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OPTIMIZATION OF CORS STATION PLACEMENT USING MULTI-CRITERIA DECISION ANALYSIS: AN AHP-BASED GIS APPROACH FOR UZBEKISTAN

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Abstract: The establishment of a dense and optimally distributed Continuously Operating Reference Station (CORS) network is a fundamental requirement for achieving high-precision GNSS positioning, geodetic monitoring, and spatial data infrastructure development. In countries with complex topography, seismic activity, and uneven population distribution, the placement of CORS stations must be based on a comprehensive, multi-criteria evaluation rather than uniform spacing alone. This study presents an integrated Geographic Information System (GIS) and Analytic Hierarchy Process (AHP) framework for optimizing the spatial distribution of CORS stations across the territory of Uzbekistan. Six key thematic criteria-agricultural land use, population density, existing CORS coverage, seismic hazard, digital elevation model (DEM), and terrain slope-were standardized, reclassified, weighted, and integrated into a composite suitability index. The results demonstrate that the proposed approach effectively identifies priority zones for new CORS station deployment, particularly in densely populated, agriculturally intensive, and seismically active regions with limited current coverage. The proposed methodology provides a replicable and scalable decision-support tool for national geodetic authorities and contributes to the advancement of evidence-based geodetic network planning.

Keywords: CORS, GNSS, AHP, GIS, site selection, multi-criteria decision analysis, Uzbekistan.

Introduction

Continuously Operating Reference Stations (CORS) constitute the backbone of modern geodetic infrastructure, supporting high-precision Global Navigation Satellite System (GNSS) applications such as real-time kinematic (RTK) positioning, deformation monitoring, cadastral surveying, precision agriculture, and infrastructure development. Over the past two decades, many countries have transitioned from classical geodetic networks to GNSS-based reference systems to improve accuracy, reliability, and operational efficiency [1, 2].

However, the effectiveness of a CORS network depends not only on the quality of equipment and data processing strategies but also on the spatial configuration of stations. Uniform inter-station spacing, while useful as a general guideline, often fails to account for regional heterogeneity in population distribution, land use intensity, seismic risk, and topographic complexity. As a result, suboptimal station placement can lead to reduced positioning accuracy, inefficient resource allocation, and limited service coverage in high-demand areas [3, 4].

Uzbekistan presents a particularly challenging case for CORS network optimization due to its diverse physiographic conditions, including vast lowland deserts, fertile irrigated valleys, mountainous regions with steep slopes, and zones of high seismic activity [5]. Furthermore, population density and agricultural activity are highly uneven, creating spatially variable demand for precise GNSS services. These factors necessitate a multi-criteria, data-driven approach to CORS station placement.

In this context, Multi-Criteria Decision Analysis (MCDA), and particularly the Analytic Hierarchy Process (AHP), has gained increasing attention in geospatial planning and infrastructure optimization studies. AHP allows for the systematic weighting of heterogeneous criteria based on expert judgment while ensuring logical consistency [6]. When integrated with GIS, AHP enables spatially explicit suitability modeling that supports transparent and reproducible decision-making [7].

The primary objective of this study is to develop and apply an AHP-based GIS framework for optimizing the placement of CORS stations across Uzbekistan. By integrating multiple thematic layers derived from spatial datasets and reclassifying them into a unified suitability scale, this research aims to identify priority zones for future CORS network expansion and provide methodological guidance for national geodetic planning.

Materials and Methods

Study Areas

The study covers the entire territory of the Republic of Uzbekistan, located in Central Asia and characterized by significant geographic and socio-economic diversity. The country includes extensive desert areas in the west and northwest, intensively irrigated agricultural zones in the Amu Darya and Syr Darya basins, densely populated intermountain valleys in the east, and seismically active mountainous regions along the Tien Shan and Pamir-Alay systems. These contrasts make Uzbekistan an appropriate case study for evaluating spatially differentiated CORS station placement strategies.

Data Sources and Thematic Layers

Six thematic layers were selected based on international best practices in GNSS network design and national planning requirements. Agricultural land use data were used to represent zones of intensive land management and precision farming demand. Population density data served as a proxy for GNSS service demand related to urban development, cadastral activities, and infrastructure projects. Existing CORS station locations and their service buffers were included to account for current coverage and identify underserved areas. Seismic hazard data reflected the need for geodetic monitoring in tectonically active regions. Digital Elevation Model (DEM) data were used to characterize altitude variations, while slope data represented terrain complexity affecting signal quality and station accessibility. All spatial datasets were projected into a unified coordinate reference system and resampled to a common spatial resolution to ensure compatibility during raster-based analysis.

Reclassification of Criteria

To enable integration within the AHP framework, all thematic layers were standardized through reclassification into a common ordinal scale ranging from 1 to 5, where higher values indicate greater suitability for CORS station placement (Figure 1). Agricultural lands with high irrigation intensity were assigned higher suitability scores due to their reliance on precise positioning. Areas with higher population density received higher scores to reflect increased demand for

GNSS services. Regions located beyond effective coverage zones of existing CORS stations were assigned higher suitability values, emphasizing network densification.

Seismic hazard zones were reclassified to prioritize areas with moderate to high seismic activity, where continuous geodetic monitoring is essential. DEM values were reclassified to favor moderate elevations that balance signal stability and accessibility. Similarly, slope values were reclassified to favor gentle to moderate slopes, as extremely steep terrain complicates installation and maintenance while flat areas may suffer from multipath effects in urban environments.

Analytic Hierarchy Process (AHP)

The AHP methodology was applied to determine the relative importance of each criterion. Expert judgment from geodesy, GNSS engineering, and geoinformatics specialists was used to construct a pairwise comparison matrix. The matrix quantified the relative importance of each criterion using Saaty’s fundamental scale. Eigenvector normalization was performed to derive the final weight of each criterion.

Consistency of expert judgments was evaluated using the Consistency Index (CI) and Consistency Ratio (CR). A CR value below 0.10 indicated acceptable consistency, ensuring the reliability of the weighting scheme [4].

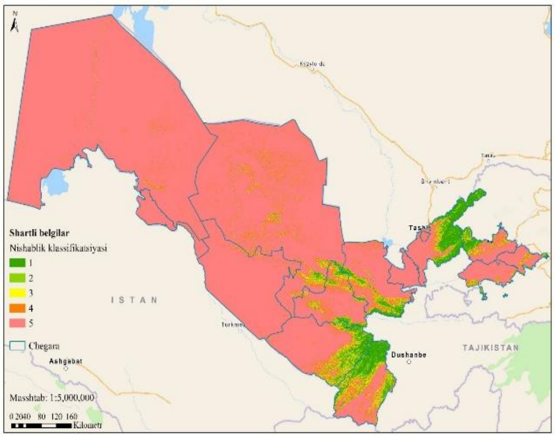
Construction of the Pairwise Comparison Matrix

Let the decision problem consist of n criteria. A square pairwise comparison matrix A of size n × n is constructed as follows:

$$A=\begin{bmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{n1} & \cdots & a_{nn} \end{bmatrix} \qquad (1)$$

where a_{ij} represents the relative importance of criterion i over criterion j, assessed using Saaty’s fundamental scale ranging from 1 (equal importance) to 9 (extreme importance). The reciprocal property is defined as:

$$a_{ji}=\frac{1}{a_{ij}}, a_{ii}=1 \qquad (2)$$



a)

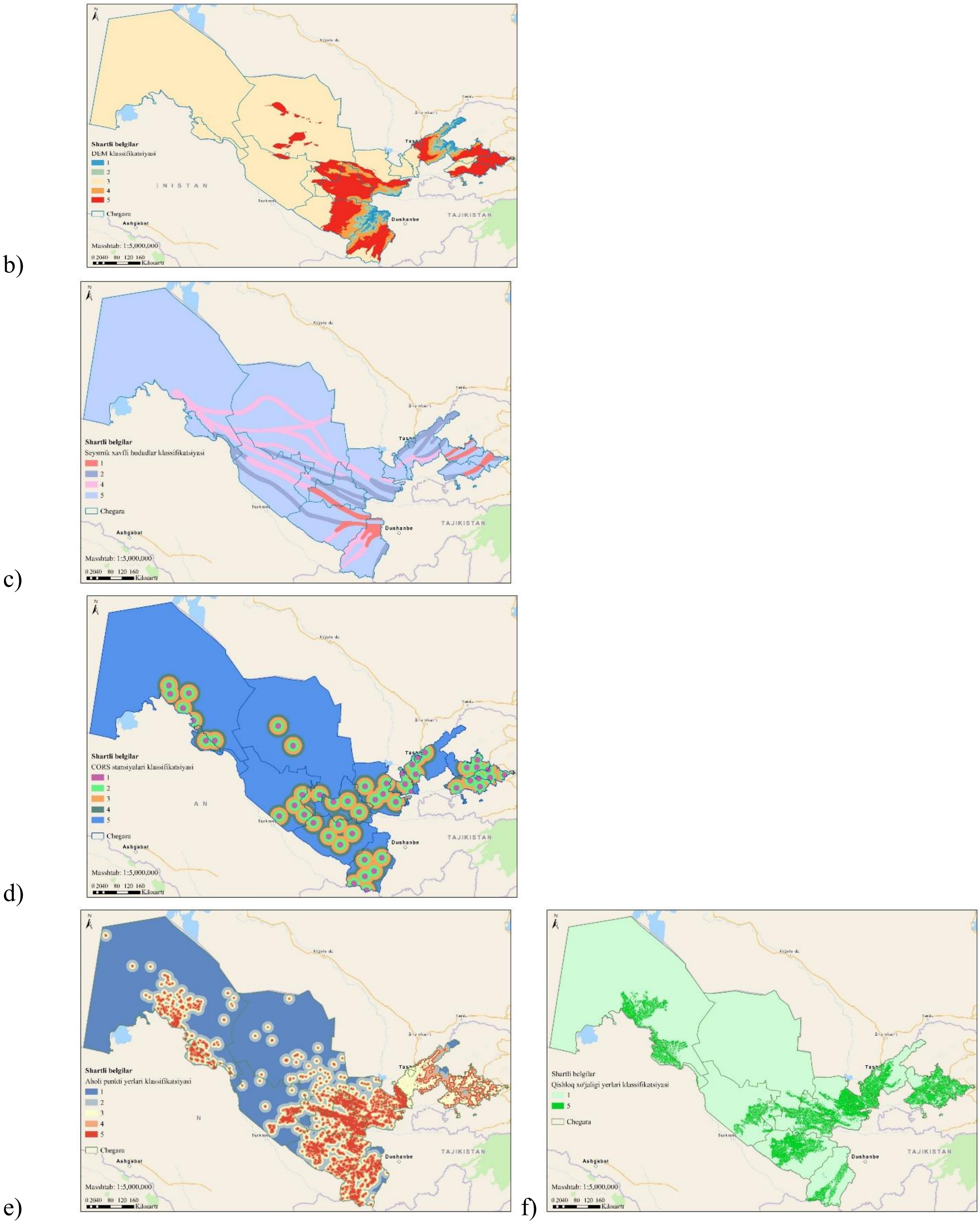


Figure 1. Multi-criteria spatial datasets applied in AHP-based CORS site suitability analysis:

(a) slope, (b) elevation (DEM), (c) seismic hazard, (d) existing CORS coverage, (e) population density, (f) agricultural land use.

Normalization of the Matrix

The pairwise comparison matrix is normalized by dividing each element by the sum of its column:

$$\tilde{a}_{ij} = \frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}} \qquad (3)$$

This step converts the matrix into a dimensionless form, allowing comparison across criteria.

Derivation of Criteria Weights

The weight vector w is obtained by calculating the arithmetic mean of each row of the normalized matrix:

$$\omega_i = \frac{1}{n} \sum_{j=1}^{n} \tilde{a}_{ij} \qquad (4)$$

where ω_i denotes the final weight of criterion i. The weights satisfy the condition:

$$\sum_{i=1}^{n} \omega_i = 1 \qquad (5)$$

Consistency Evaluation

To ensure the logical consistency of expert judgments, the maximum eigenvalue λ_{max} of the comparison matrix is calculated as:

$$\lambda_{max} = \sum_{i=1}^{n} \left(\frac{(Aw)_i}{\omega_i} \right) \div n \qquad (6)$$

The Consistency Index (CI) is then computed as:

$$CI = \frac{\lambda_{max} - n}{n - 1} \qquad (7)$$

The Consistency Ratio (CR) is obtained by comparing CI with the Random Index (RI), which depends on the matrix size:

$$CR = \frac{CI}{RI} \qquad (8)$$

A value of $CR < 0.10$ indicates an acceptable level of consistency and confirms the reliability of the weighting process (Saaty, 1980).

Integration into GIS-Based Suitability Analysis

The derived AHP weights were integrated into a GIS environment using a weighted linear combination approach. The overall suitability index S for CORS station placement was calculated as:

$$S = \sum_{i=1}^{n} \omega_i * r_i \qquad (9)$$

where r_i represents the reclassified raster value of criterion i at each spatial location. Higher values of S indicate greater suitability for CORS station installation.

Suitability Modeling

The weighted criteria layers were integrated using a weighted linear combination approach within the GIS environment. The resulting suitability index map represents the spatial distribution of optimal locations for new CORS stations. Areas with higher composite scores indicate higher suitability, reflecting favorable conditions across multiple criteria.

Results and Discussion

The resulting suitability map reveals a clear spatial differentiation in optimal CORS station placement across Uzbekistan (Figure 2). High-suitability zones are predominantly concentrated in the eastern and southeastern regions, including densely populated valleys and agriculturally productive areas with limited existing CORS coverage. These regions also coincide with zones of elevated seismic hazard, reinforcing the strategic importance of enhanced geodetic monitoring.

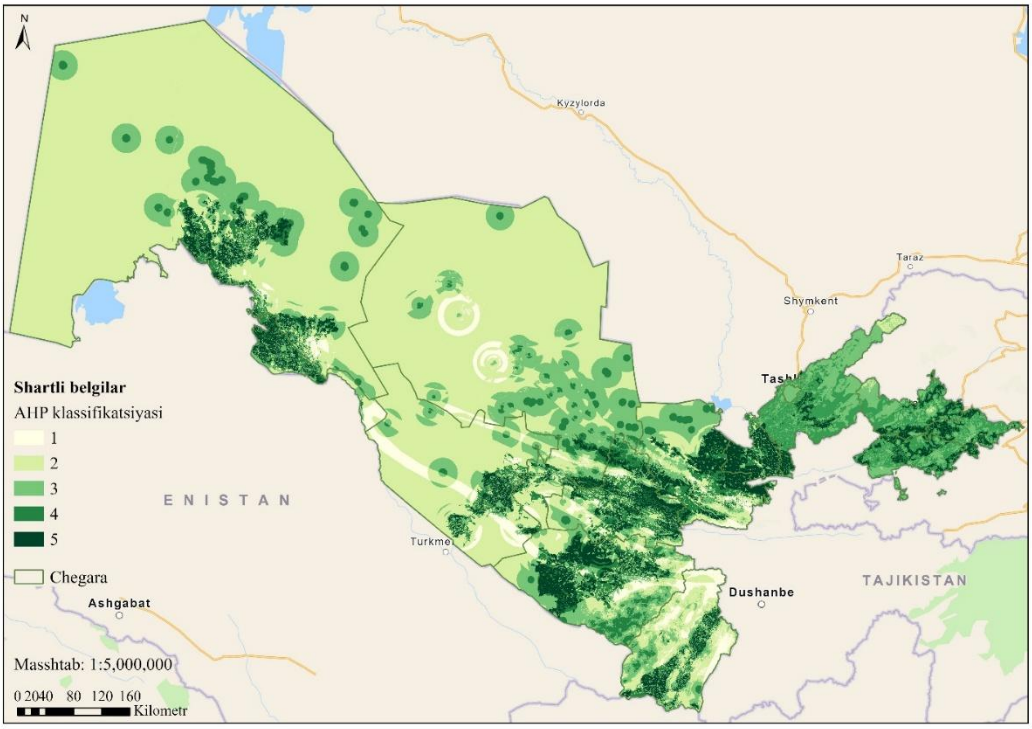


Figure 2. AHP-based spatial suitability map for optimal CORS station placement in Uzbekistan.

Moderate suitability zones are observed in transitional areas where some criteria are favorable while others are limiting, such as regions with adequate population density but challenging topography. Low-suitability zones are primarily located in sparsely populated desert regions with minimal agricultural activity and relatively stable tectonic conditions.

The analysis demonstrates that the integration of socio-economic, environmental, and geophysical criteria provides a more nuanced understanding of CORS network requirements than distance-based approaches alone.

The findings highlight the importance of adopting a multi-criteria perspective in CORS network planning. Traditional approaches based solely on inter-station distance fail to capture spatial variability in demand and risk. By contrast, the AHP-based GIS framework allows decision-makers to balance competing priorities in a transparent and systematic manner.

The prioritization of agriculturally intensive and densely populated regions aligns with international experiences, where GNSS infrastructure investment is increasingly driven by precision agriculture and urban development needs [8]. The inclusion of seismic hazard as a key criterion further enhances the relevance of the proposed model for disaster risk reduction and geodynamic studies.

Despite its strengths, the study is subject to limitations related to the subjectivity inherent in expert-based weighting and the static nature of input datasets. Future research may address these limitations by integrating machine learning techniques, time-series data, and real-time GNSS performance indicators.

Conclusion

This study demonstrates that the integration of AHP and GIS provides an effective and scientifically robust framework for optimizing CORS station placement in geographically and socio-economically diverse regions. The proposed methodology enables the identification of priority zones for network expansion based on multiple, interrelated criteria. Applied to Uzbekistan, the model highlights areas where new CORS stations would maximize technical performance, service demand, and monitoring capability. The approach is adaptable to other national contexts and offers valuable support for strategic geodetic infrastructure planning.

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