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EXTENDED ABSTRACT 009

Geological suitability in remote mountainous settlements using the AHP method. The case study of the settlement of Klepa in Greece

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Research Highlights: **GIS-based Analytical Hierarchy Process (AHP) for geological suitability evaluation in remote mountainous settlements**

Introduction

The evaluation of geological suitability is crucial in managing and planning residential development in settlements, where geological conditions are harsh, and accessibility is limited. This becomes even more critical in areas affected by geohazards, such as landslides that primarily occur in remote mountainous regions due to their complex terrain, geological characteristics, and human activities. These studies are compulsory in every case of urban planning or demarcation of a settlement and aim to safeguard the built environment from natural hazards or hazards resulting from human intervention and activities (Depountis, 2023).

Focusing on mountainous remote settlements influenced by landslide events, this study employs a GIS-based multicriteria analysis using the Analytical Hierarchy Process (AHP) to evaluate geological suitability. This methodology incorporates various geological factors affecting the study area to produce a suitability map and categorize existing settlement conditions into safe or unsafe building zones. The Analytical Hierarchy Process (AHP) assigns certain weights to the chosen criteria and spatial datasets are produced within a GIS environment to create a geological suitability map that identifies optimal areas for development; thus, categorizing them as suitable, unsuitable, or suitable under specific conditions.

Background

The settlement of Klepa, located in the Central Western Greece, belongs to the regional unit of Aitoloakarnania. The geology of the study area is characterized by the presence of Alpine bedrock, specifically the Pindos unit. The formations in the study area are primarily comprised of flysch, limestone and cherts. In addition, Quaternary deposits are present, including fluvial deposits, scree and landslide materials.

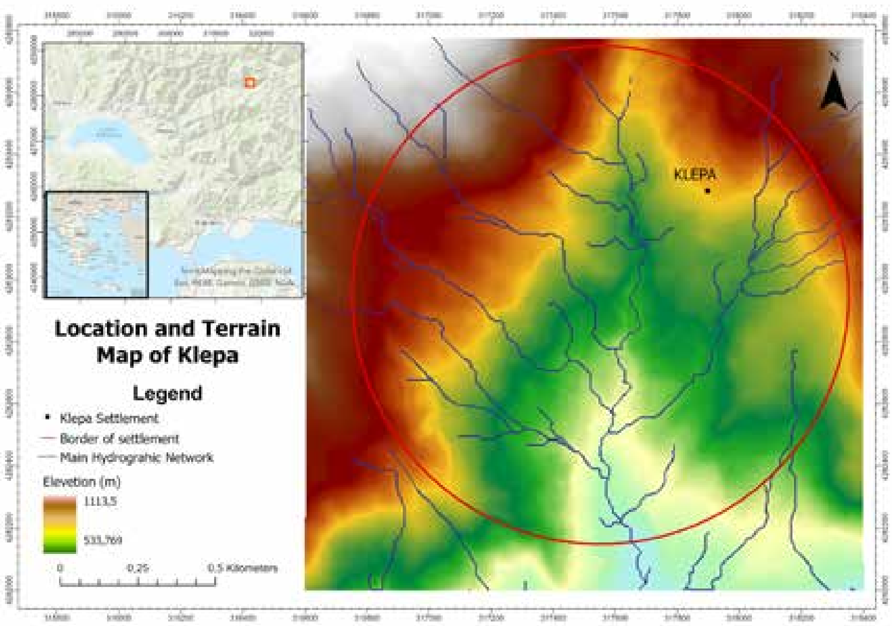

Figure 1. Location and terrain map of the study area.

The landslide problem in the wider area of Klepa is well-known and has been repeatedly examined by the Hellenic Survey of Geology and Mineral Exploration. In particular, the area has recorded activations of old or recent landslides at least four times in the last 35 years, with the most recent and severe occurred in 2015. The impact of landslides was severe, destroying several houses and a section of the provincial road about 120 meters long.

Methodology

The methodology of this study is divided into four key phases: a) criteria selection, b) AHP application, c) spatial analysis and standardization, and d) suitability assessment. The criteria were selected from the study by Depountis (2023), which proposes an outline for the application of various parameters for MCE suitability related to different land uses. The selected criteria are (1) Geohazards/Landslides, (2) Geomorphology/Slope, (3) Geology/Lithology, (4) Hydrology/Rivers, (5) Ground Seismicity Hazard and (6) Tectonics/Faults. The current study employs the Analytic Hierarchy Process by Saaty (1980), a multicriteria decision method that uses eigenvalue theory to compute weights and maintain consistency in pairwise comparisons. The AHP is a comprehensive measurement theory, which allows the creation of ratio scales through comparison of discrete and continuous variables (Hajar, 2017) and is a globally recognized technique aiding in risk assessment and mitigation planning (Mokhtari et al., 2023).

The pairwise comparison of the chosen criteria was performed to assess their relative importance to a defined objective, using Saaty's weighting scale 1-9. After the process of the matrix's normalization to ensure logical consistency, the Consistency Ratio (CR) is calculated, which includes the following indices:

- Random Index (RI): A constant derived from Saaty's random index scale, based on the number of criteria.
- Maximum Eigenvalue (λmax): The mean obtained by multiplying elements of the normalized comparison matrix by the priority vector (weights).
- Consistency Index (CI): A measure of matrix consistency, using the number (n) of criteria and calculated as:

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

The CR is computed by dividing the CI by the RI, with values ≤0.10 deemed acceptable; higher values suggest the need for revised comparisons (Saaty, 1980).

The main purpose of the application of the analytical hierarchy process is to determine the weight values of the criteria discussed to solve the problem and their place in the hierarchical structure at the solution stage (Topuz & Deniz, 2023).

The criteria (or factors) used in this study and their calculated weights are presented in Table 1. In Table 2 the criteria used are presented as data layers imported in the GIS framework and divided into four classes (1-4) for proper suitability assessment.

Table 1. Pairwise matrix of the criteria and produced weightage W_i.

Criteria	Geohazards/ Landslides	Geomorphology/ Slope	Geology/ Lithology	Hydrology/ Rivers	Ground Seismicity Hazard	Tectonics/ Faults	Weight W_i.
Geohazards/ Landslides	1	2	3	4	4	4	0.368
Geomorphology/ Slope		1	2	3	3	3	0.236
Geology/ Lithology			1	2	2	2	0.144
Hydrology/ Rivers				1	2	2	0.106
Ground Seismicity Hazard					1	1	0.073
Tectonics/Faults						1	0.073

Table 2. Division of criteria into classes and Suitability assessment.

Data Layer	Class	SC	Data Layer	Class	SC	Data Layer	Class	SC
Landslides	Active/ recent	4	Slope (%)	<10	1	Lithology	Recent loose Landslide materials	4
	Inactive/ older	3		10-20	2		Paleo & Older semi-compacted Landslide materials	3
	Absence	1		20-35	3			
				>35	4			
Distance from Streams (m)	<10	4	Ground Seismicity Hazard	A	1		River bed deposits	3
	10-50	3		B	2		River terrace	1
	50-100	2		C	3		Scree	3
	>100	1		D, X	4		Sandstone/ Flysch Pindos Unit	2
Distance from Faults (m)	0-20	4					Siltstone/ Flysch Pindos Unit	2
	>20	1					Limestone/ Pindos Unit	1
							Cherts/ Pindos Unit	2
CR= 0.0192 ≤ 0.10								

1: Suitability Class (SC) refer as; (1) Highly Suitable, (2) Moderately suitable, (3) Marginally suitable and (4) Unsuitable.

The spatial analysis was conducted in ArcGIS Pro 3.1 software. To illustrate the spatial distribution of the relevant criteria, six thematic maps were developed based on the data layers and classification categories specified in Table 2. These maps provide a detailed spatial representation, contributing to a more thorough understanding of the patterns and relationships within the study area (Figure 2, 3). The data necessary for the creation of the aforementioned layers were sourced from various references, which are detailed subsequently. Moreover, a modification and validation of vector data was performed, specifically for the limits of the area of active landslides. Figure 2A depicts the landslide inventory, classifying areas into three distinct classes: (i) absence, (ii) inactive/older landslides, and (iii) active/recent landslides. This classification is crucial for identifying regions with historical or ongoing instability. Slope plays a pivotal role in affecting the occurrence of landslide events. Steeper slopes are more prone to instability due to the greater gravitational force acting along the slope surface, which increases the probability of failure. A slope map was generated by processing the Digital Elevation Model (DEM) of the area, which has a grid size of 5x5m. The layer was classified into four distinctive categories that are: (i) less than 10, (ii) 10 to 20, (iii) 20 to 35 and (iv) greater than 35, each representing different slope percentages (Figure 2B).

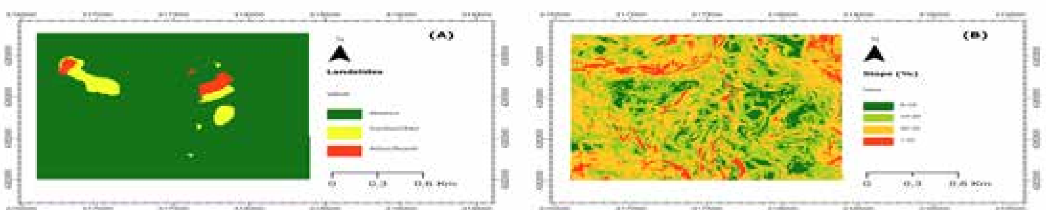

Figure 2. Thematic layer maps: (A) Landslides, (B) Slope.

Figure 3C presents the lithological classification, detailing various geological formations. The geological and lithology features were digitized from a large-scale (1:2.000) Engineering Geological map produced by the Hellenic Survey of Geological and Mineral Exploration (T-2855/2016) and an update was made after an on-site geological surveying.
The distance from streams portrays a critical hydrological factor influencing slope stability. The drainage network was derived from the Digital Elevation Model (DEM) and subsequently verified against the Engineering Geological map. The vector data was modified to define the boundaries of the river banks, and buffer zones were established around the streams, categorized as follows: (i) less than 10 meters, (ii) 10 to 50 meters, (iii) 50 to 100 meters, and (iv) greater than 100 meters. These buffer zones are represented as a layer in Figure 3D.
Furthermore, Figure 3E illustrates the proximity to fault lines, categorizing the study area into two classes: (i) areas within 0 to 20 meters from faults and (ii) areas beyond 20 meters, based on the provided data of the Engineering Geological map. Figure 3F represents the ground seismicity hazard of the geological formations, with the layer classified into four categories: (i) A, (ii) B, (iii) C, (iv) D, X, corresponding to the Engineering Geological map of the area and the Greek Code for Seismic Resistant Structures (EAK 2000). It is important to note that the third class is not represented in the thematic map, as no geological formations were classified within this category.

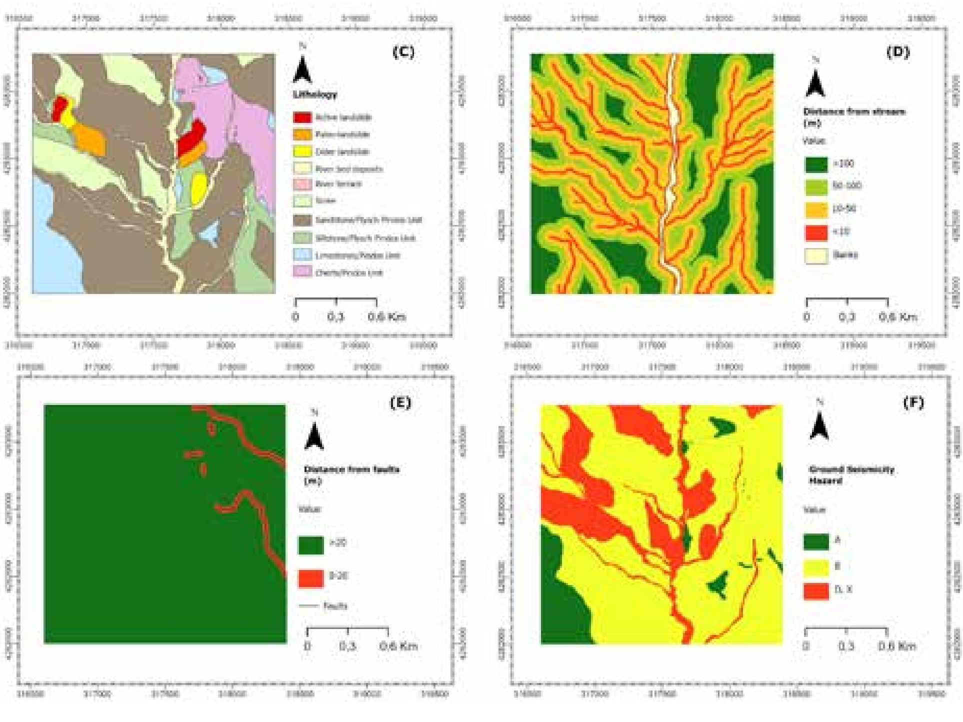

Figure 3. Thematic layer maps: (C) Lithology, (D) Distance from stream, (E) Distance from faults and (F) Ground Seismicity Hazard.

The raster layers were exported and then a scale of 1-4 was applied for the process of reclassification, following the scale of suitability values mentioned in Table 2. The levels of suitability were evaluated based on the relative significance of the contribution made by each criterion as has been suggested by Feizizadeh (2012). The reclassification of the spatial layers was made in order to eliminate the units of measurement and transform the data into a unitless format as has been suggested by Mansour et al. (2019). This process enhances compatibility, allowing for smoother integration with other datasets, regardless of their measurement system.
Following spatial analysis, a geological suitability map was obtained by the Weight Linear Combination

(WLC) method, then reclassified with Jenks natural break, categorizing the study area into four suitability categories (Figure 4). The WLC approach is one of the most frequently used in GIS-MCDA (Malczewski, 2000). The criteria and their individual weights are summed up in WLC, and the combined sum presents the final suitability map using the equation:

$$\sum_{i=1}^{n} = w_i \cdot c_{ij} \qquad (2)$$

Where Wi: weights of selected criterion i, Cij: Reclassified criteria and n denotes total number of criteria.

Results

Each individual category of the final map corresponds to a unique geological suitability level with a specific color (Figure 4). For example, the lowest suitability level, represented by the highest weighted score, is highlighted in red. In this study, the suitability map shows four suitability categories as follows: (a) Unsuitable, (b) Marginally suitable, (c) Moderately suitable and (d) Highly suitable.

The analysis reveals that 38.58% of the total area is classified as highly suitable for residential development. The largest share of the land, 44.85%, falls under the “Moderately suitable” category, making it the most dominant classification in the analysis. While considering the land area that is not suitable, it is seen that a small area of the field consists of the Marginally suitable class 12.77%, whereas 3.80% of the study area is considered unsuitable for residential development.

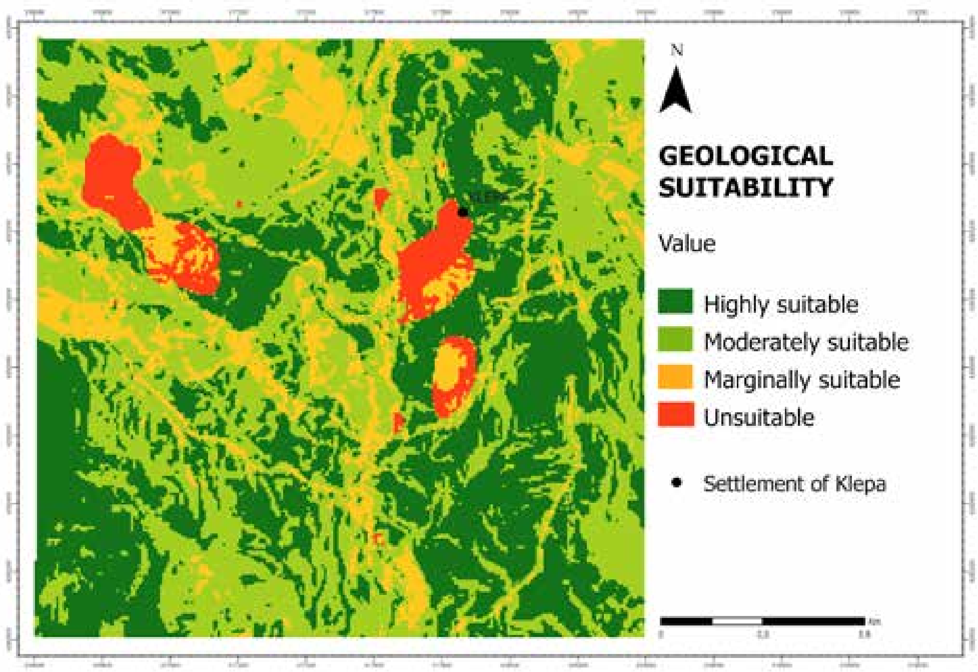

Figure 4. Geological Suitability map of the study area with color classification for each suitability category.

Conclusions

This study effectively combines Geographic Information Systems (GIS) and the Analytic Hierarchy Process (AHP) to assess geological suitability and residential development in mountainous settlements impacted by landslide events. By prioritizing key criteria through AHP and via GIS for spatial analysis, a geological suitability map is obtained. The produced map presents four levels of suitability: Unsuitable, Marginally Suitable, Moderately Suitable, and Highly Suitable. The analysis reveals that 38.58% of the investigated area is highly suitable for development, whereas 44.85%, of the total area falls under the Moderately

Suitable category. A smaller portion, 12.77%, is Marginally Suitable and 3.80% is classified as Unsuitable. This comprehensive approach provides a valuable decision-making tool for sustainable residential development and planning, particularly in remote settlements and geohazard-prone areas, that can be adapted to diverse cases and assess the influence of multiple factors in a region.

References

Depountis, N. (2023). Geological studies for regional and urban planning in Greece. European Geologist, 56.

Elhadj Mokhtari, Farouk Mezali, Brahim Abdelkebir, Bernard Engel, (2023). Flood risk assessment using analytical hierarchy process: A case study from the Cheliff-Ghrib watershed, Algeria. Journal of Water and Climate Change 14 (3): 694–711.

Feizizadeh, B., & Blaschke, T. (2012). Land suitability analysis for Tabriz County, Iran: a multi-criteria evaluation approach using GIS. Journal of Environmental Planning and Management, 56(1), 1–23. https://doi.org/10.1080/09640568.2011.646964

Hajar YAA, (2017). Using Analytical Hierarchy Process (AHP) to build suppliers' selection model. Int J Acad Res Bus Soc Sci. Pages 772-787. ISSN: 2222-6990. http://dx.doi.org/10.6007/IJARBSS/v6-i12/2552

Hellenic Survey of Geology and Mineral Exploration (2016). Engineering Geological study of the Kato Klepa settlement, Municipality of Nafpaktia, Regional Unit of Etoloakarnania (T-2855).

Malczewski J (2000) On the use of weighted linear combination method in GIS: common and best practice approaches. Trans GIS 4(1):5–22

Mansour, Shawky & Al-Awadhi, Talal & Al-Hatrushi, Salim. (2019). Geospatial based multi-criteria analysis for ecotourism land suitability using GIS & AHP: a case study of Masirah Island, Oman. Journal of Ecotourism. 19. 1-20. 10.1080/14724049.2019.1663202.

Saaty, Thomas. (1980). The Analytic Hierarchy Process. McGraw-Hill, New York.

Topuz, M., Deniz, M. (2023). Application of GIS and AHP for land use suitability analysis: case of Demirci district (Turkey). Humanit Soc Sci Commun 10, 115. https://doi.org/10.1057/s41599-023-01609-x