

Development of GNSS geodetic networks for improving geospatial accuracy in remote sensing applications

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ABSTRACT

Accurate geospatial referencing is essential for Earth remote sensing, geographic information systems (GIS), cadastral activities, and spatial data management. Recent advances in Global Navigation Satellite Systems (GNSS) have enabled the development of high-precision geodetic networks that improve coordinate consistency and support geospatial applications. This study presents recent activities related to the development and densification of GNSS-based geodetic networks in Uzbekistan and evaluates their contribution to improving geospatial accuracy for remote sensing applications. The study is based on GNSS observations conducted at State Geodetic Network control points within the implementation of the National Coordinate System. A total of 1659 GNSS observations were completed nationwide, and more than 2000 additional measurements were conducted in 2025 in selected regions. The methodological framework included GNSS data acquisition, coordinate adjustment, integration into the national coordinate system, and network densification procedures. The results demonstrate continued strengthening of geodetic infrastructure through coordinate modernisation and improved spatial consistency. Class IV levelling works were completed over a total distance of 358,658 km, and 15 new geodetic stations were established in regions with insufficient network coverage. The obtained results indicate that GNSS-based positioning provides improved coordinate accuracy compared with conventional approaches and supports more reliable georeferencing of remote sensing imagery. The study demonstrates the practical value of GNSS network densification for supporting Earth observation workflows and strengthening geospatial infrastructure in Uzbekistan. Although independent validation experiments were outside the scope of this study, the results of the presented implementation indicate the potential of modern GNSS technologies to improve positional consistency in remote sensing applications.

Keywords: GNSS, geodetic network densification, remote sensing, geospatial accuracy, coordinate adjustment, Earth observation, georeferencing, geographic information systems (GIS).

1. INTRODUCTION

Accurate geospatial referencing has become a fundamental requirement for Earth remote sensing, geospatial analysis, cadastral management, and digital mapping applications. Modern Earth observation systems increasingly depend on geodetic infrastructure to ensure positional consistency among satellite imagery, field measurements, and geographic information systems (GIS). In this context, Global Navigation Satellite Systems (GNSS) have become the primary technology for establishing and maintaining high-precision geodetic networks. Modern satellite geodetic networks are based on the integration of multiple global navigation systems, including the United States Global Positioning System (GPS), the Russian GLONASS, the European Galileo, and the Chinese BeiDou Navigation Satellite System (BDS). The development of multi-constellation GNSS technologies has significantly improved positioning reliability, coordinate stability, and operational efficiency in geospatial applications. Compared with conventional geodetic approaches, GNSS-based observations provide rapid coordinate determination with centimetre-level precision and support direct integration with remote sensing products [1].

The growing demand for high-resolution spatial data requires continuous improvement and densification of geodetic control networks. In practical applications, especially for cadastral and remote sensing tasks, maintaining positional consistency between local geodetic networks and national coordinate systems remains an important challenge [2].

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International practice shows that modern geodetic infrastructures increasingly target coordinate consistency at the centimeter level in order to support accurate mapping, land administration, and spatial monitoring. Recent advances in GNSS technologies have also expanded the role of geodetic networks beyond traditional surveying tasks [3,4]. Continuous GNSS observations support coordinate transformation, georeferencing procedures, Earth surface monitoring, and integration with remote sensing workflows. The availability of modern GNSS processing approaches and geospatial technologies enables more efficient establishment and maintenance of geodetic infrastructure while reducing time and operational costs.

In Uzbekistan, modernization of the national geodetic framework has become an important direction of geospatial development. Within the implementation of the national coordinate system, GNSS observations were conducted at State Geodetic Network control points across the country. A total of 1659 GNSS observations were completed in all regions of Uzbekistan. In addition, more than 2,000 GNSS measurements were conducted in 2025 across the Navoi, Bukhara, Kashkadarya, and Surkhandarya regions [5,6]. The Republican Center for Aerogeodesy established the initial reference (“0”) point of the National Coordinate System in the Samarkand region as part of the transition toward a unified coordinate framework [7]. These activities provide an opportunity to evaluate the practical contribution of GNSS network densification to geospatial accuracy and Earth observation applications. Rather than focusing on theoretical aspects of geodetic network construction, this study analyzes recent implementation activities and summarizes their outcomes for improving positioning consistency and supporting remote sensing workflows.

The objective of this study is to present recent GNSS-based development and densification activities in Uzbekistan's geodetic networks and to evaluate their contribution to improving geospatial accuracy for remote sensing applications. The novelty of this work lies in consolidating recent national GNSS measurement campaigns and demonstrating their practical significance for strengthening the integration between geodetic infrastructure and Earth observation systems.

2. MATERIALS AND METHODS

The study was conducted within the territory of the Republic of Uzbekistan as part of ongoing activities aimed at modernizing the national geodetic infrastructure and supporting geospatial applications. The geodetic framework of the study is based on the State Geodetic Network and its integration with GNSS positioning technologies. Uzbekistan is located within the Central Asian geodetic region, where large-scale geodetic infrastructure was historically established to support mapping, cadastral, and engineering activities. Existing geodetic networks provide the spatial reference basis for further GNSS densification and coordinate modernization. Table 1 presents summary information on the geodetic network structure in the Central Asian region and the corresponding coverage within Uzbekistan.

Table 1. Information on geodetic networks of the Central Asian region.

No.	Types of work	By region	Including in Uzbekistan
1	Triangulation level 1	663	122
	Triangulation level 2	4517	3602
	Triangulation level 3	16359	5640
2	Polygonometry 2nd level	117	85
	Polygonometry Level 3	7	5
3	Astronomical points	351	208
4	Measured bases and base sides	369	244
5	Density of points per 1 km ²	48	48

The existing network configuration served as a reference framework for conducting additional GNSS observations and supporting network densification activities. GNSS observations were performed at State Geodetic Network points to support the implementation of the National Coordinate System and improve geospatial consistency [8]. Measurements were carried out using modern satellite geodetic receivers and multi-constellation GNSS positioning technologies.

The observation campaign included 1659 GNSS measurements distributed across all regions of Uzbekistan. Additional measurements exceeding 2000 observations were conducted in 2025 in selected regions, including Navoi, Bukhara, Kashkadarya, and Surkhandarya. The measurement program also supported the establishment of the initial reference (“0”) point of the National Coordinate System in the Samarkand region.

The measurement design followed standard geodetic requirements to ensure sufficient coordinate accuracy, consistency with the State Geodetic Network, adequate point density, and reduced adjustment errors.

The collected GNSS observations were processed through a sequential workflow for coordinate integration and network improvement (Figure 1).

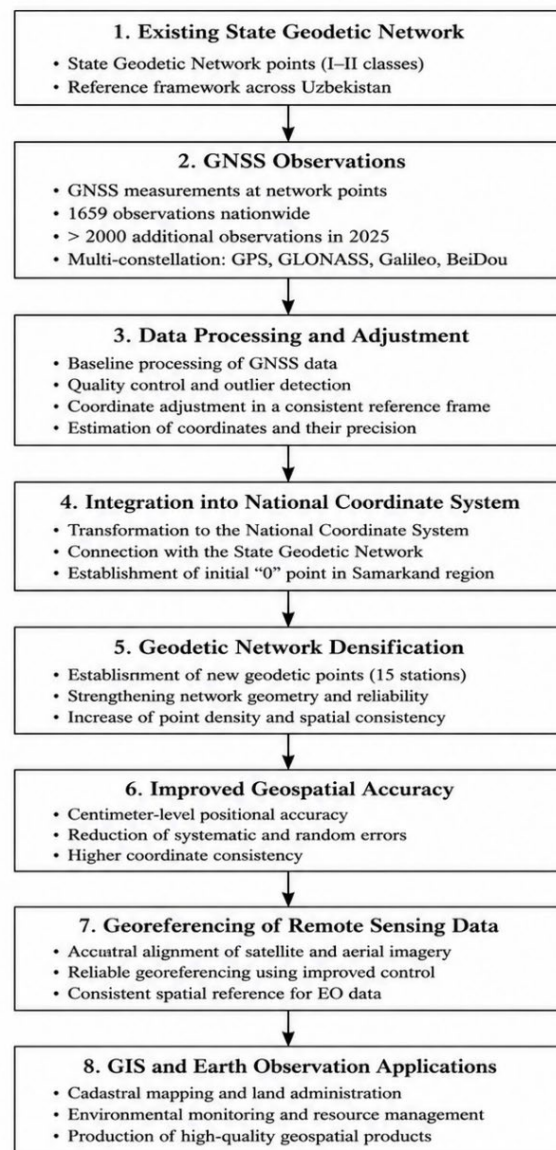


Figure 1. Workflow of GNSS network densification for remote sensing applications.

Figure 2 illustrates the methodological workflow for integrating GNSS observations into the national geodetic framework. The processed coordinates were used to densify the network and improve positional consistency, providing a reliable spatial reference for remote sensing and geospatial applications.

3. RESULTS AND DISCUSSION

The conducted GNSS measurement campaign demonstrated the ongoing modernization of geodetic infrastructure in Uzbekistan and its increasing integration with geospatial applications. GNSS observations were performed at State Geodetic Network control points to support implementation of the National Coordinate System and improve positional consistency across regions.

A total of 1659 GNSS observations were completed nationwide. Additional field campaigns conducted in 2025 included more than 2,000 GNSS measurements in the Navoi, Bukhara, Kashkadarya, and Surkhandarya regions. These observations provided updated coordinate data and helped strengthen the national geodetic reference framework.

The implementation process included observation acquisition, coordinate adjustment, and integration into the national reference system to improve compatibility with remote sensing and GIS applications. Figure 2 presents the conceptual integration of GNSS network development with remote sensing workflows.

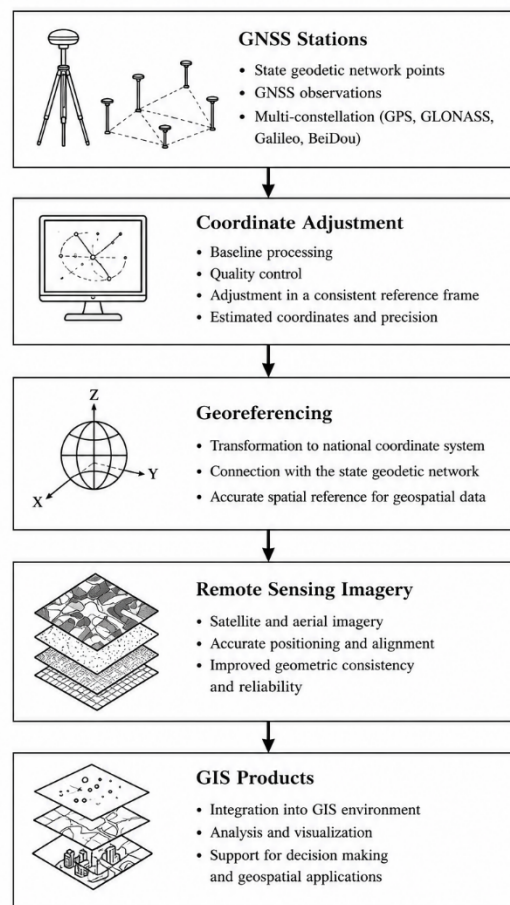


Figure 2. Integration of GNSS networks with remote sensing applications.

The results indicate continued densification of the geodetic network in areas with insufficient control-point coverage. Additional geodetic infrastructure was developed to improve the availability of coordinates and spatial consistency. Leveling works of class IV were completed over a total distance of 358,658 km. Furthermore, 15 new geodetic stations were established in the Syrdarya and Jizzakh regions and their coordinates were determined and integrated into the existing

State Geodetic Network. Table 2 summarizes the main outcomes of the GNSS measurement and network densification campaign.

Table 2. Summary of GNSS measurements and network densification results.

Indicator	Result
State GNSS observations	1659
Additional GNSS observations (2025)	>2000
Leveling distance (km)	358,658
Newly established geodetic stations	15

The modernization process also contributed to improved positioning performance compared with traditional coordinate transfer approaches. Table 3 presents a simplified comparison of achievable positioning accuracy based on the methods described in this study.

Table 3. Comparison of positioning accuracy.

Positioning method	Typical positioning accuracy
Classical geodetic approach	up to 20 cm
GNSS-based positioning	1–2 cm

Figure 3 illustrates field installation activities during geodetic network development.



Figure 3. Installation of new geodetic stations during network densification activities in the Fergana Valley.

The results demonstrate that GNSS-based densification improves the spatial reliability of geodetic infrastructure and creates better conditions for remote sensing applications. Higher coordinate consistency supports more accurate georeferencing of satellite imagery and facilitates integration of Earth observation data with GIS environments [9].

The achieved positional improvement enables more efficient use of geospatial datasets in cadastral activities, land administration, urban planning, and environmental monitoring. The integration of GNSS measurements with the national coordinate framework also contributes to the long-term development of geospatial infrastructure in Uzbekistan.

Although this study summarizes implementation activities and does not include independent positional validation experiments, the presented results indicate the practical value of GNSS network modernization for supporting remote sensing applications.

4. CONCLUSION

This study presented recent GNSS-based development and densification activities of geodetic networks in Uzbekistan and examined their contribution to improving geospatial accuracy for remote sensing applications. The conducted observation campaigns and coordinate integration procedures demonstrated the practical role of modern GNSS technologies in strengthening the national geodetic framework.

The implementation included 1659 GNSS observations conducted nationwide and more than 2000 additional observations performed in selected regions during 2025. Network modernization activities also included Class IV leveling works over a total distance of 358,658 km and the establishment of 15 new geodetic stations in areas with insufficient control-point density. These activities contributed to improved coordinate consistency and supported integration into the National Coordinate System.

The obtained results indicate that GNSS-based positioning provides substantially improved spatial accuracy compared with conventional geodetic approaches and creates more favorable conditions for georeferencing and processing remote sensing data. Improved positional consistency supports applications in cadastral management, spatial planning, environmental monitoring, and GIS-based decision-making.

The present study is limited to summarizing implementation and measurement outcomes and does not include independent quantitative validation of remote sensing products. Future research should focus on evaluating the direct impact of GNSS network densification on satellite image georeferencing accuracy and assessing long-term performance of the national geodetic infrastructure.

ACKNOWLEDGEMENTS

These studies were carried out by the Republican Center for Aerogeodesy of Uzbekistan on the basis of Resolution No. 299 of the Cabinet of Ministers to conduct an inventory of land plots and determine their boundaries.

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