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Landslide Susceptibility Zonation in a 1:100,000 Geological Map (Case Study: Kiasar, Mazandaran Province)

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Abstract

Landslides represent a significant natural hazard, causing substantial damage and economic losses worldwide. Accurate landslide susceptibility assessment is crucial for mitigating these risks. This study employs a Geographic Information System (GIS) and the Analytical Hierarchy Process (AHP) to investigate and map landslide susceptibility in the Kiasar 1:100,000 quadrangle, Iran. This study employed a comprehensive set of influencing factors to assess landslide susceptibility including geology, slope, aspect, precipitation, seismicity, faults and folds, distance to roads, distance to rivers, erosion, and land use. Among the selected criteria, precipitation and slope were assigned the highest weights of 0.27 and 0.22, respectively, reflecting their significant influence on landslide occurrence. Conversely, drainage and land use received the lowest weights of 0.034, indicating their relatively lesser impact. The study findings revealed that approximately 6% (151.68 square kilometers) of the total study area (2500 square kilometers) is classified as susceptible to landslides. This corresponds to 22% of the total area occupied by villages within the investigated region. Furthermore, field verifications confirmed that the main power transmission lines and primary oil pipelines are not exposed to landslide hazards. However, some mines within the study area were identified as being at risk. Within the study area, two industrial facilities – a bakery and a fruit preservation plant – were identified as being located within landslide-prone zones. The high correlation between historical landslide occurrences and the methodology employed in this research suggests that the adopted approach is well-suited for landslide susceptibility mapping in mountainous regions characterized by climatic and vegetation diversity.

Key words: **Zonation, Landslide, Overlay, Kiasar, GIS, AHP**

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Extended Abstract

Introduction

Shallow landslides accompanied by debris flows are one of the major causes of damage to structures and infrastructure, as well as casualties in mountainous and hilly areas, typically triggered by short but intense rainfall events. In recent years, global climate change has led to severe weather events that have increased the likelihood of landslides. Additionally, human activities can accelerate the dynamics of natural processes by altering the threshold of slope stability, thereby creating potential hazards for communities. Changes in land use and improper land management can heighten the risk of landslide occurrences. Hydrological disasters, such as floods, account for the largest share of natural events (51.7%), while geophysical disasters, including earthquakes and landslides, comprise 9.1%. The preparation of landslide hazard maps is essential for proper land use management and risk assessment. Furthermore, given that landslides can pose serious problems for social and economic well-being, the development of accurate landslide maps is crucial for implementing targeted risk management programs, particularly in mountainous regions. In recent years, many governmental organizations worldwide have sought solutions to mitigate the catastrophic consequences of landslides by educating the public to better understand the severe impacts of landslides and developing appropriate tools for planning and decision-making. With the rapid development of Geographic Information Systems (GIS) over the past three decades, various modeling methods have been employed globally for spatial analysis of landslides and mapping the sensitivity of land to landslide occurrences. This study utilized GIS and the Analytic Hierarchy Process (AHP) to conduct landslide hazard zoning within the quadrangle of the Kiasar geological map. The study area was selected due to the extensive occurrence of hazardous landslides, which have led to the displacement of residential and agricultural lands, road blockages, destruction of power, gas, water, and sewage lines, as well as mines, workshops, and factories, consequently introducing various pollutants into the environment.

Data and Methodology

In this research, initial desk studies and data collection were conducted, which included gathering resources and baseline information such as geological reports, theses, websites, and other materials compiled by various organizations and agencies over the years within the study area. The data utilized in this study included the 1:100,000 geological map of the Kiasar sheet, topographic data at a scale of 1:25,000, seismic data (from the Geological Survey of Iran), precipitation information, and vegetation maps (from the Meteorological Organization and Watershed Management Organization of Mazandaran Province). After preparing the necessary data, the digitization of baseline maps, including topographic, geological, precipitation, and seismic maps, was carried out. Subsequently, criteria layers were developed, and the weighting of factors influencing landslides was performed based on expert opinions and the analytic hierarchy Process. Finally, the areas prone to landslide occurrences were validated through field visits.

Results and Discussion

In this method, the factors influencing zoning were identified based on the general conditions of the area, geological characteristics, and climatic conditions, and these specifications were

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modeled as layers using ArcGIS software. After modeling the layers, they were classified using existing standards from various sources, and ultimately, by integrating and combining the layers with appropriate weighting, the hazard zoning map was created. The weighting in the overlay method is relative. In this study, the Analytic Hierarchy Process (pairwise comparison method) was employed for weighting the influential layers, ensuring that the total weight of the criteria equals 1. In the pairwise comparison method proposed by Professor Saaty, the criteria are compared two by two to determine their relative importance. Subsequently, by placing the criteria in a matrix and using various methods (in this research, the arithmetic mean method was applied), the weights of the criteria were calculated, and the inconsistency ratio was determined. After calculating the relative weights of the influential layers, the overlay of the layers in the ArcGIS environment was performed using the Weighted Sum tool. Based on the conducted studies and recorded earthquakes, it was determined that the most significant factors influencing landslide occurrences in the study area are geological factors, slope, and precipitation. In the study area, most landslides occurred on slopes ranging from 15 to 35 degrees, which significantly impacts rainfall is a significant factor in the occurrence of landslides. Due to rainfall, water has more opportunity to infiltrate these slopes, which reduces friction and/or increases the weight of layers (shale, clay, marl, and loose Quaternary sediments), leading to landslides in the direction of the slope.

Conclusion

Regarding the impact of slope direction on landslide occurrence within the study area, it can be stated that the northern and western slopes are more susceptible to landslides. This is because, considering the general trend of geological layers (east-west) and the direction of sunlight, the northern and western slopes are more shaded than other slopes, resulting in higher moisture retention. This increased moisture facilitates greater water infiltration into the soil, contributing to landslide phenomena. Field visits to the area revealed that the main factors contributing to landslides in the region are the soil type (clay, marl, gypsum, and shale), slope, and rainfall. By creating a landslide hazard zoning map using the overlay index method in ArcGIS and weighting the factors using the Analytical Hierarchy Process (AHP) in the Expert Choice software, it was shown that this method is suitable for landslide zoning in mountainous areas and regions with significant elevation changes and vegetation diversity. The results obtained closely match the recorded landslides. According to the calculations, the area of regions at risk of landslides constitutes 6% (151.68 km²) of the total area (2500 km²) of the study area. The area of villages at risk of landslides accounts for 24%, or 2.04 km², of the total area of the villages (8.53 km²). The investigations revealed that the main power transmission lines and oil pipelines are not at risk. Among the existing mines in this study area, only the zinc mine is at risk, and out of the total industrial factories in this area, two factories one for bread production and one for fruit preservation are located within the landslide hazard zone.

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