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Examining the Geomorphological Factors Affecting the Optimal Location of Military Bases Using Remote Sensing Data in GIS Environment (Case Study: Khalkhal Township, Ardabil Province)[1]

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Abstract

Background and Objective: The optimal location of military bases is one of the major challenges in the planning and development of defense infrastructure. Selecting an appropriate site for these facilities requires a thorough assessment of various environmental, strategic, and social factors to ensure security while minimizing negative impacts on natural resources and communities.

Methodology: In this study, the optimal location of military bases in Khalkhal Township was determined using remote sensing data and the Analytic Network Process (ANP) model within a GIS environment. For this purpose, 12 effective variables were considered, including distance from rivers, geology, elevation, slope, slope direction, land use, vegetation cover, distance from faults, distance from roads, distance from villages, distance from cities, and soil type. The required data were extracted from various sources, such as ASTER sensor images, GLC-FCS30D database, Sentinel-2 satellite images, and geological maps. In the ANP process, criteria were initially classified into two clusters: natural and human-made, and then, pairwise comparisons were performed using Super Decisions software to determine the relative weights of the criteria. Subsequently, the initial, weighted, and final supermatrices were formed to determine the final weight of the criteria.

Findings and Conclusion: The results indicated that areas with medium vegetation cover, slopes less than 10 degrees, brown steppe soils, and barren land are more favorable for the establishment of military bases. Furthermore, appropriate distances from faults, rivers, and human settlements were considered as key factors in decision-making. Analysis of elevation, slope, slope direction, vegetation cover, and land use maps revealed that the central and eastern regions of the township, due to their convenient access to infrastructure and stable environmental conditions, are the best options for establishing military bases.The results of this study can contribute to the optimization of military base location by considering strategic, environmental, and security criteria. This would enhance the efficiency of military operations, improve crisis management, reduce infrastructure costs, and decrease vulnerability to natural disasters.

Keywords: Optimal Location, Analytic Network Process, Sentinel, RS, Khalkhal.

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Extended Abstract

Introduction:

The strategic placement of military camps is a critical component of national defense planning, particularly in regions with complex environmental and geopolitical conditions. An optimally located military base not only enhances operational efficiency and logistical support but also reduces potential environmental impacts and conflicts with civilian land use. In recent years, the application of Geographic Information Systems (GIS) integrated with Multi-Criteria Decision-Making (MCDM) techniques has emerged as a powerful approach for solving spatial planning problems, including military site selection. Khalkhal County, located in Ardabil Province of northwestern Iran, is characterized by diverse topographical, climatic, geological, and land use features. These environmental complexities necessitate a comprehensive and scientifically grounded framework for military camp site selection. The present study adopts the Analytical Network Process (ANP), a sophisticated MCDM method, in combination with GIS to evaluate and prioritize multiple spatial criteria influencing site suitability. Unlike traditional methods, ANP considers interdependencies among criteria, offering a more realistic assessment in complex decision-making scenarios. The criteria employed in this study include slope, elevation, aspect, land use/land cover (LULC), vegetation index (NDVI), geological structure, proximity to roads, rivers, residential areas, and active faults. These layers were derived from high-resolution remote sensing data, digital elevation models, and existing thematic maps. Each factor was weighted using expert judgment and ANP pairwise comparisons to reflect its relative importance in military planning. The main objective of this research is to generate a suitability map for military camp placement in Khalkhal County, balancing strategic, environmental, and infrastructural considerations. By employing a GIS-ANP integrated model, the study aims to provide a replicable and scientifically robust framework for decision-makers involved in defense and land use planning.

Methodology:

Khalkhal County, located in the southern part of Ardabil Province, exhibits diverse topographical and geological characteristics, including mountainous terrain, variable vegetation, and complex soil structures. In this study, twelve environmental and infrastructural criteria were used for site suitability analysis: distance from rivers, geology, elevation, slope, aspect, land use, vegetation cover, and proximity to faults, roads, villages, urban centers, and soil type. Spatial data were obtained from various sources:

Digital Elevation Model (ASTER, 30m resolution)
Geological maps (1:100,000 scale)
Sentinel-2 satellite imagery for vegetation cover (June 2024)
GLC-FCS30D land use data
Google Earth Engine for data processing and classification

The ANP model was applied using Super Decisions software to weight the criteria. The process included pairwise comparisons, construction of the supermatrix, and derivation of final weights. These weights were then implemented in the GIS environment to generate the final suitability map through weighted overlay analysis.

Results and Discussion:

The spatial analysis conducted in this study resulted in a comprehensive suitability map for military camp site selection in Khalkhal County. The integration of the Analytical Network Process (ANP) with Geographic Information Systems (GIS) enabled a precise evaluation of multiple environmental, topographic, and infrastructural criteria. The Normalized Difference Vegetation Index (NDVI), derived from Sentinel-2 imagery (June 2024), showed a variation from -0.14 to 0.47

across the study area. This index helped in assessing vegetation density, which is a critical factor in military site selection due to its role in concealment and land stability. Areas with NDVI values between 0.15 and 0.37 were considered moderately vegetated and ideal for camp construction, offering natural cover without significant ecological constraints. Zones with dense vegetation (NDVI > 0.37) or very sparse vegetation (NDVI < 0.10) were excluded due to ecological sensitivity and lack of ground stability, respectively. The land use/land cover (LULC) classification revealed five dominant categories: barren lands, agricultural lands, forests/vegetation, residential areas, and water bodies. Barren lands and sparsely vegetated areas constituted the most suitable classes due to minimal environmental disturbance and reduced land acquisition costs. Agricultural lands and forest areas were classified as moderately to poorly suitable, as their exploitation for military use may lead to ecological degradation or conflicts with local land use priorities. Residential areas and water bodies were deemed unsuitable, as proximity to civilian infrastructure could pose safety and social risks. Topographical analysis using a Digital Elevation Model (DEM) indicated that optimal locations were situated at elevations between 1400 and 2000 meters above sea level, with slope gradients less than 15 degrees. Areas with steep slopes were excluded due to construction challenges, erosion risk, and operational limitations. Furthermore, northern and northeastern aspects were favored as they provide cooler microclimates and lower solar exposure, which are operationally beneficial in military settings. Geological data highlighted regions with stable formations, such as limestone and conglomerates, as more suitable due to their structural integrity and lower seismic risk. Fault proximity was another critical factor; sites located within 1 km of active faults were marked unsuitable due to potential earthquake hazards. Accessibility factors, including distance from roads, villages, and urban centers, were also incorporated. Ideal sites were found to be within 2–5 km of major roads to ensure logistic efficiency but at least 1.5 km away from settlements to minimize civilian exposure and security risks. The final weighted overlay analysis using ANP-derived weights resulted in a suitability classification of the study area into five categories: very suitable (6.3%), suitable (15.8%), moderately suitable (29.5%), poorly suitable (32.6%), and unsuitable (15.8%). The “very suitable” zones were primarily concentrated in the central and southwestern parts of the county, characterized by moderate vegetation, gentle slopes, stable geology, and appropriate distances from residential areas and fault lines.
These findings confirm that a multi-criteria, GIS-based ANP approach can effectively identify optimal locations for military infrastructure with consideration of both strategic and environmental requirements.

Conclusion:

The integration of ANP and GIS provides a robust framework for multi-criteria spatial decision-making in military site selection. In Khalkhal County, areas with moderate vegetation, stable geological formations, and low to moderate slope, and sufficient distance from residential zones were identified as the most suitable for military camp establishment. The methodology presented in this study can be extended to other strategic land use planning applications, particularly in sensitive or border regions requiring a balance between security and sustainability.

Declarations

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•**Conflict of Interest:** The authors declare no conflict of interest.
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