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A COMPLIANCE ASSESSMENT OF GNSS STATION NETWORKS IN SERBIA

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Abstract: Since the early 21st century, Global Positioning System (GPS) technology has dominated geodetic reference networks. Almost all countries established a permanent Global Navigation Satellite System (GNSS) station network to augment all available GNSS systems. By the end of 2005, Serbia completed the Active Geodetic Reference Network as a particular project of Serbia's Republic Geodetic Authority (RGA). Besides RGA, two private companies, Vekom and Geotaur, have established permanent station networks. This paper assesses the compliance of all the three networks, and network results are evaluated against the spatial distance determined by classical geodetic methods. When all available GNSS constellations are utilized, NAVSTAR, GLONASS, BEIDOU, and GALILEO, in the processing procedure, the established networks in Serbia align within a margin of about 3 mm across all coordinate axes. The results obtained within the research indicate that by using GNSS networks, it is possible to provide the coordinates of the points for the establishment of the national spatial reference system of Serbia, the reference system in almost all engineering fields, reference systems for the maintenance works of the real estate cadastre, and it is also possible to provide coordinates of points that can be used to define local, national, and world reference heights surfaces.

Keywords: GNSS receiver networks; compliance evaluation; AGROS; VekomNet; GeotaurNet

1. Introduction

In the last decade of the 20th century, some countries such as the United States of America, Canada, and Germany started Differential Global Navigation Satellite System (DGNSS) services, including a permanent station network for real-time positioning (Héroux et al., 2006; Kee et al., 1991; Weber et al., 2007). All of mentioned services allows for quick and efficient position determination with centimeter-level accuracy. This kind of service provided revolutionary, elegant, fast, and smooth solutions for completing fundamental geodetic tasks or engineering problems during this period.

The European Position Determination System (EUPOS) is an initiative to establish a uniform DGNSS infrastructure in Central and Eastern Europe based on the European Terrestrial Reference System 1989 (ETRS89; Śledziński, 2004). The German National Survey Satellite

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Positioning System (SAPOS) referenced the EUPOS Project. Such a positioning system supports navigation and positioning with decimeter− or centimeter−level of accuracy in real-time, which can reach a sub−centimeter level of accuracy with post-processing (Milev et al., 2004).

Both of the initiatives mentioned above started when only the Navigation Satellite Timing and Ranging (NAVSTAR) Global Positioning System (GPS) was available. Meanwhile, three additional global systems have reached their full constellation, so the establishment of the DGNSS infrastructure refers to the auxiliary infrastructure that supports all available global systems:

- Russian Global Navigation Satellite System—GLONASS (GLONASS, 2020; Revnivykh et al., 2017);
- European Union Navigation Satellite System—GALILEO (Duan et al., 2023; Falcone et al., 2017; GALILEO, 2019); and
- Chinese Navigation Satellite System—BEIDOU or COMPASS (China Satellite Navigation Office, 2018; Yang et al., 2017).

These navigation systems are commonly referred to as the Global Navigation Satellite Systems (GNSS; Seeber, 2003). GNSS network consists of continuous operative (permanent) reference stations (CORS) covering some territory at the Earth's surface, and a Control Center responsible for collecting data from GNSS stations and communicating with users. The primary purpose of establishing this type of network was to support the solution of a wide range of geodetic tasks with high efficiency at a lower cost. The examples of these tasks are as follows:

- Geodetic survey;
- Maintenance of real-estate cadaster;
- Establishment of a GIS system;
- Support for engineering and technical works and
- Vehicle navigation, etc.

All GNSS networks offer users services to solve the mentioned tasks. Generally, they can be divided into two primary services: Real Time Kinematic (RTK) and post-processing (Hofmann-Wellenhof et al., 2008). The RTK service has an accuracy of 1–3 cm and it is used for various geodetic activities (engineering geodesy, land surveying, etc.). This service is available in the Radio Technical Commission for Maritime Services (RTCM) format, and data transfer is performed via mobile Internet (RTCM, 2022). A post-processing service is provided for users whose activities require a higher positioning accuracy (sub-centimeter accuracy). These activities include establishing a geodetic control network, scientific research, or deformation analysis. Communication between users and services is realized via the Internet. Research on the quality of post-processing service work in GNSS networks is a prominent topic across several levels of study. This type of research is very current in almost all countries of the world. CORS networks are being developed at the level of continents, countries, regions, or even cities. State geodetic administrations and private companies often create networks, and the founders are often universities, that is, their institutes and faculties.

One of the essential GNSS networks is the Euref Permanent Network (EPN), which has over 420 GNSS receivers (EUREF, 2023). The points of the network often reach an accuracy of 1 mm, and this network includes almost all European countries that use the EPN network as a reference (Bruyninx et al., 2019; EUREF, 2022).

Many scientific papers (García-Asenjo et al., 2021; Rodríguez et al., 2022; Wagner et al., 2022) describe the networks that cover the territory of a country, especially from Western and Central European countries. One such work is a presentation of five networks on the territory of Poland that cover the entire country (Uznański, 2023) and contain almost 600 receivers. In the framework of these studies, the authors, in addition to a relatively detailed description of the network, show that the network's agreement in the horizontal sense is in the range of 1–11 mm and the vertical sense of 8–23 mm. One example of a university network is the CORS network developed by the University of Palermo. The network consists of nine stations; using it, the points reach an accuracy of several millimeters (Pipitone et al., 2023).

This article provides an overview of the current GNSS networks in Serbia and proposes a methodology for evaluating their compliance. The data utilized in the study are either publicly available data or data gained through direct communication with the owners of GNSS networks. These studies focus on describing networks and explaining how coordinates are determined. Special emphasis is placed on external verifying the accuracy of these coordinates by comparing them directly with spatial distances calculated using traditional geodetic methods. In this case, the distance between two GNSS receivers is found to be 4.1555 m.

2. GNSS networks in Serbia

During the last 20 years, in Serbia, three GNSS networks were established: Active Geodetic Reference Network of Serbia—AGROS, VekomNet, and GeotaurNet.

All the three GNSS networks cover the entire territory of Serbia, with an average distance of 70 km between each station (Odalović & Aleksić, 2006). Furthermore, high-precision GNSS receivers are deployed at each and every station, regardless of which network is participating.

2.1. AGROS

AGROS is the Serbian national reference GNSS network consisting of continuous operative reference stations covering the entire territory of the Republic of Serbia. In collaboration with the Faculty of Technical Science at the University of Novi Sad, the RGA initiated the project for the creation of AGROS of Serbia in 2003. By the end of 2005, approximately 80% of the Serbian territory was covered (RGA, 2023). The network was fully established in 2007. In addition to the basic purpose of the GNSS network, Serbian research institutions have significant scientific benefits as they can interpret data provided by AGROS services. Mainly, the Faculty of Civil Engineering in Belgrade (Department of Geodesy and Geoinformatics) and

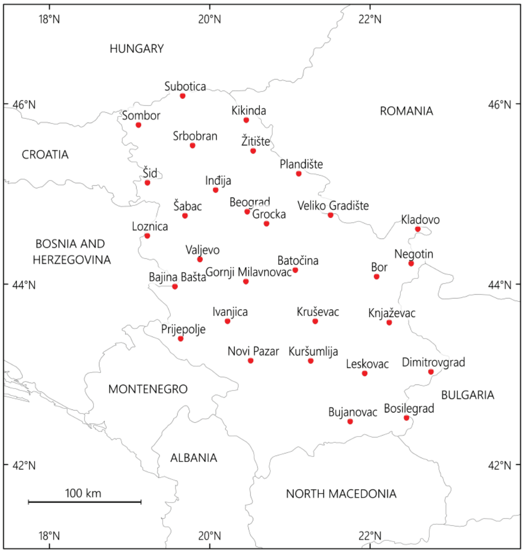

Figure 1. Spatial distribution of AGROS permanent station network.

the Faculty of Technical Science in Novi Sad used AGROS data for a wide range of scientific research (Odalović et al., 2011). After approximately 15 years of development, there are now 30 Trimble stations and their spatial distribution is shown in Figure 1.

AGROS services are primarily oriented toward the specific need for real-time positioning. All services are continuously available via the Internet. The primary focus of these services is to support customers in solving various geodetic tasks. The services, besides direct services (RTK and post-processing), also include the following services: Virtual Reference Station (VRS) service, RTCM3Net service, Differential Global Positioning System (DGPS) service, iGATE protocol, Automatic post-processing service, Subnetwork development service, Geoid undulation of the Republic of Serbia, Real-time tracking of the GNSS rovers in the field, Alarm service of the AGROS Control Center – AGROS SMS notification, AGROS Control Center monitoring service, and Quality control of receiver independent exchange format (RINEX) data (AGROS, 2023).

2.2. VekomNet GNSS network

VekomNet is a network of GNSS stations, and unlike the national AGROS network, this network is completely established on the Leica platform and is financed by Vekom Geo. The networks officially became the GNSS network in 2019, and today, they are an integral part of the spatial reference framework of the Republic of Serbia and can be used for work within the scope of the RGA. Today, VekomNet has 45 stations: 31 in Serbia and 14 in neighboring countries. The spatial distribution of stations in Serbia is shown in Figure 2. The network's control centre is in Belgrade, at the headquarters of Vekom (Vekom, 2023).

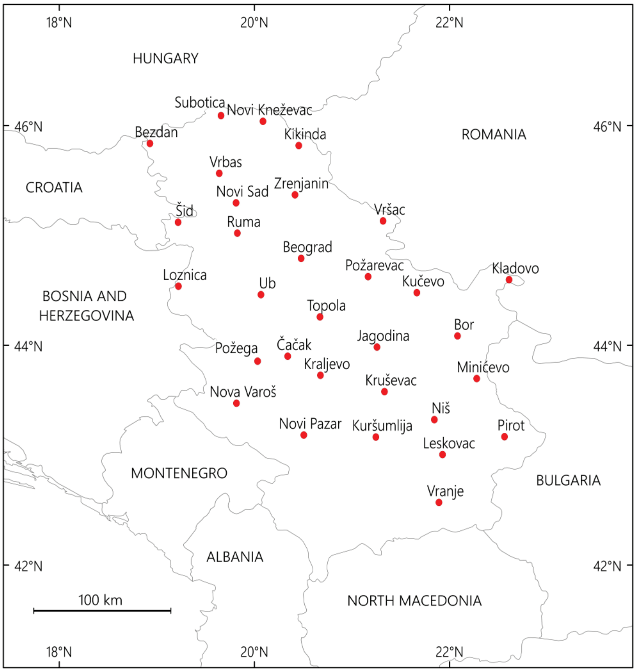

Figure 2. Spatial distribution of VekomNet permanent station network.

The VekomNet GNSS network technology provides all users maximum efficiency, supporting four satellite systems: GPS, GLONASS, GALILEO, and COMPASS. Several services that do not differ from those of the AGROS network are available to VekomNet users. Public services of VekomNet include the following: RTK, DGNSS, and RINEX data for post-processing (Vekom, 2023).

2.3. GeotaurNet GNSS network

Geotaur is a private geodetic organization founded in Belgrade that deals with geodesy and geomatic consulting. One of their main activities involves establishing and maintaining the GNSS network. The network, GeotaurNet, comprises 23 GNSS stations at the moment, and their spatial distribution is shown in Figure 3. GeotaurNet is a network of GNSS stations based on GentooARS technology that is officially approved by the RGA (according to a decision from November 27, 2019) in terms of accuracy and quality (Geotaur, 2022). The services of the GeotaurNet network are as follows: RTK service, and Service for providing RINEX data (Geotaur, 2022).

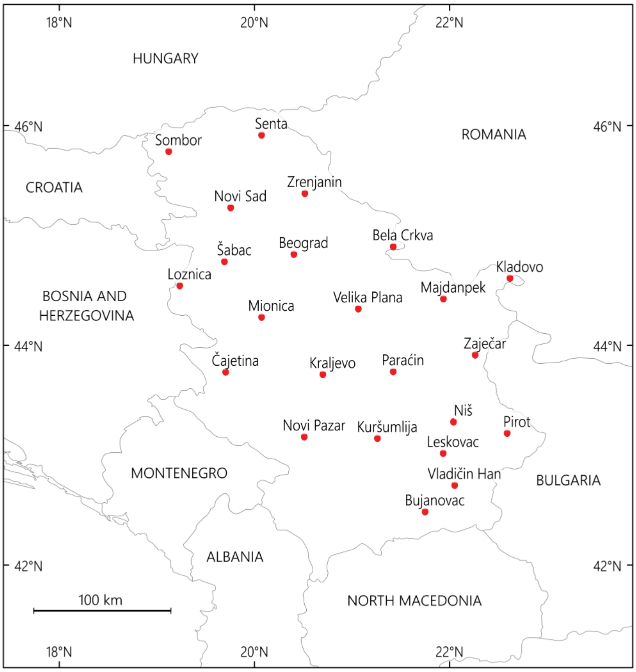

Figure 3. Spatial distribution of GeotaurNet permanent station network.

3. Methodology for compliance evaluation of GNSS networks

In order to test the homogeneity of all the mentioned networks, the values of the coordinates of two permanent stations located on the roof of the building of the Faculty of Civil Engineering of the University of Belgrade (Figure 4), which do not belong to any of the previously shown networks, were evaluated. These two points were treated as test stations in this work and were named GRF1 and GRF2. In the figure, the phase centers of the antennas are marked with red circles, while the centers of geodetic marks of the test stations are marked with green circles. The shown dimensions are used for coordinate reduction. Their basic technical characteristics are shown in Table 1. It is important to note that point GRF1, according to its configuration, only collects data from the GPS NAVSTAR system, and point GRF2 collects data from all the available global systems (GPS NAVSTAR, GLONASS, GALILEO, and BEIDOU).

Table 1. Some technical specifications of used GNSS receivers

Distance	GRF1	GRF2
Supported GNSS systems	GPS	GPS, GLONASS, GALILEO, BAIDOU
Receiver model	Trimble NetRS	Trimble SPS855
Antenna type	Zephyr Geodetic	Zephyr Geodetic 3

The spatial distance between marked test stations was determined by direct measurement using a total station, and after all the necessary corrections, it is D_{SP} = 4.1555 m. The tested homogeneity implies the differences in spatial distances determined based on permanent stations of all the relevant networks of this work and the D_{SP} distance determined by direct measurement with a total station.

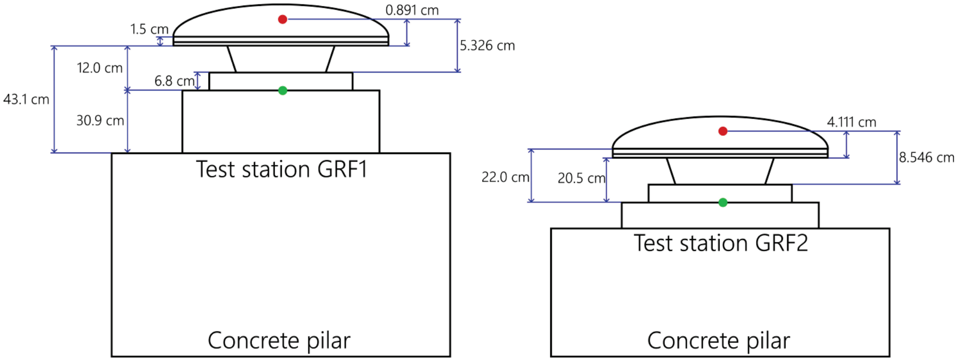

Figure 4. Schematic representation of the location of the test station.

3.1. Data collection

The data was collected from the permanent stations of the relevant networks in the period July 16–22, 2023 in the form of 24-hour RINEX files with 30-second sampling. For the specified period, i.e., for GPS week 2271, from the network:

- AGROS downloaded data from seven permanent stations whose spatial layout is shown in Figure 5A;
- GeotaurNet data were downloaded from 23 permanent stations (spatial layout shown in Figure 5B); and
- VekomNet data from six permanent stations (spatial layout shown in Figure 5C).

The data from the AGROS network were taken as publicly available (seven permanent stations of the AGROS network are part of the EUREF EPN network; Bruyninx et al., 2019), and the data from other networks were taken in direct communication with the companies that own the networks mentioned above.

The spatial distance was determined using the total station GEOMAX ZOOM 40, whose declared accuracy for distance measurement is 2 mm + 2 ppm. For the combination of the entire station and the used signal, an additional constant (a = 0.0043 m) was previously determined, which was adequately applied in the final evaluation of the spatial distance.

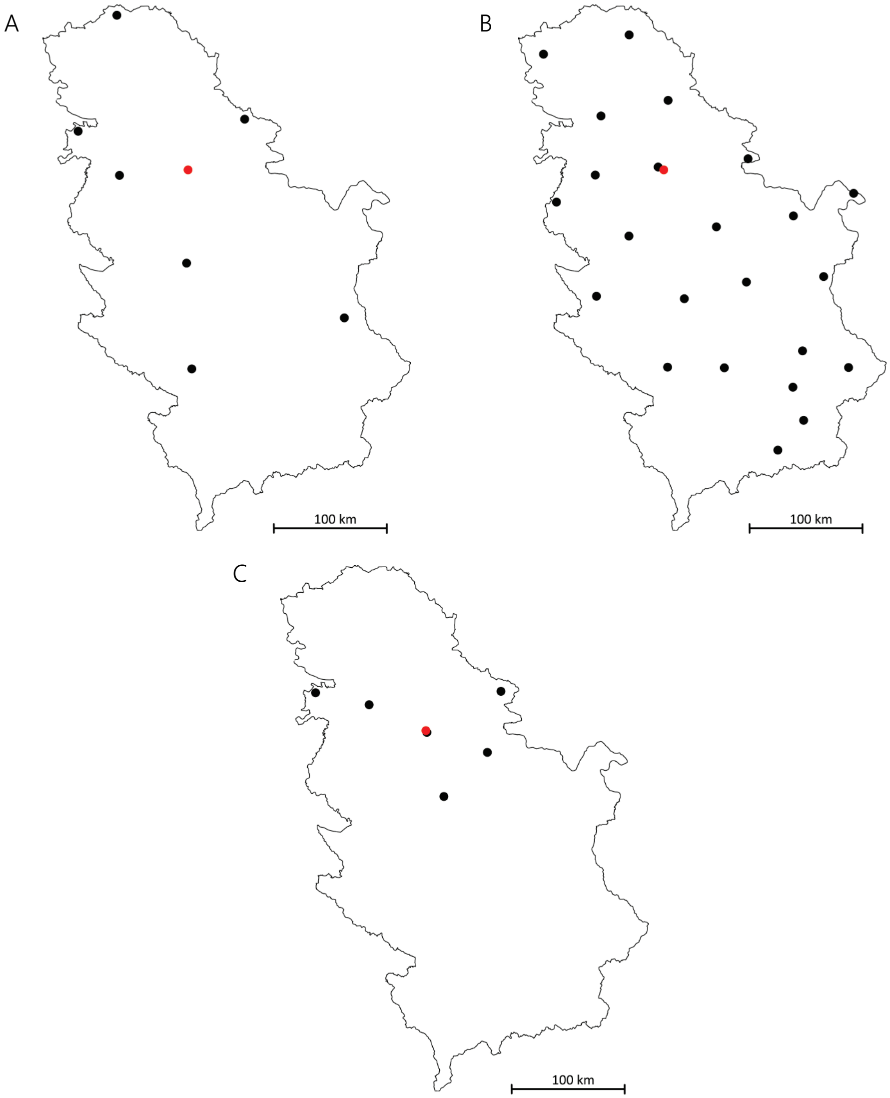

Figure 5. Spatial distribution of available stations from different GNSS networks: AGROS stations (A); GeotaurNet stations (B); VekomNet stations (C). Red point on the figures is the location of GNSS test station.

3.2. Data processing

Data from all permanent stations were processed individually. Namely, the coordinates of the test stations were determined using only AGROS, GeotaurNet, and VekomNet networks. Before processing, the coordinates of all the available stations of the mentioned networks were determined using the EUREF EPN network (one part of the network shown in Figure 6) within ITRF2020, using the data downloaded from the EPN stations for the specified period. The coordinates of the test stations were evaluated using the BERNESE GNSS 5.4 software (Dach et al., 2015), in which the coordinate evaluation methodology was used, which entirely coincides with the EUREF EPN guidance (Legrand et al., 2022).

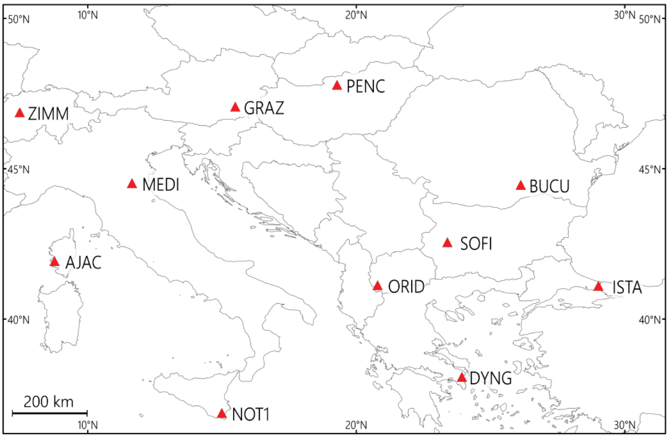

Figure 6. The spatial distribution of EUREF EPN stations chosen as a reference frame in this research.

All the data were processed so that a daily solution was obtained from the 24-hour measurements for each day of the specified period. Then, the weekly solution was determined from seven daily solutions, which refers to the fourth day of the week, epoch at 12 o'clock.

During processing, at least the following parameters were taken into account:

- Ionospheric parameters—Global Ionospheric Maps provided by the Center for Orbit Determination in Europe (CODE), which is a joint operation of the four institutions: Astronomisches Institut (AIUB), Universität Bern, Switzerland, Bundesamt für Landestopographie (L+T), Wabern, Switzerland, Institut für Angewandte Geodäsie (IfAG), Frankfurt, Germany, Institut Géographique National (IGN), Paris, France (Dach et al., 2023);
- Tropospheric parameters—Vienna Mapping Functions Grids provided by Technical University (TU) Wien (Landskron & Böhm, 2018);
- Ocean tide loading amplitude and phase provided by Onsala Space Observatory in the Swedish National Faculty for Radio Astronomy (Bos & Schernec, 2023);
- Atmosphere tide loading data provided by the Global Geophysical Fluid Center at Université du Luxembourg (Dach et al., 2015);
- Earth's orientation parameters from International Earth Rotation and Reference Systems Service (IERS) provided by International GNSS Service (IGS; Johnston et al., 2017);

- Satellite clock effects, hardware signal delays, and precise ephemerides provided by Analytical Centers of IGS (Weiss et al., 2017) and
- Planetary and lunar ephemerides provided by the National Aeronautics and Space Administration (NASA) Jet Propulsion Laboratory (JPL; JPL, 2023).

Finally, the following values were systematically calculated for all the three networks in the form of:

- Mean (averaged) coordinates of the test stations:

$$\overline{X} = \frac{1}{7}\sum_{n=0}^{6} X_n, \overline{Y} = \frac{1}{7}\sum_{n=0}^{6} Y_n, \overline{Z} = \frac{1}{7}\sum_{n=0}^{6} Z_n, \quad (1)$$

where X_n, Y_n, and Z_n are coordinates of the test stations for each epoch, and $\overline{X}$ is the average value of X coordinates, $\overline{Y}$ is the average value of Y coordinates, and $\overline{Z}$ is the value of Z coordinates. Those coordinates were transformed in geodetic coordinates related to GRS80 (Geodetic Reference System, 1980).

- Repeatability of daily solutions about mean coordinates for each axis, denoted with $r_{x,n}$, $r_{y,n}$, and $r_{z,n}$ were also calculated for each day (n = 0, ..., 6):

$$r_{x,n} = X_n - \overline{X}, r_{y,n} = Y_n - \overline{Y}, r_{z,n} = Z_n - \overline{Z}, \quad (2)$$

- The final (combined) solution from all seven days reduced to an epoch of the fourth day at 12 UTC (Coordinated Universal Time).

4. Results

By applying the processing methodology mentioned above, the solutions for test point coordinates are obtained, which are shown in the following tables. Tables 2, 3, and 4 show the solutions for the test stations using the data from the AGROS network, Tables 5, 6, and 7 show the solutions obtained using the GeotaurNet network, and Tables 8, 9, and 10 show the solutions obtained using the VekomNet network.

4.1. Results of test stations coordinates estimation with AGROS data

The mean values of the coordinates of the test stations are shown in Table 2. These coordinates refer to the phase centre of the receiver antennas.

Table 2. Mean (averaged) coordinates of test stations determined by AGROS data

Point	X (m)	Y (m)	Z (m)	Latitude (˚N)	Longitude (˚E)	Height (m)
GRF1	4246571.88911	1585754.07436	4472179.03510	44.8055085	20.4766281	198.3965
GRF2	4246570.47499	1585750.24015	4472179.53210	44.8055286	20.4765890	196.8552

The repeatability of the results is shown in Table 3. It can be seen that the mean value of the reproducibility ranges from 0.78 mm to 1.16 mm in the horizontal sense, while in terms of height, the reproducibility is from 3.58 mm to 3.97 mm, that is, it is three times higher compared to horizontal repeatability.

Table 3. Repeatability of daily coordinates of test stations determined by AGROS data

Point	Axis	Mean repeatability (mm)		Daily repeatability (mm)						
			Day:	0	1	2	3	4	5	6
GRF1	North	1.16		−1.83	−0.86	0.04	−0.43	1.52	1.17	0.39
	East	0.78		0.54	0.16	0.89	−1.52	0.28	0.05	−0.40
	Up	3.58		5.24	1.17	−2.54	−1.33	−5.35	3.34	−0.53
GRF2	North	0.95		−1.56	0.00	−0.75	−0.22	1.28	0.71	0.53
	East	0.87		0.10	−0.53	1.19	−1.49	0.55	0.45	−0.26
	Up	3.97		6.85	1.82	−0.44	−2.26	−2.88	2.05	−5.14

The coordinates considered final in the framework of this research, when using AGROS data, are reduced to the centre of the point mark according to the data shown in Figure 5. These coordinates are shown in Table 4.

Table 4. Final coordinates of test stations determined by AGROS data

Point	X (m)	Y (m)	Z (m)	Latitude (°N)	Longitude (°E)	Height (m)
GRF1	4246571.80281	1585754.04216	4472178.94351	44.8055085	20.4766281	198.2666
GRF2	4246570.30893	1585750.17819	4472179.35598	44.8055286	20.4765890	196.6053

4.2. Results of test stations coordinates estimation with VekomNet data

The mean values of the phase centre coordinates of the test stations are shown in Table 5.

Table 5. Mean (averaged) coordinates of test stations determined by VekomNet data

Point	X (m)	Y (m)	Z (m)	Latitude (°N)	Longitude (°E)	Height (m)
GRF1	4246571.88096	1585754.07041	4472179.02716	44.8055085	20.4766281	198.3845
GRF2	4246570.47649	1585750.24033	4472179.53401	44.8055286	20.4765890	196.8576

Using VEKOM data, the mean repeatability values in the horizontal sense were from 0.82 mm to 1.28 mm, while in the vertical sense, they were from 3.47 mm to 4.18 mm. Those results are shown in Table 6. Table 7 contains the final coordinate values determined using VEKOM data.

Table 6. Repeatability of daily coordinates of test stations determined by VekomNet data

Point	Axis	Mean repeatability (mm)		Daily repeatability (mm)						
			Day:	0	1	2	3	4	5	6
GRF1	North	1.28		−1.56	−1.31	−0.26	0.02	1.47	−0.19	1.83
	East	0.82		0.49	0.50	0.66	−1.53	−0.16	0.61	−0.57
	Up	3.47		4.46	1.74	−0.03	−2.54	−4.60	3.76	−2.79
GRF2	North	1.09		−1.33	−0.73	−0.45	−0.23	1.28	−0.22	1.68
	East	0.85		0.45	−0.06	1.09	−1.40	−0.02	0.68	−0.73
	Up	4.18		4.59	2.84	2.54	−2.56	−5.14	2.97	−5.24

Table 7. Final coordinates of test stations determined by VekomNet data

Point	X (m)	Y (m)	Z (m)	Latitude	Longitude	Height (m)
GRF1	4246571.79508	1585754.03833	4472178.93572	44.8055085	20.4766281	198.2551
GRF2	4246570.31084	1585750.17847	4472179.35803	44.8055286	20.4765890	196.6081

4.3. Results of test stations coordinates estimation with GeotaurNet data

As in the previous two cases, the intermediate coordinates are shown in Table 8, the repeatability values are in Table 9, and the final coordinate values are in Table 10. The horizontal mean repeatability ranges from 0.89 mm to 1.26 mm, while the values in the vertical sense range from 3.18 mm to 3.50 mm.

Table 8. Mean (averaged) coordinates of test stations determined by GeotaurNet data

Point	X (m)	Y (m)	Z (m)	Latitude (˚N)	Longitude (˚E)	Height (m)
GRF1	4246571.87834	1585754.06971	4472179.02323	44.8055085	20.4766281	198.3798
GRF2	4246570.47501	1585750.23913	4472179.53182	44.8055286	20.4765890	196.8548

Table 9. Repeatability of daily coordinates of test stations determined by GeotaurNet data

Point	Axis	Mean repeatability (mm)	Daily repeatability (mm)						
		Day:	0	1	2	3	4	5	6
GRF1	North	1.26	−1.45	−1.61	−0.71	0.41	1.17	0.67	1.51
	East	0.89	1.36	0.22	0.79	−1.37	−0.30	−0.51	−0.18
	Up	3.50	1.94	−1.41	−0.17	−2.01	−4.68	6.46	−0.13
GRF2	North	1.25	−1.49	−1.09	−1.02	0.05	1.31	0.55	1.69
	East	0.95	1.13	−0.24	1.16	−1.58	−0.06	−0.43	0.02
	Up	3.18	4.34	0.64	1.90	−1.32	−3.87	2.29	−3.97

Table 10. Final coordinates of test stations determined by GeotaurNet data

Point	X (m)	Y (m)	Z (m)	Latitude (˚N)	Longitude (˚E)	Height (m)
GRF1	4246571.79190	1585754.03734	4472178.93152	44.8055085	20.4766281	198.2497
GRF2	4246570.30879	1585750.17698	4472179.35555	44.8055286	20.4765890	196.6046

4.4. Results of inter-comparison and comparison with spatial distance determined by total station

Before the inter-comparison, we compared the formal Root Mean Square (RMS) values of Up, North, and East coordinates that follow from the daily solutions. The highest RMS values from daily estimates for coordinates are 2.1 mm, 0.63 mm, and 0.50 mm, respectively.

After the obtained solutions and formal error analysis, the spatial distances between the test stations were calculated, and the differences between the computed distances from the coordinates and the value of the results of the spatial distance measurement obtained using the total station were formed. The reduced final coordinates' data, shown in Tables 4, 7, and 10, were used to calculate the values of spatial distances obtained using the GNSS network. The results of these calculations are shown in Table 11. In the same table, the value for the spatial distance determined by the total station is also shown, as well as the differences between this distance and the distances obtained by GNSS networks.

In addition to the above distance calculations, the differences in the coordinates of the test stations determined based on all the three GNSS networks were calculated. The results are shown in Table 12. More significant differences can be noted at test station GRF1.

Table 11. Spatial distance between test stations

Distance (D)	Value (m)	Differences (mm)
D_{ARGOS}	4.1632	7.7
$D_{GeotaurNet}$	4.1571	1.6
$D_{VekomNet}$	4.1569	1.4
D_{SD}	4.1555	–

Table 12. Coordinate differences of test stations determined by all the available networks

Used network solutions	Station name	ΔX (mm)	ΔY (mm)	ΔZ (mm)
AGROS−GeotaurNet	GRF1	−10.9	−4.8	−12.0
	GRF2	−0.1	−1.2	−0.4
AGROS−VekomNet	GRF1	−7.7	−3.8	−7.8
	GRF2	1.9	0.3	2.0
GeotaurNet−VekomNet	GRF1	3.2	1.0	4.2
	GRF2	2.1	1.5	2.5

5. Conclusion

In this research, the compliance of the three existing GNSS networks was tested using two test stations located 4.1555 m apart. The specified value of the spatial distance was determined using the total station. It was treated as a true value and denoted as. The testing was conceptually based on determining the coordinates of the test stations using the GNSS networks, where the coordinates of centers of geodetic marks are considered relevant. Within the research, we obtained three total independent spatial distances, D_{ARGOS}, $D_{GeotaurNet}$, and $D_{VekomNet}$ determined by using GNSS data of AGROS, GeotaurNet and VekomNet networks, respectively. The determined spatial distances and directly compared with the spatial distance D_{SD}.

The following can be concluded from the results:

- The formal RMS values for the vertical component are three times larger than those obtained in the North and East directions;
- The repeatability of the observation results, regardless of the GNSS networks applied in the horizontal view, is in the mean value in the range from 0.78 mm to 1.28 mm;
- The repeatability of the observation results in the vertical view and also independent of the network applied in the mean value is in the range from 3.18 mm to 4.18 mm;
- The standard deviations of the mean repeatability values do not exceed 0.19 mm in horizontal and 0.36 mm in vertical;
- GNSS networks VekomNet and GeotaurNet have stations near the test receivers, so when compared with the distance determined by the total station, a difference of 1.4 mm and 1.6 mm can be observed, respectively. In comparison, the mutual distance difference is only 0.2 mm; and
- A significant discrepancy between the spatial distance determined by the total station and the distance determined between the test stations using the AGROS network, which is 7.7 mm, occurs due to the considerable distance between the test stations and publicly available AGROS stations.

Also, based on a direct comparison of the values of the coordinates of the test stations determined by all the three mentioned GNSS networks, it is possible to observe differences in the coordinates that reach values of up to 12 mm in the case of test point GRF1. The main reason is that test point GRF1 collects only data from the GPS NAVSTAR system, while point GRF2 has available data from all other systems.

Suppose all available GNSS constellations are used in the processing procedure. In that case, the mentioned networks established and active in Serbia agree with each other up to approximately 3 mm regarding all the coordinate axes.

As a final conclusion of this research, it can be said that the theoretical and practical importance is reflected in the following:

- This research shows that GNSS networks on the Serbian territory can be used to determine point coordinates with sub-centimeter (millimeter) accuracy. Such coordinates can be directly used to define Serbia's national reference frame and establish the reference frames of engineering objects in all engineering works;
- In addition to the reference frames mentioned, the application of networks in the determination of coordinates in the described manner also meets all the requirements for establishing reference frames for the real estate cadaster;
- This research particularly shows the high agreement between the results of determining spatial distances using GNSS and the results of determining classical terrestrial geodetic methods. Therefore, this approach to determining coordinates enables a high-quality combination of terrestrial and satellite methods. In addition to the above, the aforementioned high agreement indicates the possibility of developing methods for metrological purposes for many activities for which positioning is a prerequisite for calibrating geodetic instruments and
- The extremely high agreement regarding the heights of the points indicates that this method of determining the heights of the points can be used to define local, national, and world reference surface heights.

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