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Assessment of Climatic and Geomorphological Factors in Military Base Site Selection Using Remote Sensing and GIS (Case Study of the Moghan Plain, Ardabil Province)[1]

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Abstract
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Background and Objective: Location selection is one of the strategic elements in the development of a country's defense infrastructure, requiring precise analysis of environmental, climatic, and human factors using modern spatial approaches. Therefore, the objective of this research is to investigate the role of climatic and geomorphological factors affecting the site selection of military garrisons in Moghan Plain, located in Ardabil Province, by utilizing remote sensing and GIS capabilities.
Methodology: To fulfill the research objective, 14 relevant criteria were selected, including precipitation, temperature, actual evapotranspiration, elevation, slope, aspect, vegetation cover, land use, distance from rivers, faults, roads, cities, villages, and geology. The required spatial layers were derived from remote sensing data sources such as Sentinel-2 imagery, the 12.5-meter ALOS PALSAR Digital Elevation Model, and global climate datasets including TerraClimate, and were processed within the Google Earth Engine (GEE) environment. Subsequently, training sample points representing suitable and unsuitable locations were defined, and the Random Forest (RF) algorithm was trained and applied to produce the final suitability zoning map.
Results and Findings: The variable importance analysis indicated that proximity to cities and villages, slope, vegetation cover, and distance from geological faults were the most influential factors in military base site selection within the study area. The final suitability map classified the region into five categories: very suitable, suitable, moderately suitable, unsuitable, and very unsuitable. Notably, portions of the northern and eastern sections of the Moghan Plain were identified as very suitable zones. This study demonstrates that the integration of machine learning algorithms with remote sensing data offers a robust and efficient approach for spatial analysis and supports strategic decision-making in the defense and military planning sectors.
Conclusion: The findings of this study can support the optimization of military base site selection by integrating strategic, environmental, and security-related criteria. Such an approach has the potential to enhance military operational efficiency, strengthen crisis management capabilities, reduce infrastructure development costs, and minimize vulnerability to natural hazards.

Keywords: Random Forest model, Military Base Site Selection, Geographic Information System (GIS), Google Earth Engine, Moghan Plain.

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Extended Abstract

Introduction:

Site selection is a fundamental step in spatial planning that involves identifying optimal locations based on predefined criteria, considering that each geographic location offers distinct environmental and functional potentials. The process plays a critical role in ensuring efficient land use by analyzing multiple spatial and non-spatial factors such as environmental impact, infrastructural accessibility, service availability, and geospatial connectivity. While site selection is not formally categorized under passive defense measures, it significantly contributes to minimizing human vulnerability—particularly in cases such as shelter location planning. When it comes to military land use, the process becomes even more complex and sensitive due to the involvement of various geological, hydrological, climatic, and geopolitical considerations. Ensuring that military installations are located in areas that not only meet operational requirements but also minimize exposure to threats necessitates a comprehensive, multidisciplinary approach. Traditional planning methods are often insufficient in addressing these multi-criteria needs, which highlights the importance of using expert-driven models and advanced geospatial tools. Moreover, military site selection requires compliance with specific defense-related criteria. These include maintaining a minimum distance of 20 kilometers from urban and industrial zones, ensuring at least 100 kilometers separation from critical infrastructure and borderlines, avoiding natural wind corridors, and securing areas with minimal vulnerability to aerial detection or attack. Given the strategic importance of military bases in ensuring national and regional security, improper site selection—especially in hazard-prone or climatically unsuitable regions—can negatively affect operational efficiency, infrastructure resilience, and personnel safety. The Moghan Plain, located in northwestern Iran, is a strategically significant region due to its unique climatic and geomorphological characteristics and its proximity to international borders. As such, it necessitates a detailed geospatial evaluation for optimal military base deployment. Recent advancements in remote sensing and geographic information systems (GIS), along with the integration of intelligent algorithms such as the Random Forest model, have opened new avenues for accurate, data-driven spatial decision-making. These technologies enable simultaneous analysis of multiple geospatial layers, thereby improving the precision and reliability of site selection processes. Accordingly, the present study aims to apply a modern geospatial approach using the Random Forest algorithm to identify optimal zones for military base placement within the Moghan Plain.

Methodology:

The Moghan Plain, located in the north of Ardabil Province, is one of the most fertile and strategically significant plains in northwestern Iran. Geographically, it lies approximately between 47°20′ to 48°50′ eastern longitudes and 38°55′ to 39°35′ northern latitudes. It is bordered to the north by the Aras River and the Republic of Azerbaijan, to the east by the western foothills of the Talesh Mountains, to the south by Bileh-Savar County, and to the west by Germi County. In this study, a total of 14 variables were utilized to produce a military base suitability map for the Moghan Plain. These variables include climatic factors (precipitation, temperature, actual evapotranspiration), geomorphological and anthropogenic factors (distance to rivers, geology, elevation, slope, slope aspect, vegetation cover, distance to faults, distance to roads, distance to villages, distance to urban areas, and land use/land cover). To prepare these variables, various datasets and techniques were employed. The elevation, slope, and aspect layers were extracted from the ALOS PALSAR Digital Elevation Model (DEM) with a spatial resolution of 12.5 meters. River networks were delineated using the Hydrology tool in ArcGIS. Geological formations were digitized from the regional 1:100,000 geological map within the ArcGIS environment. The land use map of the study area was derived from the GLC-FCS30D product using the Google Earth Engine platform. Vegetation cover was mapped using Sentinel-2 satellite

imagery acquired in June 2024. To perform the military site suitability analysis, the Random Forest (RF) model was implemented through coding in the Google Earth Engine (GEE) environment. The Random Forest algorithm, a popular machine learning technique, is widely used for classification and zoning tasks due to its high accuracy and robustness against overfitting. It constructs an ensemble of decision trees, each trained on a random subset of data and features, and combines their predictions to produce the final output (Sheikhzadeh Qahnavieh et al., 2021). In the present study, the Random Forest model effectively identified complex patterns within the 14 selected variables and produced an accurate suitability map for military base location. The use of Google Earth Engine enabled the efficient processing of large datasets and complex calculations. The Random Forest algorithm is a decision-tree-based model that aggregates the outcomes of multiple trees to estimate the relationship between natural hazards and environmental variables (Jafarian & Kargar, 2017). In regression problems, it utilizes an ensemble of unpruned trees trained on subsets of independent variables to predict the probability or intensity of a dependent hazard variable. This technique offers a powerful analytical framework for variable exploration and optimizing the number of trees in the model. The integration of the Random Forest package within Google Earth Engine supports effective modeling of natural hazard susceptibility and enhances decision-making in spatial planning.

Results and Discussion:

Analysis of Climatic, Geomorphological, and Human Factors in the Optimal Location of Military Bases in the Moghan Plain: The spatial distribution of rainfall in the Moghan Plain ranges from 342.01 to 607.27 mm. The southern parts receive more rainfall, while the north experiences lower precipitation. Lower rainfall areas are more suitable for military bases due to reduced flood risk and easier logistics. However, areas with higher rainfall may be preferable for water availability. emperature varies between 18.53°C and 30.70°C, with the central and southern parts being hotter. Cooler areas in the north and northeast are more favorable for base location due to reduced energy consumption and better environmental conditions. Actual evapotranspiration ranges from 24.27 to 37.16 mm, with lower values in the north. Lower evapotranspiration indicates higher soil moisture retention, making the northern areas more suitable for base installation. Elevation data show that lower elevations (17 to 561 meters) are concentrated in the north and northeast, offering easier access and construction advantages. However, mid-elevation zones (561–1651 meters) may offer a balance between logistical ease and strategic security. Slope in the region varies from 0 to 58 degrees. Northern areas with slopes less than 5 degrees are ideal for construction, while steeper southern slopes are less suitable due to engineering limitations. Aspect analysis reveals that north-facing slopes dominate the area. These slopes receive less direct sunlight, helping to moderate temperatures and making them preferable for long-term military installations. Vegetation cover varies between -0.34 and 0.70, with denser vegetation in the north and northwest. Areas with sparse vegetation may offer easier construction conditions but are more prone to erosion. Vegetation should be considered when selecting base sites. The distance from waterways ranges from 0 to 5057 meters. Areas further from rivers (more than 2000 meters) are safer from flooding and are preferred for military infrastructure. Regarding seismic safety, proximity to faults ranges from 0 to 39315 meters. Areas more than 15726 meters away from faults are considered safer and better suited for military bases. Distance from roads affects logistical efficiency. Zones closer to roads (0 to 4841 meters) are more favorable for base establishment due to better access to transport and supply routes. The distance to villages ranges up to 5697 meters. Sites over 3400 meters away from villages are more suitable to avoid social, environmental, and security conflicts. Distance to cities ranges from 0 to 30483 meters. Areas located over 18 km from urban centers are more appropriate for military base installation, offering better security and reduced environmental and social conflicts. Land use data show that most of the Moghan Plain consists of agricultural lands and rural settlements. Military base siting should avoid fertile lands and residential areas. However, barren lands in the northeast and central regions may offer suitable locations. Final Zoning Using the Random Forest Model (RF); After preparing all environmental, geomorphological, and human layers in ArcGIS, they were input into the Random Forest model in Google Earth Engine. The final suitability map was produced and then analyzed in ArcGIS. The results showed that 2.19 km² in the south, southeast, and parts of the northwest are completely unsuitable due to steep slopes, poor access, and fault proximity. Conversely, 3.11 km² in the north and

central parts are identified as highly suitable due to mild slopes, good accessibility, and safe distances from natural hazards.

Conclusion:
This study used a combination of remote sensing, GIS, and machine learning to optimize military base location in the Moghan Plain. Fourteen environmental and human factors, including rainfall, temperature, evapotranspiration, elevation, slope, vegetation cover, land use, distance from rivers, faults, roads, cities, and villages, were selected for analysis. Remote sensing data, such as Sentinel2 images, the ALOS PALSAR DEM, and TerraClimate climatic databases, were used to prepare the layers. The Random Forest algorithm was then applied for final base location modeling. The model results showed that Random Forest performed well in classifying areas suitable for military base establishment, with northern and eastern parts of the Moghan Plain classified as "highly suitable." This research demonstrated that using remote sensing data and machine learning algorithms in Google Earth Engine provides an accurate and efficient tool for military base location analysis.

Declarations

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