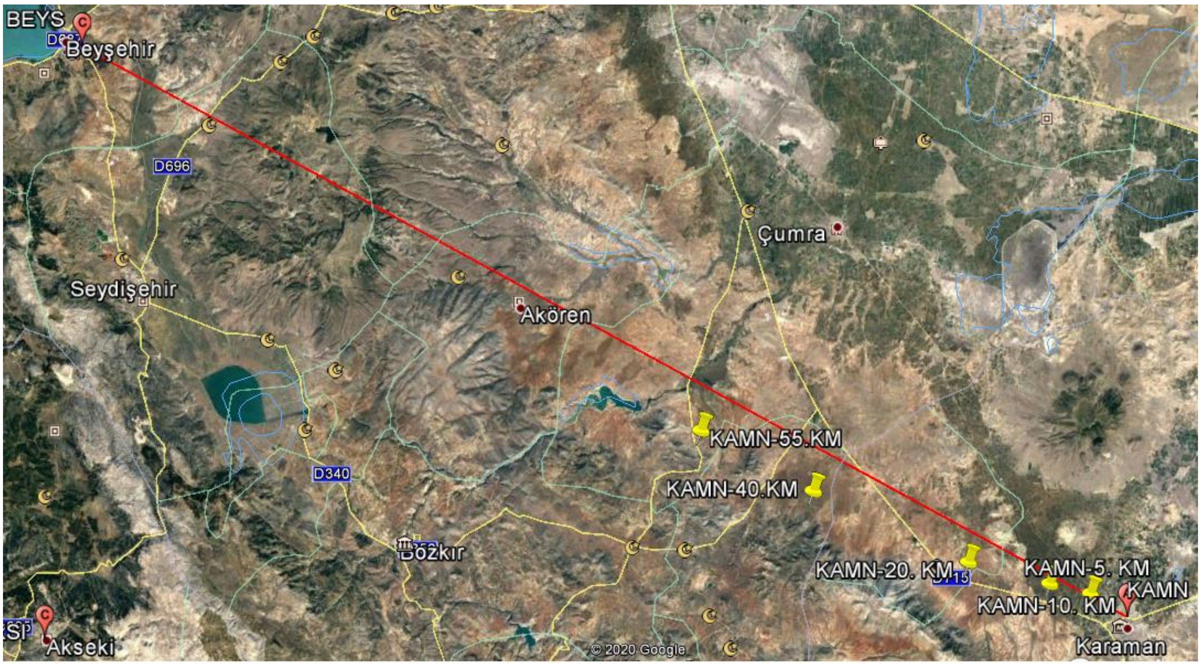

Figure 2. Test site and test points (Google Earth image)

Figure 3.GNSS measurement platform

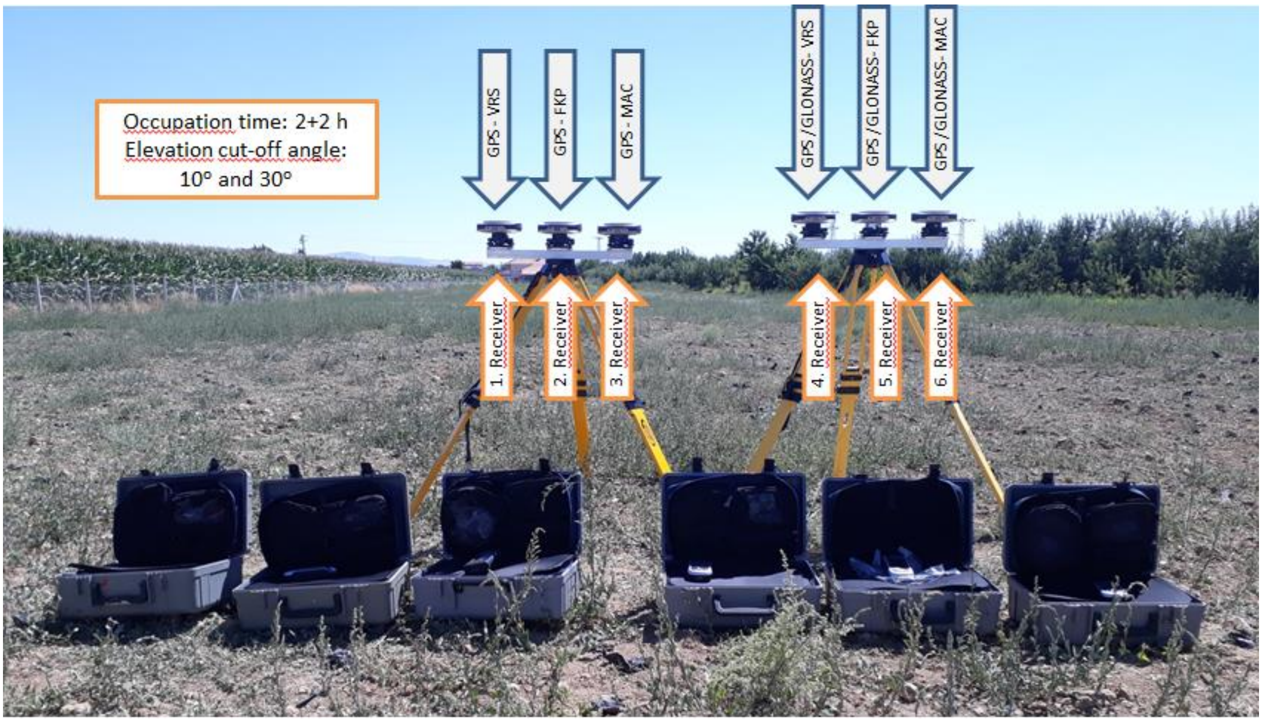

Figure 4. Network-Based RTK measurement

Projection coordinates of the points (ITRF96 Datum 2005.00 Reference Epoch) were obtained by transferring the data obtained from the measurements to the computer. Average number of satellites and PDOP values used by Network-Based RTK techniques during measurement are given in Table 2. After the Network-Based RTK measurements, 4 hours of static session measurement were made without touching the devices. Obtained static session data were analyzed with a single point-based unforced processing method in Leica Geo Office 8.4 licensed software. The coordinates found were accepted as the horizontal and vertical correct coordinates of the points where the device was installed (ITRF96 datum 2005.00 reference epoch, 3° slice width 33rd-degree central meridian in Gauss-Kruger projection).

Table 2. Average number of satellites and PDOP values used during the measurement of Network-Based RTK techniques

				1.Receiver GPS - VRS	2.Receiver GPS - FKP	3.Receiver GPS - MAC	4.Receiver GPS+GLO. - VRS	5.Receiver GPS+GLO. - FKP	6.Receiver GPS+GLO. - MAC
TEST POINTS BETWEEN KAMN - BEYS CORS STATIONS	1. KAMN 5.KM	NRTK 10°	NoS	8	9	8	13	14	13
			PDOP	2.0	1.9	2.0	1.4	1.4	1.4
		NRTK 30°	NoS	5	5	5	9	9	8
			PDOP	3.5	3.5	3.5	3.2	3.2	3.5
	2. KAMN 10.KM	NRTK 10°	NoS	8	8	8	13	14	14
			PDOP	2.0	2.0	2.0	1.4	1.4	1.5
		NRTK 30°	NoS	5	5	5	9	9	9
			PDOP	3.3	3.3	3.3	3.3	3.2	3.2
	3. KAMN 20.KM	NRTK 10°	NoS	8	8	8	12	13	13
			PDOP	2.0	2.0	2.0	1.5	1.5	1.5
		NRTK 30°	NoS	5	5	5	8	8	8
			PDOP	3.6	3.6	3.6	3.4	3.4	3.4
	4. KAMN 40.KM	NRTK 10°	NoS	8	8	8	11	12	12
			PDOP	2.0	2.0	2.0	1.5	1.4	1.5
		NRTK 30°	NoS	5	5	5	7	7	7
			PDOP	3.6	3.7	3.5	3.7	3.7	3.7
	5. KAMN 55.KM	NRTK 10°	NoS	8	8	8	11	11	11
			PDOP	1.9	1.9	1.9	1.4	1.4	1.4
		NRTK 30°	NoS	5	5	5	8	8	8
			PDOP	3.5	3.5	3.5	3.6	3.6	3.4
CONTROL TEST POINTS BETWEEN CIHA - AKSR CORS STATIONS	6. CIHA 20.KM	NRTK 10°	NoS	8	8	8	12	12	12
			PDOP	2.0	2.0	2.0	1.5	1.5	1.5
		NRTK 30°	NoS	6	6	6	10	9	10
			PDOP	4.2	4.2	4.0	2.9	2.9	2.8
	7. AKSR 43.KM	NRTK 10°	NoS	8	8	8	11	11	11
			PDOP	2.0	2.0	2.0	1.5	1.5	1.5
		NRTK 30°	NoS	5	5	5	9	8	8
			PDOP	3.4	3.4	3.5	3.3	3.3	3.3

In the measurements, six Spectra Precision SP80 brand advanced GNSS receiver devices that can work with geodetic multi-satellite systems were used. While determining the location of the measurement points, care has been taken to keep them away from any object that may cause signal reflection and to ensure that the internet infrastructure is suitable. To ensure the same satellite geometry at all measurement points, attention has been paid to ensure that there is no object around the measurement points that will obstruct the satellite signals above 10° and that all measurements are made simultaneously. Care has been taken to ensure that all GNSS receiver devices and control units have the same firmware to eliminate the effects caused by the software. However, GSM lines (Turkcell) with the same feature were used to obtain correction data.

The conformity of the indices (Dst and Kp) related to ionospheric and geomagnetic storms on the days of the measurement (02 – August 08, 2019) was checked on the website of the International Geomagnetic Indexes Service and it was found to be suitable for measurement on these dates (ISGI Official Webpage 2021). Dst index is a parameter obtained from geomagnetic observatories and provides information about the degree of a geomagnetic storm. Index data less than or equal to -100 nt (Nano tesla) are an indication of a geomagnetic storm. The Kp index is a parameter used in the monitoring and investigation of geomagnetic storms. The Kp index takes values between 0 ≤ kp ≤ 9, and values ≥5 indicate that there is a geomagnetic storm (İnyurt and Şentürk 2020; El-Eraki et al. 2018; Öğütcü 2017; Cander 2012).

3.1. Analyses of The Data

3.1.1. Outlier measurements test

Measuring sets obtained with 6 GNSS receiver devices at each test point (7 test points and 6 GNSS receiver devices and 84 measurement sets with satellite elevation cut-off angle of 10° and 30°) to determine rough or incompatible measurements outlier measurements test was conducted. Generally, errors of ± 10 cm and above are accepted as outlier measurements in most geodetic applications and scientific studies. Especially in RTK applications since, the accuracies below cm and dm are generally within the nominal accuracy limits, ± 10 cm is accepted as the threshold value for outlier measurements (Öğütcü and Kalaycı 2018; Geng and Shi 2017; Öğütcü 2017; Geng et al. 2010). The differences between the correct coordinates of the measurement points and the coordinates obtained from Network-Based RTK techniques, the coordinate components (easting value, northing value, and ellipsoidal height) were taken. For each coordinate component, values greater than ±10 cm were taken from the measurement group by applying the method of accepting outlier values. In the whole measure group (308.908 epoch measurements/data in total), only 2.789 measurements were outliers because of the test. After discarding the outlier measurements, the analysis continued with the remaining correct measurements (306.119 epoch measures).

Table 3 shows the ratio of outlier measurements to Network-Based RTK techniques, Table 4 shows the ratio of outlier measurements to baseline distances, Table 5 shows the ratio of outlier measurements to satellite elevation cut-off angles, and Table 6 shows the ratio of outlier measurements to GNSS systems.

Table 3. The ratio of outlier measurements to Network-Based RTK techniques

Techniques	Total number of outlier measurements	General Total	Ratio of outlier measurements
1.Receiver GPS - VRS	7	45492	0.02%
2.Receiver GPS - FKP	237	45157	0.52%
3.Receiver GPS - MAC	860	45991	1.87%
4.Receiver GPS+GLONASS - VRS	364	56752	0.64%
5.Receiver GPS+GLONASS - FKP	364	57850	0.63%
6.Receiver GPS+GLONASS - MAC	957	57666	1.66%
Total	2789	308908	0.90%

Table 4. The ratio of outlier measurements to baseline distances

Baseline distance	Total number of outlier measurements	General Total	Ratio of outlier measurements
1.KAMN 5. KM	251	43271	0.58%
2.KAMN 10. KM	2	44594	0.00%
3.KAMN 20. KM	456	44224	1.03%
4.KAMN 40. KM	643	41991	1.53%
5.KAMN 55. KM	690	44606	1.55%
6.CIHA 20. KM	16	46928	0.03%
7.AKSR 43. KM	731	43924	1.66%
Total	2789	308908	0.90%

Table 5. The ratio of outlier measurements to satellite elevation cut-off angles

Baseline distance	Elevation cut-off angle 10°	Elevation cut-off angle 30°	Total
1.KAMN 5. KM	249	2	251
2.KAMN 10. KM	2	0	2
3.KAMN 20. KM	1	455	456
4.KAMN 40. KM	10	633	643
5.KAMN 55. KM	650	40	690
6.CIHA 20. KM	14	2	16
7.AKSR 43. KM	666	65	731
Total	1592	1197	2789
Ratio	57.08%	42.92%	

Table 6. The ratio of outlier measurements to the GNSS system

GNSS System	Number of outlier measurements	The total measurements	Ratio	Ratio of total outlier measurements
GPS only	1104	136640	0.81%	0.36%
GPS + GLONASS	1685	172268	0.98%	0.55%
Total	2789	308908	0.90%	0.90%

3.1.2. Root mean square (rms, accuracy) and standard deviation (precision) values

The rms and standard deviation values for the measured 5 points and 2 control points were calculated using the following equations and shown in Tables 7 and 8 (Öğütcü 2017; Navidi 2011; Çelebi 2007).

$$m_0 = \pm\sqrt{\frac{[\varepsilon\varepsilon]}{n}} \quad (1)$$

$$s = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{n-1}} \quad (2)$$

Above; with equation (1) rms values are calculated from the differences (ε) between the coordinate components obtained from Network-Based RTK techniques and the correct coordinates of these coordinate components found because of the static session. With equation (2), the standard deviation values are calculated from the differences in the mean values ($\bar{x}$) of the easting value, northing value, and ellipsoidal height values obtained from Network-Based RTK techniques. Calculations are made after discarding outlier measurements and n is the number of measures.

Additionally, rms and standard deviation values of Network-Based RTK techniques of all measurement sets are given in the figures 5-12.

Accuracy criteria (rms) comparison has been made to determine the effect of GLONASS on measurements made with Network-Based RTK techniques in the CORS-TR network. For this, the horizontal rms and ellipsoidal height (vertical) rms values calculated from only GPS and GPS + GLONASS measurements, given in Tables 7 and 8, were compared.

Considering that the differences between horizontal rms values ± 1 cm and above and between vertical rms values ± 2 cm and above are significant; the differences obtained by subtracting the rms values of GPS + GLONASS measurements from the rms values of only GPS measurements, those that give results greater than +1 cm horizontally and +2 cm vertically are the criteria improved by GLONASS (Tables 9 and 10); those that give results less than -1 cm horizontally and -2 cm vertically are the criteria that GLONASS distorts (Tables 11 and 12) and those whose differences are between ± 1 cm horizontally and ± 2 cm vertically are not affected by GLONASS or its effect is neutral/it was evaluated as the criteria that it was meaningless. Comparisons; 84 rms values belonging to GPS + GLONASS measurement sets (horizontal and vertical rms values at 7 test points measured with 3 Network-Based RTK technique, 4 criteria (7x3x4), including satellite elevation cut-off angle 10° and 30°), again only for GPS measurements It was made with a value of 84 rms.

It has been observed that GLONASS improved rms values in 1 of a total 42 rms values on the horizontal component, the improvement rate was 2.5%, and 4 of the total 42 rms values on the vertical component, improved the rms values and the improvement rate was 10%, and the overall improvement rate was 6%. It was observed that the accuracy criterion improved in the horizontal component belongs to the MAC technique at 5. Km and the measurement set with a satellite elevation cut-off angle of 10° (Table 9). Improved accuracy criteria for vertical component; when examined in terms of baseline distance (total number of vertical criteria at each baseline distance is 6); it has been observed that there are 1 criterion at the 5th km, 1 at the 55th km and 2 criteria at the control point CIHA 20th km. When examined in terms of Network-Based RTK techniques (the total number of vertical criteria in each technique is 14), it was seen that there are 2 criteria in the FKP technique and 2 criteria in the MAC technique. If it is necessary to conduct an analysis according to the satellite elevation cut-off angles (the total number of vertical criteria is 42, with the satellite elevation cut-off angle being 21 at 10° and 21 at 30°), was observed that improved 3 of the vertical rms values calculated from the measurement sets with an elevation cut-off angle of 10°. We observed that the vertical rms values calculated from the measurement sets with an elevation cut-off angle of 30° improved 1 of them (Table 10).

It can be stated that the improvement rate of GLONASS is better in the vertical component, since 1 of the 5 improvement criteria is horizontal component and 4 belongs to vertical rms values.

Table 7. Rms and standard deviation values of test points (mm)

		TEST POINTS BETWEEN KAMN - BEYS CORS STATIONS									
Techniques	Rms and sd values	1. KAMN 5.KM		2. KAMN 10.KM		3. KAMN 20.KM		4. KAMN 40.KM		5. KAMN 55.KM	
		NRTK 10°	NRTK 30°	NRTK 10°	NRTK 30°	NRTK 10°	NRTK 30°	NRTK 10°	NRTK 30°	NRTK 10°	NRTK 30°
1.Receiver GPS - VRS	Easting-rms	3.5	3.6	5.0	5.7	11.0	9.4	5.5	6.5	5.5	5.8
	Northing-rms	6.9	8.4	6.5	8.0	7.5	13.4	6.5	6.7	12.0	10.4
	Horizontal-rms	7.8	9.1	8.2	9.8	13.3	16.3	8.5	9.3	13.2	12.0
	Ellip. height-rms	11.0	16.8	35.2	20.2	20.6	26.8	50.7	56.1	31.2	60.3
	Easting-sd	2.8	3.3	4.9	5.2	8.3	9.4	5.4	4.8	4.6	5.6
	Northing-sd	4.3	6.1	6.2	7.8	7.4	10.4	6.3	6.4	8.8	8.4
	Horizontal-sd	5.2	7.0	8.0	9.4	11.1	14.0	8.3	8.0	9.9	10.1
	Ellip. height-sd	8.4	11.6	12.5	14.1	19.8	26.8	18.6	19.2	17.4	14.9
2.Receiver GPS - FKP	Easting-rms	3.2	3.7	5.5	4.5	8.4	6.1	7.1	8.8	7.2	7.4
	Northing-rms	7.3	7.3	6.3	7.1	12.2	13.2	11.5	6.0	10.3	13.3
	Horizontal-rms	8.0	8.2	8.4	8.4	14.8	14.6	13.6	10.6	12.6	15.2
	Ellip. height-rms	10.3	18.0	23.5	15.1	19.3	24.0	50.8	65.2	51.4	48.3
	Easting-sd	2.8	3.4	5.5	4.4	6.8	6.1	6.0	3.7	6.5	5.4
	Northing-sd	4.4	5.4	6.1	6.9	10.8	7.4	10.3	5.4	7.4	7.0
	Horizontal-sd	5.2	6.4	8.2	8.2	12.8	9.6	11.9	6.6	9.8	8.9
	Ellip. height-sd	9.3	12.9	9.6	14.2	18.5	21.2	21.2	13.4	21.7	11.3
3.Receiver GPS - MAC	Easting-rms	18.8	9.9	5.9	5.2	11.2	9.4	5.5	7.4	4.9	5.2
	Northing-rms	26.8	10.9	7.1	9.0	7.0	6.3	6.4	6.4	9.5	7.8
	Horizontal-rms	32.8	14.7	9.3	10.4	13.2	11.3	8.5	9.8	10.7	9.3
	Ellip. height-rms	44.5	23.1	33.5	16.8	25.8	21.8	47.2	44.3	31.6	56.6
	Easting-sd	8.6	7.5	4.6	4.6	7.9	6.5	5.5	5.5	4.5	5.1
	Northing-sd	19.1	10.9	6.9	8.6	7.0	7.0	6.4	5.4	6.9	6.0
	Horizontal-sd	20.9	13.2	8.3	9.8	10.6	9.5	8.5	7.7	8.2	7.8
	Ellip. height-sd	44.5	15.9	14.4	13.4	18.3	19.8	14.2	13.9	16.6	13.2
4.Receiver GPS+GLO. - VRS	Easting-rms	3.1	3.5	3.9	5.1	9.3	8.8	5.1	5.4	5.5	6.4
	Northing-rms	5.6	8.8	7.7	5.2	11.0	6.3	5.4	7.3	6.6	8.8
	Horizontal-rms	6.4	9.5	8.6	7.3	14.4	10.9	7.5	9.1	8.6	10.8
	Ellip. height-rms	8.1	18.3	27.2	22.8	18.7	24.8	52.0	54.9	29.7	51.8
	Easting-sd	3.0	3.5	3.9	4.5	5.8	8.8	4.9	4.3	5.3	6.3
	Northing-sd	3.8	4.4	6.8	5.2	7.1	6.3	5.4	7.3	5.3	6.7
	Horizontal-sd	4.8	5.7	7.8	6.9	9.2	10.8	7.3	8.5	7.5	9.2
	Ellip. height-sd	7.5	16.6	9.4	18.4	17.9	24.7	13.8	14.8	11.9	15.4
5.Receiver GPS+GLO. - FKP	Easting-rms	2.6	3.4	4.1	6.7	7.5	6.8	4.8	5.8	5.0	6.2
	Northing-rms	5.7	9.0	5.6	5.4	7.3	7.0	8.0	5.3	8.1	8.2
	Horizontal-rms	6.3	9.6	6.9	8.6	10.4	9.8	9.4	7.8	9.5	10.3
	Ellip. height-rms	8.0	17.7	18.2	21.0	15.1	21.0	49.8	54.5	30.8	50.6
	Easting-sd	2.6	3.4	3.5	5.3	3.6	6.8	4.6	4.8	4.1	4.9
	Northing-sd	3.6	4.3	5.1	5.1	5.5	6.2	6.6	4.8	5.8	6.8
	Horizontal-sd	4.4	5.5	6.2	7.3	6.6	9.2	8.1	6.8	7.1	8.4
	Ellip. height-sd	7.7	15.8	7.3	18.8	14.2	20.6	11.7	12.7	14.2	14.7
6.Receiver GPS+GLO. - MAC	Easting-rms	3.7	6.8	6.5	7.8	11.3	11.7	8.7	10.2	16.4	6.5
	Northing-rms	8.6	15.3	12.9	5.8	13.1	8.1	11.1	8.0	15.4	7.8
	Horizontal-rms	9.3	16.8	14.4	9.7	17.3	14.2	14.1	12.9	22.5	10.2
	Ellip. height-rms	12.1	42.3	61.8	37.5	31.4	48.8	59.7	30.4	69.2	55.1
	Easting-sd	3.0	6.4	5.5	6.4	8.7	10.5	6.0	6.9	10.0	5.8
	Northing-sd	3.5	10.1	12.1	5.7	12.0	8.1	11.1	7.8	9.7	6.2
	Horizontal-sd	4.7	12.0	13.3	8.5	14.8	13.3	12.6	10.4	13.9	8.5
	Ellip. height-sd	10.2	25.1	20.9	19.7	30.5	40.9	21.3	13.3	17.4	16.8

Table 8. Rms and standard deviation values of control test points (mm)

CONTROL TEST POINTS BETWEEN CIHA - AKSR CORS STATIONS											
		6. CIHA 20.KM		7. AKSR 43.KM				6. CIHA 20.KM		7. AKSR 43.KM	
Techniques	Rms and sd values	NRTK 10°	NRTK 30°	NRTK 10°	NRTK 30°	Techniques		NRTK 10°	NRTK 30°	NRTK 10°	NRTK 30°
1.Receiver GPS - VRS	Easting-rms	8.6	7.4	6.2	6.3	4.Receiver GPS+GLO. VRS		6.0	5.7	11.2	9.2
	Northing-rms	7.1	7.4	9.7	10.6			8.3	6.3	48.2	8.0
	Horizontal-rms	11.2	10.5	11.5	12.4			10.2	8.5	49.5	12.2
	Ellip. height-rms	22.8	21.2	23.9	23.9			25.2	23.5	65.3	38.8
	Easting-sd	7.8	7.3	5.8	6.3		-	5.6	5.6	7.2	8.7
	Northing-sd	7.1	6.8	9.6	10.4			5.5	5.7	22.8	7.4
	Horizontal-sd	10.5	10.0	11.2	12.1			7.9	8.0	24.0	11.4
	Ellip. height-sd	12.7	18.4	21.9	18.0			8.7	16.4	36.4	21.4
2.Receiver GPS - FKP	Easting-rms	8.3	7.2	11.4	8.5	5.Receiver GPS+GLO. FKP		7.0	7.5	9.5	10.8
	Northing-rms	10.7	8.5	13.3	8.9			8.5	6.8	55.9	8.3
	Horizontal-rms	13.6	11.1	17.5	12.3			11.0	10.1	56.7	13.6
	Ellip. height-rms	52.7	47.6	17.9	25.7			31.0	35.8	69.0	29.0
	Easting-sd	8.1	6.6	7.8	5.6		-	6.2	6.4	7.2	9.0
	Northing-sd	9.1	6.9	12.6	8.8			4.2	6.4	10.5	6.2
	Horizontal-sd	12.2	9.6	14.8	10.5			7.5	9.0	12.7	10.9
	Ellip. height-sd	17.3	15.3	17.7	18.5			9.6	19.4	21.0	20.5
3.Receiver GPS - MAC	Easting-rms	7.8	5.6	7.1	5.0	6.Receiver GPS+GLO. MAC		8.1	6.7	6.7	9.0
	Northing-rms	7.1	9.1	13.8	10.7			6.3	6.3	17.9	7.5
	Horizontal-rms	10.6	10.7	15.5	11.8			10.3	9.2	19.1	11.7
	Ellip. height-rms	18.7	54.1	43.8	36.5			25.8	22.5	25.3	39.5
	Easting-sd	5.8	5.3	6.7	4.7		-	5.5	5.5	6.0	9.0
	Northing-sd	6.2	6.7	9.7	6.8			5.6	6.3	6.5	7.1
	Horizontal-sd	8.5	8.5	11.8	8.3			7.8	8.4	8.9	11.4
	Ellip. height-sd	15.0	16.6	19.4	13.1			9.6	17.2	21.7	25.0

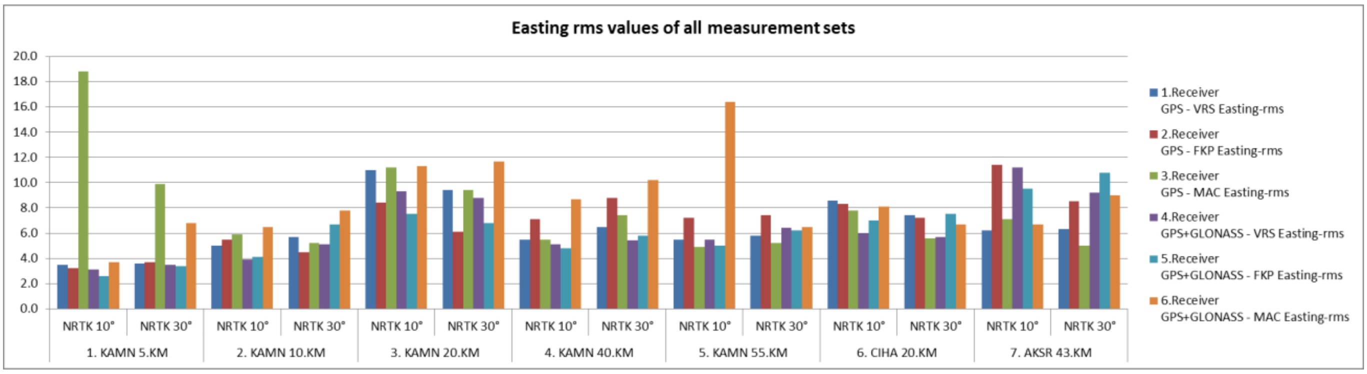

Figure 5. Easting rms values of all measurement sets (mm)

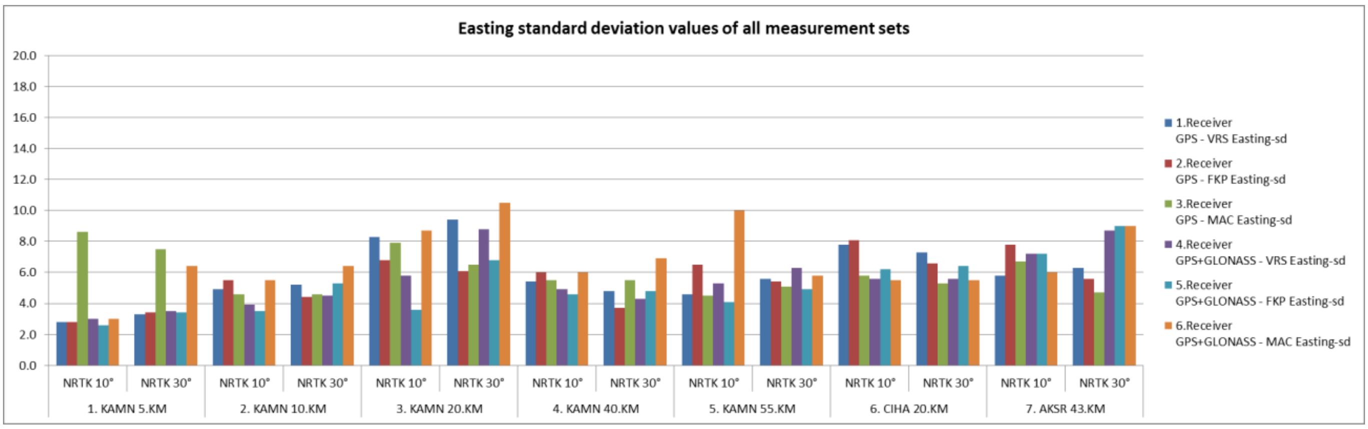

Figure 6. Easting standard deviation values of all measurement sets (mm)

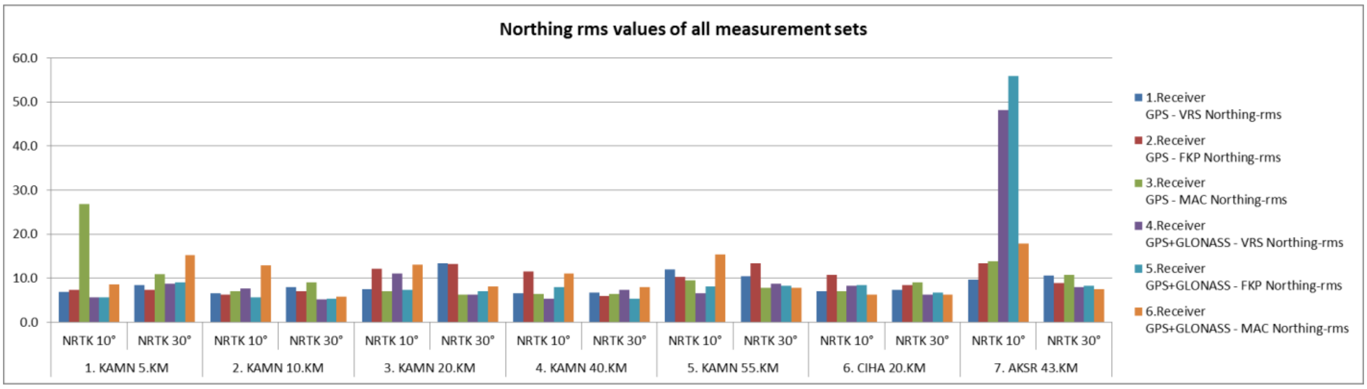

Figure 7. Northing rms values of all measurement sets (mm)

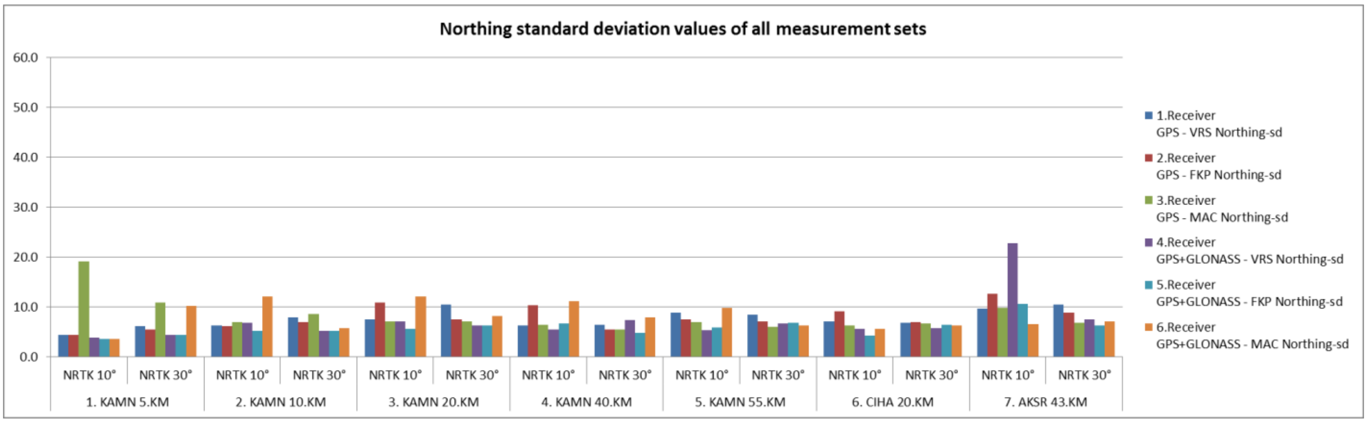

Figure 8. Northing standard deviation values of all measurement sets (mm)

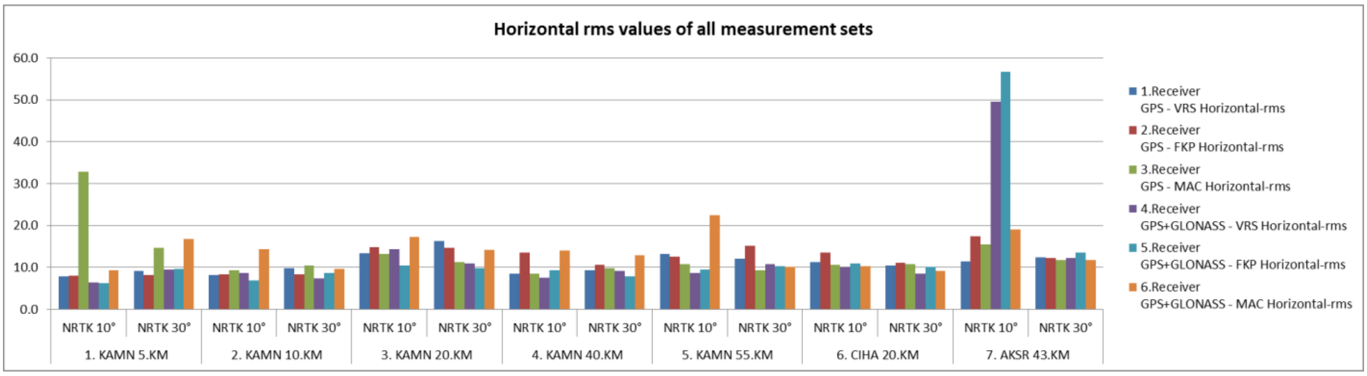

Figure 9. Horizontal rms values of all measurement sets (mm)

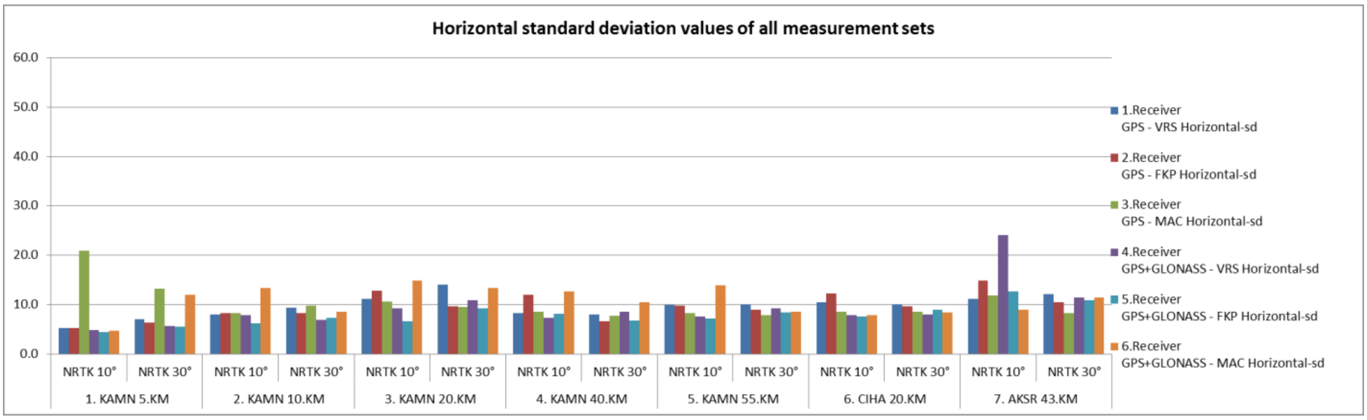

Figure 10. Horizontal standard deviation values of all measurement sets (mm)

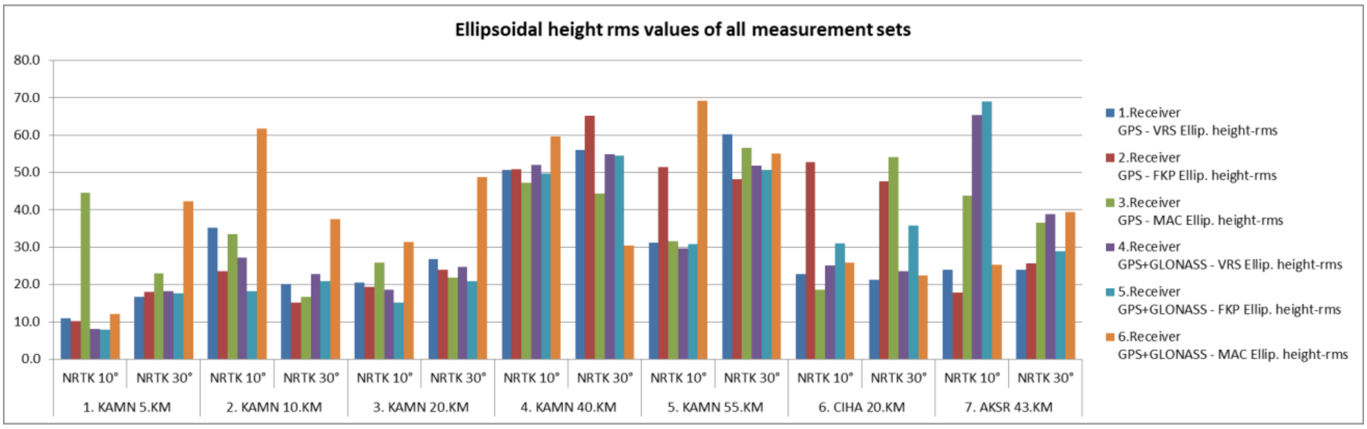

Figure 11. Ellipsoidal height rms values of all measurement sets (mm)

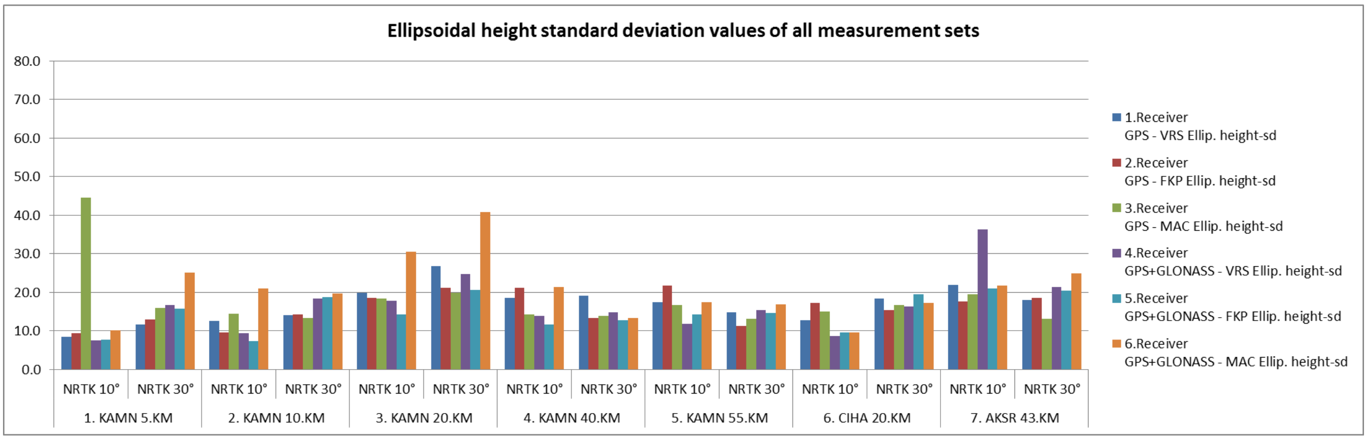

Figure 12. Ellipsoidal height standard deviation values of all measurement sets (mm)

Table 9. The criteria that GLONASS has improved in the horizontal component

S.No	Baseline distance	Teknique	Accuracy criteria	GPS (cm)	GPS+GLONASS (cm)	Difference (cm)
1	5.KM	MAC - 10°	Horizontal-rms	3.28	0.93	2.35

Table 10. The criteria that GLONASS has improved in vertical component

S.No	Baseline distance	Teknique	Accuracy criteria	GPS (cm)	GPS+GLONASS (cm)	Difference (cm)
1	5.KM	MAC - 10°	Ellip. height-rms	4.45	1.21	3.24
2	55.KM	FKP - 10°	Ellip. height-rms	5.14	3.08	2.06
3	CIHA 20.KM	FKP - 10°	Ellip. height-rms	5.27	3.10	2.17
4		MAC - 30°	Ellip. height-rms	5.41	2.25	3.16

It has been observed that GLONASS distorts the rms values in 3 of the total 42 rms values in the horizontal component, the distortion rate is 7%, it distorts the rms values in 6 of the total 42 rms values in the vertical component, the distortion rate is 14% and the overall distortion rate is 11%. It has been observed that horizontally distorted accuracy criteria belong to the MAC technique at the 55th Km and to the VRS and FKP techniques at the 43th Km of the AKSR, which is the control point, and measurement sets with the satellite elevation cut-off angle of 10° in each 3 criteria (Table 11). In the vertical component, the distorted accuracy criteria; when examined in terms of baseline distance (total number of vertical criteria at each baseline distance is 6); it has been observed that there are 2 criteria at the 10th km, 1 at the 20th km, 1 at the 55th km and 2 criteria at the control point AKSR 43rd km. When examined in terms of Network-Based RTK techniques (the total number of vertical criteria in each technique is 14), it was seen that there are 1 criterion in the VRS technique, 1 in the FKP technique and 4 in the MAC technique. According to these results, it can be stated that GLONASS gives worse results in vertical component in MAC technique. If it is necessary to conduct an analysis according to satellite elevation cut-off angles (the total number of vertical criteria is 42, with the satellite elevation cut-off angle being 21 at 10° and 21 at 30°), while disrupting 4 of the vertical rms values calculated from the satellite elevation cut-off angle 10° measurement sets, it was observed that the vertical rms values calculated from the measurement sets with a satellite elevation cut-off angle of 30° distorted 2 of them (Table 12).

Table 11. The criteria that GLONASS has distorted in the horizontal component

S.No	Baseline distance	Teknique	Accuracy criteria	GPS (cm)	GPS+GLONASS (cm)	Difference (cm)
1	55.KM	MAC - 10°	Horizontal-rms	1.07	2.25	-1.18
2	AKSR 43.KM	VRS - 10°	Horizontal-rms	1.15	4.95	-3.80
3		FKP - 10°	Horizontal-rms	1.75	5.67	-3.92

Table 12. The criteria that GLONASS has distorted in vertical component

S.No	Baseline distance	Teknique	Accuracy criteria	GPS (cm)	GPS+GLONASS (cm)	Difference (cm)
1	10.KM	MAC - 10°	Ellip. height-rms	3.35	6.18	-2.83
2		MAC - 30°	Ellip. height-rms	1.68	3.75	-2.07
3	20.KM	MAC - 30°	Ellip. height-rms	2.18	4.88	-2.70
4	55.KM	MAC - 10°	Ellip. height-rms	3.16	6.92	-3.76
5	AKSR 43.KM	VRS - 10°	Ellip. height-rms	2.39	6.53	-4.14
6		FKP - 10°	Ellip. height-rms	1.79	6.90	-5.11

In 38 of the total 42 rms values of GLONASS in the horizontal component, the differences between the rms values remained between +1 cm and -1 cm, and these criteria were evaluated as the criteria that GLONASS did not affect or the effect was neutral/meaningless, and it was found to be 90.5% proportionally. On the vertical component, 32 of 42 rms values, the differences between rms values are between +2 cm and −2 cm and these criteria are considered neutral/meaningless the effect of GLONASS, it is 76% proportionally and the overall neutral rate was found to be 83%.

All measurement sets obtained from Network-Based RTK measurements; the average of the measurements/epochs of 5 minutes, 15 minutes, 30 minutes, 1 hour and 2 hours (300, 900, 1800, 3600, and the average of all measurements/epoch respectively) was classified as one measurement. By taking the differences between the correct coordinates of the test points and the measurement averages, the differences obtained from only GPS measurements and GPS + GLONASS measurements were compared in graphics. As an example, the comparison graphics of the 5th km of the KAMN - BEYS route for the VRS technique are given in Figures 13, 14, 15 and 16.

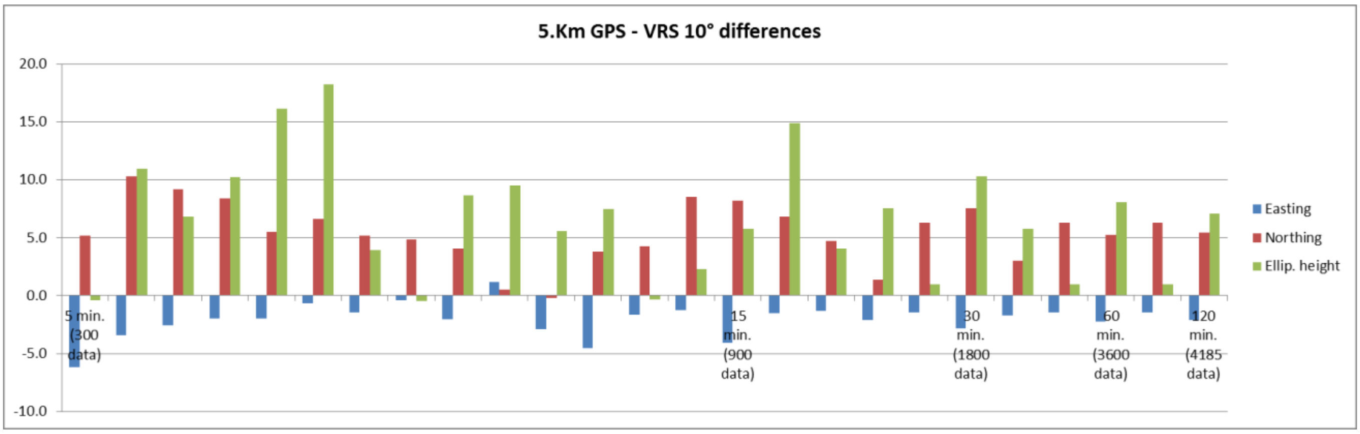

Figure 13. KAMN 5. Km. 5 min., 15 min., 30 min., 1 h. and 2 h. only GPS - VRS (satellite elevation cut-off angle 10°) coordinate differences in measurements (mm)

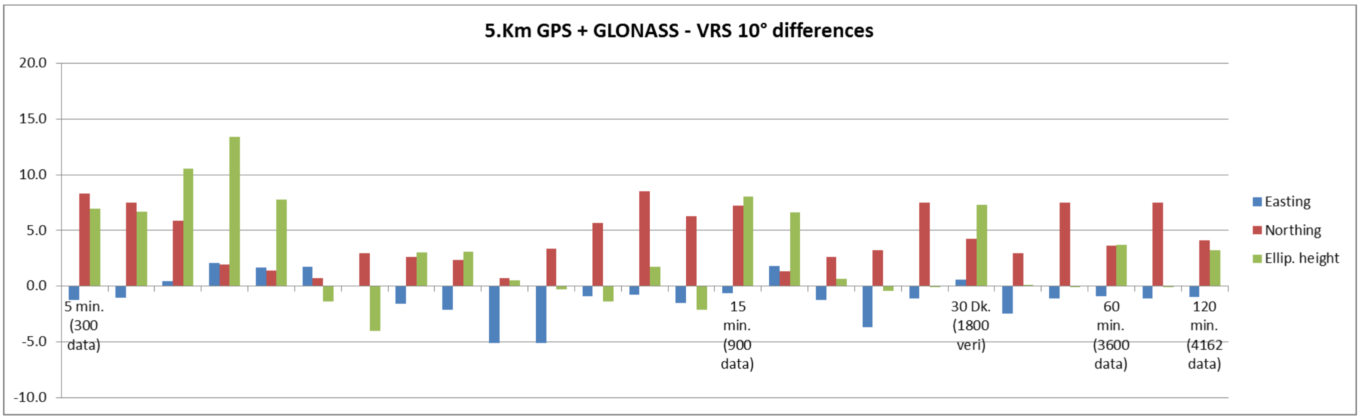

Figure 14. KAMN 5. Km. 5 min., 15 min., 30 min., 1 h. and 2 h. GPS + GLONASS - VRS (satellite elevation cut-off angle 10°) coordinate differences in measurements (mm)

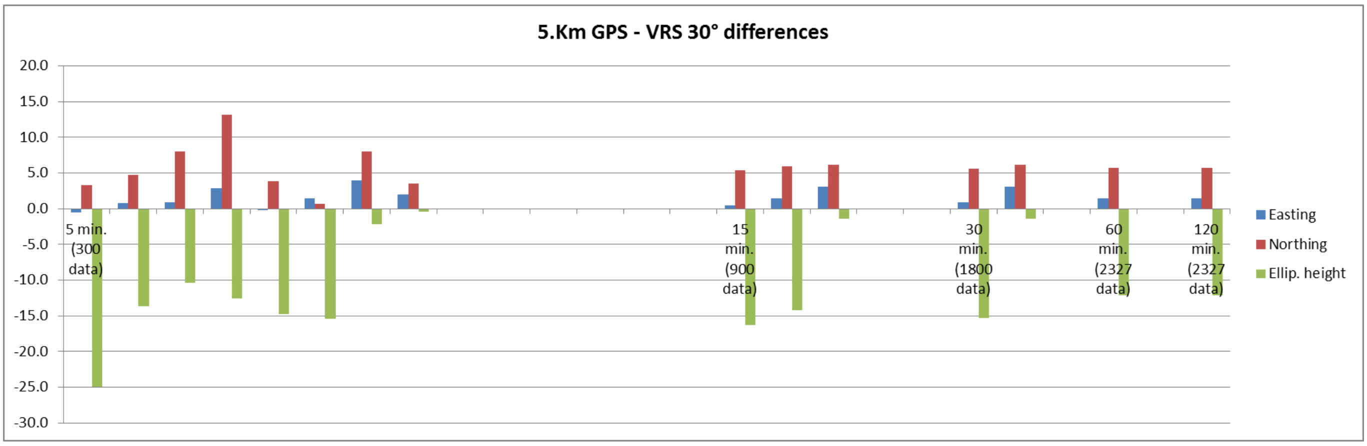

Figure 15. KAMN 5. Km. 5 min., 15 min., 30 min., 1 h. and 2 h. only GPS - VRS (satellite elevation cut-off angle 30°) coordinate differences in measurements (mm)

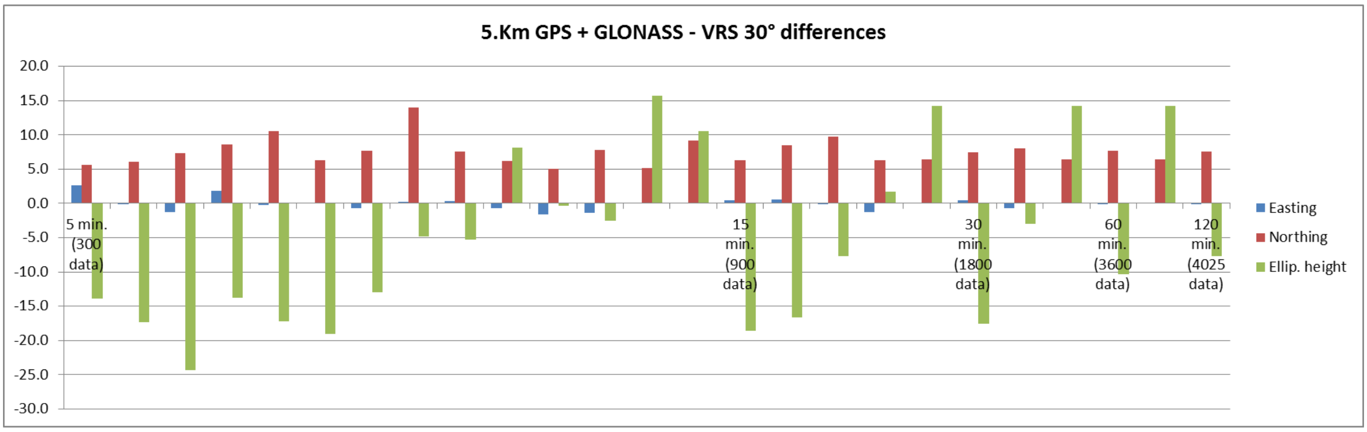

Figure 16. KAMN 5. Km. 5 min., 15 min., 30 min., 1 h. and 2 h. GPS + GLONASS - VRS (satellite elevation cut-off angle 30°) coordinate differences in measurements (mm)

4. RESULTS

To determine the effect of GLONASS on location accuracy in CORS-TR measurements, a test study was conducted and the obtained data and evaluations were explained in the previous section. The findings obtained because of the application can be summarized as follows.

In total, 308,908 epoch data measurements were made at seven test points and all three techniques. In measurements, it was observed that GLONASS increased the feasibility of measurements by increasing the number of observable satellites, especially in 30° measurements; this situation was seen more clearly and decreased PDOP values (Table 2). The number of satellites to be observed with the GLONASS system is increasing. Thus, it has been understood that GLONASS can have a positive effect in built-up areas such as city centers and forested areas where satellite signals are blocked.

With the outlier measurements test, it was observed that only 2,789 measures were outliers in a total of 308,908 epoch data, and the ratio of outliers to the total measurements was 0.90% (Table 3). It was found that the most outlier measurements were in MAC, FKP, and VRS techniques, respectively (Table 3). It was observed that there is a direct proportionality between the baseline distance and the outlier measurements (Table 4). It was understood that the outlier measurements were in the measurements of 10° at most (Table 5). It was observed that the outlier measurements were higher in GPS + GLONASS measurements than only GPS measurements (Table 6).

The rms and standard deviation values were calculated for all measurement sets (Tables 7 and 8). By evaluating the rms and standard deviation values, as the baseline distances increase, the horizontal rms, horizontal standard deviation, and vertical standard deviation values increase (according to the level of mm), but decrease after 20 Km and enter an increasing trend again, and the vertical rms values generally increase as the baseline distance increases, found to have an increasing trend. It was observed that the results of the VRS and FKP techniques were close to each other, and the rms and standard deviation values were higher in the MAC technique compared to the other two techniques. It has been understood that measurements with a satellite elevation cut-off angle of 10° give good results with small differences. When only GPS and GPS + GLONASS measurements are compared with each other, it is seen that GLONASS improves the results in general, but has a disruptive effect at some test points. When the rms and standard deviation values are compared with each other, it has been observed that the rms values are higher and the standard deviation values are lower, that is, the precision values of the measurements are better than the accuracy values.

Accuracy criteria (rms) comparison was made to determine the effect of GLONASS on measurements made with Network-Based RTK techniques in the CORS-TR network. Separate comparisons of horizontal rms and ellipsoidal height (vertical) rms values calculated from GPS + GLONASS measurements and only GPS were made and the results are given above. According to these results, it has been observed that the improvement rate of GLONASS does not form a trend in the horizontal component and is better in the vertical component due to the close results, and among the Network-Based RTK techniques, the MAC technique gives worse results in the vertical component.

All measurement sets obtained from Network-Based RTK measurements; The average of the measurements/epochs of 5 min., 15 min., 30 min., 1 h., and 2 h. (300, 900, 1800, 3600, and the average of all measurements/epochs) was classified as one measurement. By taking the differences between the correct coordinates of the test points and the measurement averages, only the differences obtained from GPS measurements and GPS + GLONASS measurements were compared in graphics. With the evaluation of the graphics, it was observed that the error differences such as 5 min and 15 min were especially high in the measurement groups where the number of measurements/epochs was low, and the accuracy increased by decreasing the error differences as the number of measurements/epochs increased. It has been observed that the effect of the baseline distance on the measurement groups is at the maximum level in the vertical component, the coordinate differences in the vertical direction increase as the baseline distance increases, that is, the accuracy decreases, and the effect is at the minimum level in the horizontal component. It was understood that the error differences were more stable in the measurement groups with a high number of measurements/epochs. When Network-Based RTK techniques are compared, it has been observed that the results obtained from the VRS and FKP techniques are close to each other, while the accuracy of the measurements obtained from the MAC technique is lower. It has been observed that measurements of 10° satellite elevation cut-off angle generally give more accurate results (especially in the vertical direction). It has been observed that the effect of GLONASS is generally positive, but it also has a ground-disturbing effect, and the most important contribution is that it increases the number of measurements made, especially in the measurement groups with a satellite elevation cut-off angle of 30°, by providing the minimum number of satellites required for measurement.

Additionally, because of the measurements, the smallest (best) rms and standard deviation values are given in Table 13, and the largest (worst) rms and standard deviation values are given in Table 14.

Table 13. Minimum rms and standard deviation values

		Minimum value (mm)	Baseline distance	Teknique	Elevation cut-off angle	GNSS	Receiver No
Rms	Easting	2.6	5. Km	FKP	10°	GPS+GLONASS	5
	Northing	5.2	10. Km	VRS	30°	GPS+GLONASS	4
	Horizontal	6.3	5. Km	FKP	10°	GPS+GLONASS	5
	Ellip. height	8.0	5. Km	FKP	10°	GPS+GLONASS	5
Standard deviation	Easting	2.6	5. Km	FKP	10°	GPS+GLONASS	5
	Northing	3.5	5. Km	MAC	10°	GPS+GLONASS	6
	Horizontal	4.4	5. Km	FKP	10°	GPS+GLONASS	5
	Ellip. height	7.3	10. Km	FKP	10°	GPS+GLONASS	5

Table 14. Maximum rms and standard deviation values

		Maximum value (mm)	Baseline distance	Teknique	Elevation cut-off angle	GNSS	Receiver No
Rms	Easting	18.8 16.4	5. Km 55. Km	MAC	10°	GPS GPS+GLONASS	3 6
	Northing	55.9	AKSR 43. Km	FKP	10°	GPS+GLONASS	5
	Horizontal	56.7	AKSR 43. Km	FKP	10°	GPS+GLONASS	5
	Ellip. height	69.2	55. Km	MAC	10°	GPS+GLONASS	6
Standard deviation	Easting	10.5	20. Km	MAC	30°	GPS+GLONASS	6
	Northing	22.8	AKSR 43. Km	VRS	10°	GPS+GLONASS	4
	Horizontal	24.0	AKSR 43. Km	VRS	10°	GPS+GLONASS	4
	Ellip. height	44.5 40.9	5. Km 20. Km	MAC	10° 30°	GPS GPS+GLONASS	3 6

As a result, it has been observed that the most accurate and most precise measurements belong to the measurement sets with VRS and FKP techniques and GLONASS, at the shortest base distances, 5th and 10th km, with a satellite elevation cut-off angle of 10°. It was concluded that the worst results were in the long baseline distances (generally 43 and 55 km) and the measurement groups belonging to the MAC technique.

5. CONCLUSION

With this study, a test application was performed to determine the effect of the GLONASS system on the position accuracy in the CORS-TR network in terms of baseline distance and Network-Based RTK techniques, and the results of the application were discussed.

The main subjects targeted in the study were determined. These were, first, determining the effect of GLONASS on position accuracy in CORS-TR measurements. Because of the application, it has been determined that GLONASS has a positive effect on position accuracy. However, in some cases, it has been seen to have a disruptive effect. It has been predicted that the reason for this is that the satellite distributions in the sky are unevenly distributed, but may have accumulated in one direction, and may be caused by the algorithms/software used to evaluate the GPS and GLONASS satellite data together. However, using GPS and GLONASS satellite systems together; it has been evaluated that it may be caused by differences in signal structures, coordinates, time systems, and orbit numbers, receiver clock errors, carrier phase observation models, deviations between GNSS receiver device channels, and their modeling, as well as some difficulties. Additionally, in the literature reviews, it is stated that the FDMA method, which is the signal separation technique used by GLONASS, is used in first and second-generation GLONASS satellites (first generation of GLONASS and GLONASS-M satellites) and this method may cause deviations in cm levels. The phase initial ambiguity resolution performance of the FDMA method is lower than the CDMA method and the failure to completely eliminate some errors such as modeling receiver clock errors in the phase initial ambiguity resolution reflects the negative effect of GLONASS on the measurement results. However, the most important contribution of GLONASS; it has been observed that increasing the number of visible satellites, especially in measurements where the satellite elevation cut-off angle is 30°, the number of satellites required for a measurement is easily provided, and in areas where the satellite elevation cut-off angle is narrowed such as city centers and forest areas, it provides the ability to make measurements with GLONASS satellites in cases where only GPS satellites are not sufficient. Second, accuracy and precision comparisons were made between Network-Based RTK techniques (VRS, FKP, and MAC). Although the comparison results are close to each other, it has been concluded that in general, VRS and FKP techniques give closer, more accurate, and precise results. Finally, the effect of the baseline distance on the position accuracy for each test point was determined. With the evaluation of rms and standard deviation values, it has been observed that as the baseline distances increase, the horizontal rms, horizontal standard deviation, and vertical standard deviation values increase (according to the level of mm), but decrease after 20. Km and enter an increasing trend again, and the vertical rms values generally increase as the baseline distance increases.

As a result; it has been obtained that GLONASS has a significant effect on position accuracy, when used in integration with GPS and other satellite systems; it increases the number of visible satellites, decreases PDOP values, and positively affects the results, especially in disabled areas where satellites have limited visibility.

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Author contribution

Ömer Yurdakul: Conceptualization, Methodology, Software, Writing-Original draft preparation. **İbrahim Kalaycı**: Review, Writing-Review, Software-Verification, and Editing.

Conflicts of interest

The authors declare no conflicts of interest.

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