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SPATIAL POSITIONING OF TOPOGRAPHIC DETAILS WITH INTEGRATED MODERN TECHNOLOGIES, IN AREAS WITH FOREST VEGETATION

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Abstract

In order to achieve the various objectives related to the sector of terrestrial measurements in areas occupied by forest vegetation, high-performance satellite technologies are currently used. The case study was carried out within the radius of Câmpani, Bihor County, having the objective of analyzing the possibilities of positioning the topographical details, with integrated modern technologies, in areas with forest vegetation. The GNSS receivers Trimble R8, Trimble R10, Trimble R12I, the Trimble S6 total station, as well as real-time data collection and processing software - Trimble Access, were used. The rover-based real-time kinematics (RTK) method was used, with data transmission between receivers via external radio, and framed polygonal journeys. To determine the spatial position of the base points, the data recorded from the permanent GNSS station Beiuș, were used. The data collected were processed in the 2D+1D space, and the results obtained were characterized by superior precision.

***Key words**: spatial positioning, GNSS technology, total station, integrated technologies, digital topographical plan.*

INTRODUCTION

The implementation of urban development projects in rural areas, situated across diverse geographic regions, necessitates adequate infrastructure. Consequently, the provision of essential utilities for various sectors requires the establishment of access routes and a minimum level of comfort for the population within the targeted administrative-territorial units. In hilly and mountainous regions, forest vegetation constitutes a significant proportion, comprising approximately 92% of the national forested area (Florescu & Nicolescu, 1996). As a result, the establishment of infrastructure to support the spatial positioning of topographic elements in these forested terrains presents distinct technical and operational challenges, requiring tailored methodologies and equipment adapted to the environmental context (Rus, 2004). Currently, the determination of planimetric and altimetric coordinates for various characteristic topographic points within the national reference system can be efficiently performed using Global Navigation Satellite Systems (GNSS), total stations, drone-based photogrammetric recordings, or integrated combinations of these methods (Păunescu et al., 2006; Neuner, 2000). Therefore, the selection of appropriate spatial positioning technologies and corresponding working methods requires a comprehensive analysis of the site-specific working conditions, the technical requirements established by the project beneficiary, as well as the available logistics and existing infrastructure relevant to terrestrial surveying activities (Crainic, 2024; Chiţea et al., 2009).

When conditions allow for GNSS-based positioning of detail points, the most widely used method is Real-Time Kinematic (RTK) positioning. This technique employs a dual-frequency GNSS setup, consisting of a fixed receiver (base station) and a mobile receiver (rover), which work together to ensure high spatial accuracy (Adam et al., 2004).

The fixed receiver (reference station) is stationed at a point of known coordinates, and is equipped with a transmitter, and the mobile receiver - the rover (Figure 1) is equipped with a receiving device. A real-time radio link is established between the two receivers (Figure 2) (Adam et al., 2004).

The components of the reference station are represented by: GPS antenna (1), controller (3), GPS receiver (4), tripod (4), radio antenna (5) and radio modem (6) (Adam et al., 2004).

The mobile receiver is made up of the following components: GPS antenna (1), antenna support rod (2), GPS receiver (2), controller (3), radio modem (5) and radio antenna (6) (Adam et al., 2004).

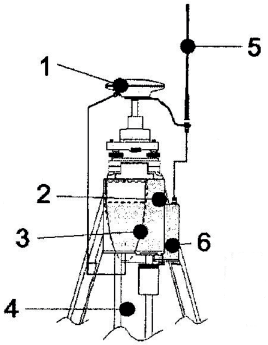

Figure 1. Elements of the reference station (Adam et al., 2004)

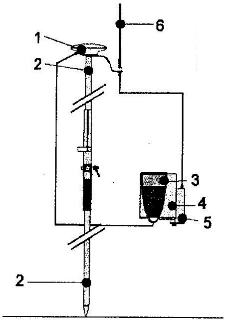

Figure 2. Mobile receiver éléments (Adam et al., 2004)

Once the receivers are mounted and the positioning method and recording parameters are configured, the initialization process - resolving carrier-phase ambiguities - is performed. With modern receivers, this process typically takes only 1-2 minutes (Adam et al., 2004).

The fixed receiver, positioned at a reference point with known coordinates, acts as a radio station that captures satellite signals and relays them, unprocessed and without delay, to the mobile receiver located at a new point. The mobile receiver then interprets this radio signal to determine its position relative to the stationary point. The position is computed by combining the components of the vector between the base station and the rover with the WGS84 coordinates of the reference station, thus obtaining the coordinates of the new point in the WGS84 system (Adam et al., 2004). These coordinates are subsequently converted into the national reference system using established transformation parameters, providing real-time final positioning data (Crainic, 2024; Teunissen & Khodabandeh, 2015).

This workflow is illustrated in Figure 3, which presents the RTK positioning method used in this study.

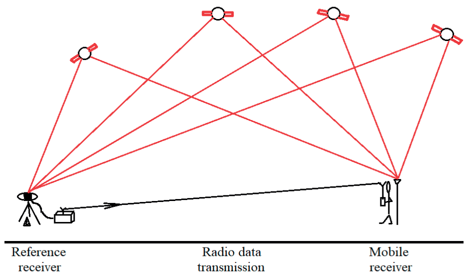

Figure 3. RTK positioning method (processing after Adam J. et al., 2004)

RTK-based spatial positioning can achieve high accuracy, efficiency, and reliability when at least five satellites are available and properly configured. The widespread adoption of this method is largely due to advancements in the rapid transmission of satellite data between receivers - now achieved within fractions of a second (Xingxing et al., 2019; Adam, 2004) - as well as the continuous refinement of computational models that enhance data processing (Odijk et al., 2016).

The accuracy obtained using this GPS measurement method is ± 1-3 cm. This GPS measurement method is recommended for tracing construction elements, positioning details in cadastral works, extension and rehabilitation of communication routes, extension and rehabilitation of water supply and sewage networks, in the agricultural and forestry sectors (Sicoe et al., 2023; Pica et al., 2022), etc. Although in specialized treatises it is not recommended for determining the coordinates of support or thickening network points, currently, due to the existence of an appropriate infrastructure in the terrestrial measurement sector and efficient logistics, geodetic network thickening works can also be carried out, with optimal precision (Adam et al., 2004).

The RTK positioning method appeared in the first half of the 1990s, using single-frequency receivers. In this case, the distance between the fixed and mobile receivers did not exceed a few km, due to the technical possibilities of performing initialization over long distances and transmitting records at an increased distance from the base (Adam et al., 2004; Hofmann-Wellenhof et al., 1997). With the rapid development of satellite positioning technology, and the existence of permanent GNSS stations, at optimal distances in each county, the remote RTK method emerged (Zavate, 2008). In this variant, the distance between the reference receiver, which can be represented by the permanent GNSS station (or a virtual station, as the case may be), and the mobile one, can reach even 30-40 km, in which case dual-frequency receivers will be used (Adam et al., 2004).

Modern programs can perform the initialization again in case of signal loss, even while moving - on-the-fly (OTF) technique, recordings made with the second frequency also play an important role (Adam et al., 2004). Currently, increasing the distance between the reference receiver and the rover is only required by the possibility of transmitting recordings in record time, continuously, using a modern infrastructure, appropriate for these applications and respectively high-performance computational models (Basso et al., 2021; Haojun et al., 2018). Variations in atmospheric conditions can negatively influence the atmospheric error modeling process, resulting in significant atmospheric errors that affect the coordinate determination accuracy, initialization speed, and efficiency of network RTK positioning. Consequently, there is now the possibility of using a fast and reliable network RTK positioning method that uses sequential ambiguity resolution (SAR) of combined multi-frequency observations (Liu et al., 2024).

Also, current research has highlighted the fact that there is currently the possibility of integrating conventional RTK-GNSS methods with a new working technique that capitalizes on recordings from surplus satellites, namely those that were not initially used for positioning, to more efficiently identify incorrect fixation solutions. Consequently, this positioning variant improves positioning accuracy, characterized by high reliability (Fredeluces et al., 2024).

In some situations, working conditions determined by the terrain configuration and respectively the presence of forest vegetation become unsuitable for the use of established positioning methods with GNSS technology. As a result, in these situations, the total station (T.S.) can be used to determine the coordinates of the detail points, using established working methods, such as: polygonometric tracking framed with erasures, polygonometric tracking closed on the starting point, with views to known points and the free station.

Consequently, to streamline the positioning process of detailed topographic points, integrated working methods can be used, related to satellite technology and total station technology, respectively. An opportunity for integrated use of positioning technologies is represented by the presence of permanent GNSS stations, at optimal distances in each county (Rus, 2004). In this context, the existence of an appropriate infrastructure and, respectively, of a high-performance equipment, ensures the obtaining of coordinates with high precision and accuracy (Tang et al., 2017).

MATERIALS AND METHODS

The case study was conducted in Cîmpani Commune, Bihor County (Figure 4).

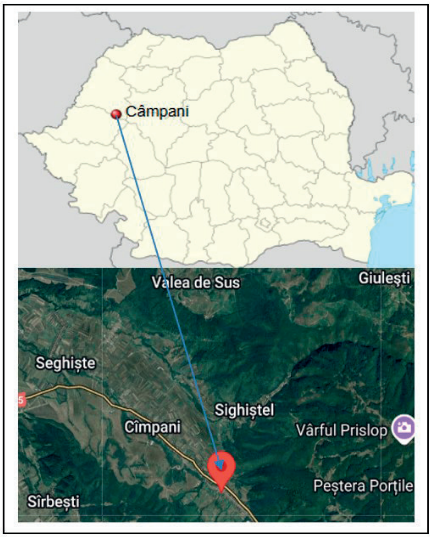

Figure 4. Case study location
(https://ro.wikipedia.org/wiki/C%C3%A2mpani,_Bihor; https://comuna.info/harta-campani-bh/)

The objectives of this case study focus on the research and analysis of spatial positioning methods for topographic detail points required in the design and implementation of water supply and sewage network expansion and rehabilitation projects in the forested areas of Câmpani commune, Bihor County, Romania. Additionally, the study explores the specific aspects of generating detailed plans in both digital and analog formats for the case study site.

The research methodology employed includes bibliographic review, on-site and in-station observations, experimentation, simulation, comparison, and analysis.

The bibliographic documentation covered spatial positioning techniques for topographic details in forested environments, based on specialized literature, technical reports, and related project documentation.

Observations conducted in the field and at control stations aimed to identify and mark detail points, define the positioning technologies, and establish the field routes.

The experiment involved the practical spatial positioning of the detailed points required for infrastructure development.

Simulation was used to generate final products based on experimental data.

All methods, outcomes, and observed particularities were critically analyzed and compared, leading to the formulation of conclusions.

The equipment and software used included:

- GNSS receivers with internal and external radio transmission, accompanied by data logging and processing programs;
- recordings from the Beiuș permanent GNSS station;
- a total station with corresponding software;
- digital cartography software for reporting the coordinates and producing graphical outputs in both digital and print formats.

Although low-cost single- and dual-frequency GNSS receivers (SF-LC and DF-LC) can perform comparably to geodetic-class receivers in open-sky conditions, geodetic receivers are preferred for large-area surveys requiring high precision (Hamza et al., 2025).

Satellite data acquisition was conducted using high-performance GNSS receivers from the Trimble range: R8, R10, and R12I. RTK-GNSS and UAV-based multispectral photogrammetry both offer high-precision mapping. A comparative study showed minimal geometric discrepancies between maps derived from the two methods - only −0.26% in perimeter and −0.23% in area (Dlamini & Ouma, 2025). Therefore, in forested yet accessible areas, RTK-GNSS remains the preferred solution.

Studies have demonstrated that geodetic positioning using network RTK, even with GNSS baselines up to 40 km, does not significantly affect coordinate accuracy (Gökdaş & Özlüdemir, 2020). When nearby permanent stations are inaccessible, a Virtual Reference Station (VRS) may be used, generating correction data from surrounding GNSS stations without extra hardware. This approach provides horizontal accuracy of 1- 2 cm and vertical accuracy of 2-5 cm, even in forested areas (Kurtulgu & Pirti, 2025).

The spatial positioning method applied was the real-time kinematic (RTK) base-rover configuration. In the first stage, ten base points were established for detail point measurements. This process occurred in three phases using data from the Beiuș permanent GNSS station.

In the second stage, topographic detail points were positioned using RTK-GNSS receivers wherever satellite signal reception was optimal. Routes and point attributes were predefined for consistency.

- At base points 1 through 8, the Trimble R8 (4W external radio) functioned as the base, while R10 and R12I units (2W internal radios) served as rovers.
- For base points 9 and 10, the R10 (2W external radio) was used as the base and the R12I as the rover.

In areas with suboptimal GNSS signal due to forest cover, a Trimble S6 total station was used. Surveying was performed via framed polygonal traverses or closed traverses connected to known points. These methods were applied on portions of the routes connected to GNSS base points 1, 2, 7, 8, and 10.

As a result, integrated positioning methods were adopted, tailored to site-specific conditions - an approach previously validated in similar research (Crainic, 2024).

Data collection, processing, and conversion were performed using:

- Trimble Access – for recording and processing GNSS and total station data;

- TransDatRo4.01 – for transforming ellipsoidal coordinates into the national reference system;
- MapSys 11.0 – for graphical reporting of positioned points (Marton, 2007).

The stages of the experimental process are summarized in Figure 5, which was developed following extensive field inspections and consultations with project beneficiaries.

The case study involved a high volume of fieldwork, primarily due to terrain configuration and challenges related to spatial positioning in densely vegetated areas.

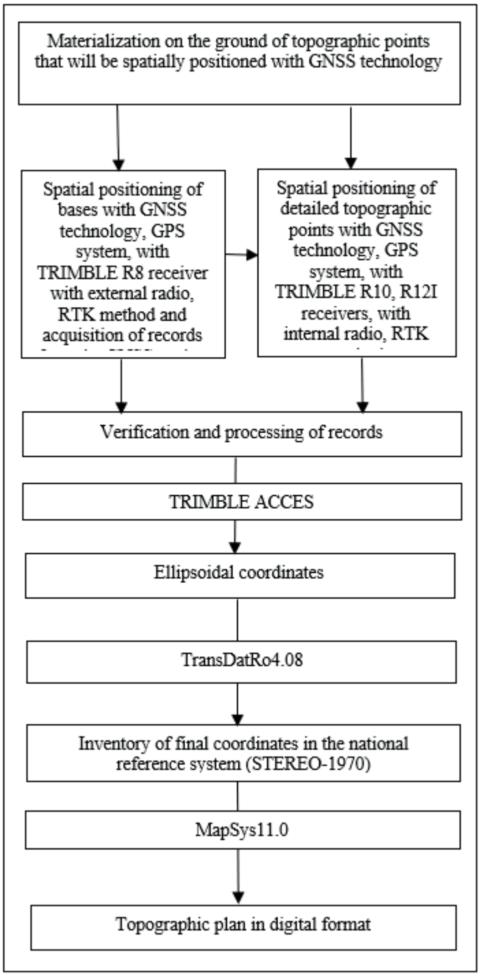

Figure 5. The sequence of steps for carrying out the case study

RESULTS AND DISCUSSIONS

The GNSS-based positioning results were obtained in two stages. First, the coordinates of ten densification base points were determined via the RTK-distance method using data from the Beiuș GNSS station (Table 1). Second, coordinates for the detail points positioned from these bases using RTK and total station measurements were recorded, with a representative sample shown in Table 2.

Table 1. Inventory of coordinates of topographic points for the support network density, in the national reference system STEREO-1970, MN-1975

No. point	X (m)	Y (m)	Z (m)	Code
1	558161.822	313687.201	480.774	1
2	558189.851	313283.842	427.653	1
3	558197.790	313247.390	425.990	1
4	558029.432	312190.031	377.281	1
5	558118.550	312494.411	396.370	1
6	559983.221	310006.410	324.461	1
7	561449.041	312888.373	387.982	1
8	563843.210	311435.491	307.411	1
9	561350.431	308104.100	304.390	1
10	560646.620	311262.131	337.382	1

Table 2. Extract of coordinate inventory for detailed topographic points in the national reference system

No. point	X (m)	Y (m)	Z (m)	Code
2000	558699.750	311654.233	359.123	8
2001	558699.761	311654.231	359.159	8
2002	558699.765	311654.225	359.139	8
2003	558699.751	311654.211	359.128	8
2004	558700.057	311654.252	359.142	8
20005	558700.049	311654.247	359.167	8
20006	558699.733	311654.057	359.117	8
20007	558699.736	311654.058	359.109	8
20008	558699.732	311654.054	359.124	6
20009	558650.975	311618.299	357.702	10
20010	558647.208	311619.045	357.970	16
20011	558645.940	311617.726	357.749	4
20012	558640.476	311622.345	357.891	4
20013	558643.866	311624.572	357.902	3
20014	558636.674	311630.409	358.192	3
20015	558634.739	311632.161	358.239	17
20016	558633.450	311633.239	358.236	28
20017	558632.932	311629.894	358.189	20
20018	558634.333	311629.659	358.094	8
20019	558629.894	311632.099	358.236	4
20020	558624.162	311637.450	358.448	4
20021	558623.258	311642.443	358.692	28
20022	558622.084	311643.597	358.730	10
20023	558619.047	311644.945	358.853	16
20024	558614.824	311646.680	358.801	4
20025	558615.370	311650.340	359.044	10
20026	558613.984	311648.645	358.877	8
20027	558612.612	311650.768	358.893	20
20028	558613.652	311652.786	359.059	10
20029	558614.321	311655.261	359.285	10
…	…	…	…	…
22590	558988.527	311309.790	349.843	38
22591	558991.803	311306.062	349.829	38
22592	558992.446	311306.525	349.396	6
22593	558988.461	311311.027	349.427	6
22594	558984.196	311314.825	350.151	38

The identified detail points are essential for implementing the water supply and sewage network expansion and rehabilitation project in the case study area. To ensure efficient data integration, each point was assigned a code corresponding to a specific layer, depending on the type of detail it represents. The relationship between point codes and their respective layers is summarized in Table 3.

To streamline the use of the final coordinates in accordance with the project's technical requirements, the data was organized into a .txt file. This was subsequently imported and graphically rendered using the MapSys 11 software, resulting in a digital topographic plan containing all the positioned detail points. Overlaying the topographic plan onto the orthophoto map of the project area provides a comprehensive visual representation of the spatially positioned features (Figure 6). Representative excerpts from the graphic outputs are shown in Figures 7 and 8. The digital plan enables versatile usage - either in digital or printed analog format (Figure 9).

Printing of the detail plan was carried out after the layout, sheet coverage, and sequencing were established (Figure 10). In addition, a printed version of the coordinates inventory was prepared for delivery to the project beneficiary.

Based on the analysis of the results obtained during the case study, the total surveyed area was S = 399,550 m², with a cumulative measured route length of L = 32,000 m.

Table 3. Characteristics of the detailed points spatially positioned and graphically represented using the MapSys 11 program

Layer	Name	Point	Line	ArcDeC	Curve	Symbol
1	Street limit	11	0	0	0	11
3	Construction	2940	1084	0	4	4028
4	Roadside	6483	442	0	3	6928
5	Forest vegetation	496	0	0	0	496
6	Groove	4251	1071	0	0	5322
8	Altitudes	6303	0	0	0	6303
9	Bridge (h<5)	1113	433	0	0	1546
10	Fence	2570	750	0	0	3320
14	Duct	1196	0	0	0	1196
15	Wooden telephone pole	162	0	0	0	162
16	Concrete electric pole	365	0	0	0	365
17	Gate access	1109	0	0	0	1109
18	Tap	1	0	0	1	2
19	Retaining wall	590	176	0	0	766
20	Sewerage house	1196	0	0	0	1196
21	Traffic signs	84	0	0	0	84
23	Road axis line	2858	223	0	0	3081
24	Bridge tube	243	95	0	0	338
26	Text	0	0	0	626	626
27	Shrubby vegetation	106	0	0	0	106
28	Concrete fence	874	415	0	1	1290
29	Trinity	18	0	0	0	18
35	Kilometer milestone	6	0	0	4	10
37	Telephone home	3	0	0	0	3
38	Alley	2809	868	0	44	3721
39	Hydrant	20	0	0	0	20
40	Hectometric milestone	40	0	0	17	57
42	Gas pipeline	12	0	0	0	12
43	Fountain	2	0	0	1	3
45	Trench edge	3255	606	0	0	3861
47	Gabions	182	44	0	5	231
48	Lighting pole	26	0	0	0	26
49	Battlement	5	0	0	0	5
50	Construction without elevation	1	0	0	0	1
52	Ditch without elevation	1	0	0	0	1
53	Gate symbol	0	0	1081	0	1081
68	Street fountain	4	0	0	0	4
69	Border	124	54	0	3	181
Total		**38566**	**6368**	**1081**	**716**	**46731**

Figure 6. The location of the ten GNSS bases on the orthophoto plane, which were positioned in stage I, and were used as density points for the following stages of work

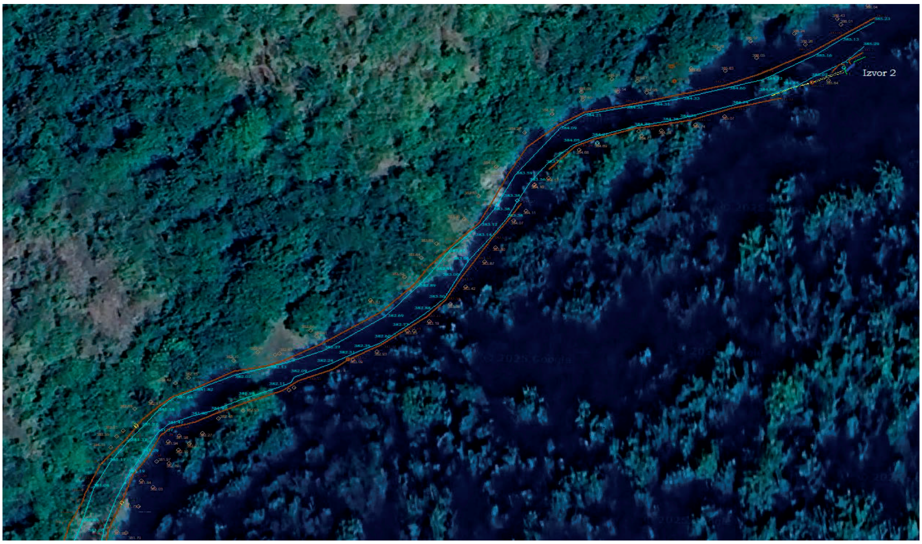

Figure 7. Overlay of the detailed plan of the water supply network on the orthophoto plane, in the spring 2 area

Figure 8. Detailed plan of the water supply and sewage network, superimposed on the orthophoto plane

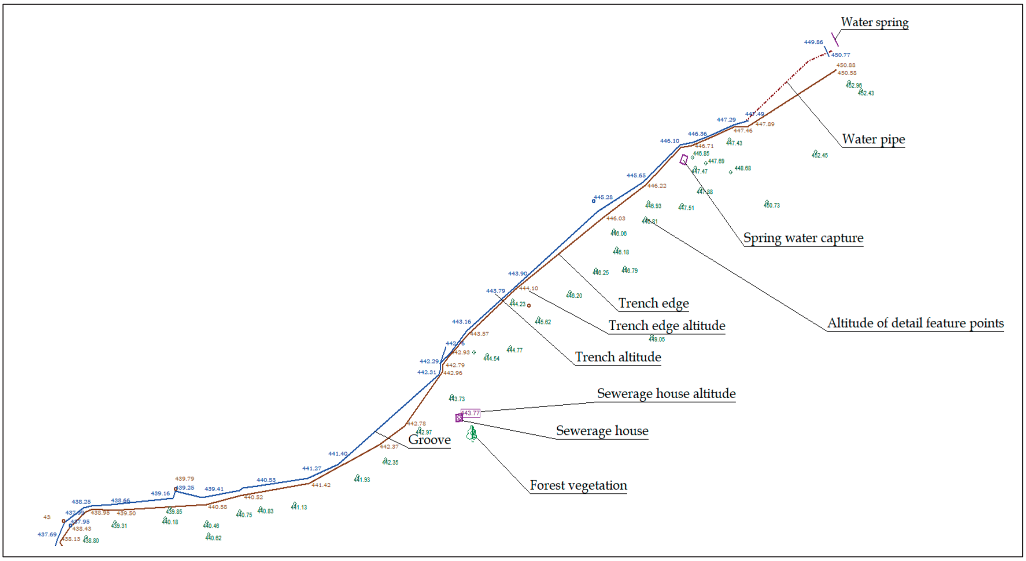

Figure 9. Extract from the detailed plan, related to the water supply network (spring collection)

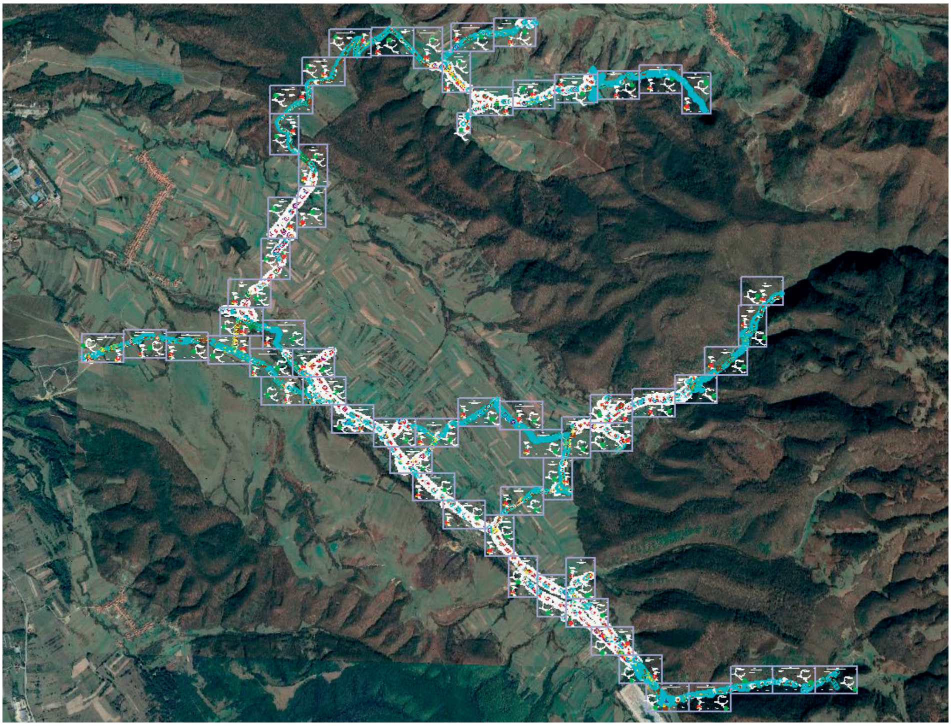

Figure 10. Layout, coverage and sequence of the sheets related to the situation plan

CONCLUSIONS

Given the topographic and vegetation characteristics of the analyzed area, appropriate spatial positioning methods were selected to ensure the successful completion of the case study. The use of GNSS receivers with radio communication between base and rover units - within the RTK framework - proved to be a technically efficient solution under challenging field conditions, particularly those imposed by rugged terrain and forested areas.

Data transmission from the base station was performed using a 4W external radio module, while data reception at the rover was handled by a 2W internal radio, both operating with high efficiency. Under optimal conditions, this configuration enables transmission over distances of up to 20-25 km. In contrast, when both transmission and reception are managed by 2W modules, the effective communication range varies from 5-6 km in suboptimal conditions to a maximum of approximately 11 km under ideal conditions.

The selection of base points was made with strict consideration for uninterrupted satellite signal reception throughout each observation session, accounting for the presence of forest canopy or other local obstructions. The integration of recordings from the Beiuș permanent GNSS station - located within a reasonable range of the study area - further optimized the RTK method's application. Additionally, the use of a total station in zones where satellite positioning was impeded proved to be a suitable alternative, enabling continued detail acquisition. This dual approach - merging GNSS-based satellite positioning (for densification points) with total station surveying methods - resulted in a cohesive, integrated spatial positioning strategy. Finally, the use of the MapSys 11 digital cartography program allowed us to produce comprehensive graphical outputs, facilitating multi-format usage of the final deliverables (alphanumeric, digital, and analog). Moreover, derivative products such as databases and GIS components specific to the surveyed site and associated activities were generated under optimal conditions.

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