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Landslide Hazard Assessment in the Kurdistan Mountains, Northern Iraq: A Remote Sensing and GIS Perspective

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SUMMARY

Landslides are major geological hazards in mountainous regions, driven by both natural processes and human activities. They pose significant environmental challenges, causing extensive damage to infrastructure, property, and landscapes, often resulting in casualties. This study focuses on evaluating and mapping landslide susceptibility in the Zagros Mountains of Kurdistan, northern Iraq, using GIS-based techniques. A comprehensive landslide inventory map was developed through detailed field investigations, remote sensing data analysis, and Google Earth imagery interpretation. Ten key influencing factors—elevation, rainfall, lithology, slope, curvature, aspect, land use/land cover (LULC), NDVI, and proximity to roads and rivers—were analyzed using a combined frequency ratio (FR) and analytical hierarchy process (AHP) approach to assess their relationship with landslide occurrence. The results reveal that landslide susceptibility in the Kurdistan Mountains is predominantly influenced by tectonic structures, landscape characteristics, and environmental conditions, particularly rock lithology (competency), slope gradient, rainfall intensity, and human activities. The resulting susceptibility maps provide critical insights for regional planners, policymakers, and infrastructure developers, offering a foundation for effective landslide mitigation strategies and the protection of lives and property in the region.

Introduction

Kurdistan has a challenging landscape characterized by rugged mountainous, featuring heavy hydrological conditions with various exposed geological materials that make it susceptible to the risks of landslides, primarily due to its location in the frontal sector of the Zagros fold belt, situated near the NE boundary of the Arabian plate, interacting with the Eurasian plate (Jassim and Goff, 2006; Doski and McClay, 2022). The complex landscape of Kurdistan arises from the interaction of endogenous and exogenous processes during the Neogene–Quaternary time, and its surface evolution was shaped by the lithological variations, tectonic activity, climate changes, and human interventions (Forti et al., 2021). This study employed a methodology based on GIS to evaluate and map the landslide susceptibility in the Kurdistan's mountainous landscape. The main aim is to generate a susceptibility map of landslides by combining both the frequency ratio (FR) and analytical hierarchy process (AHP) models, in conjunction with GIS and remote sensing methods. The study area, between the coordinates of 36° 50` 40`` N - 37° 01` 20`` N latitude and 42° 50` 20`` E - 43° 10` 30`` E longitude, located northeast of Duhok City within both the simply folded and the high folded zones of the Zagros fold belt. The study area is distinguished by its mountains with a semi-arid continental climate. The peak elevations reaching up to 1300 meters above (S.L.) on the peaks of mountains, and the lowest points, approximately 570 meters above (S.L.). The overall drainage system primarily comprises dendritic and parallel patterns.

Research methodology

To conduct a GIS-based mapping and evaluation of landslide susceptibility in the study area, two spatial datasets were created for the inventory of landslides and the factors contributing to landslides (Fig. 1). These datasets were built utilizing the spatial analysis tools within ArcGIS 10.4 Platform. Detailed field data were collected from 282 active and past landslides. During the fieldwork, precise GPS coordinates were used to mark landslide sites, while measurements including dimensions (length and width) and thicknesses (depth), as well as observations on the type of landslides, their current state (whether active, re-activated, historic, etc.), land use/land cover, lithological units, weathering degree, slope steepness, drainage systems, and human activities were meticulously documented.
Ten factors influencing landslide susceptibility prediction were identified based on geological, topographic, and environmental considerations. These factors are elevation, rainfall, lithology, slope, curvature, aspect, LULC, NDVI, distance to roads and rivers (Fig. 1). Topographic features, including contour lines, drainage patterns, slope gradients, aspect, and curvature surfaces, were generated using the ASTER Global DEM (V2), which has a 30 m resolution. The NDVI map, LULC patterns, and road networks are delineated from field surveys and analysis of Landsat 9 imagery and maps of Google Earth. Additionally, the map of rainfall is formulated utilizing data from the Directorate of Meteorology & Seismology in Duhok.

Results and Discussion

In total, 282 landslides were detected and mapped through a fieldwork with GIS and remote sensing analyses. The identified landslides are categorized into various types, including earth slide (36.88%), rock slide (18.79%), rock fall (16.67%), debris flow (14.54%), earth flow (9.93%), and complex types (3.19%), based on the landslide classification of Varnes (1978). The recorded landslides comprise 5640 pixels and encompass an area of approximately 5.076 km2. The survey results indicate that the smallest landslide measured approximately 75.03 m2, while the biggest recorded was covered about 8590.06 m2. The average landslide area varied between 9742.00 m2 and 20527.38 m2. The landslides are shallow, with the thickness of their slide bodies being less than 10 m. This research work investigated the relationship between ten influential factors and the presence of landslides through the FR and AHP methodologies.

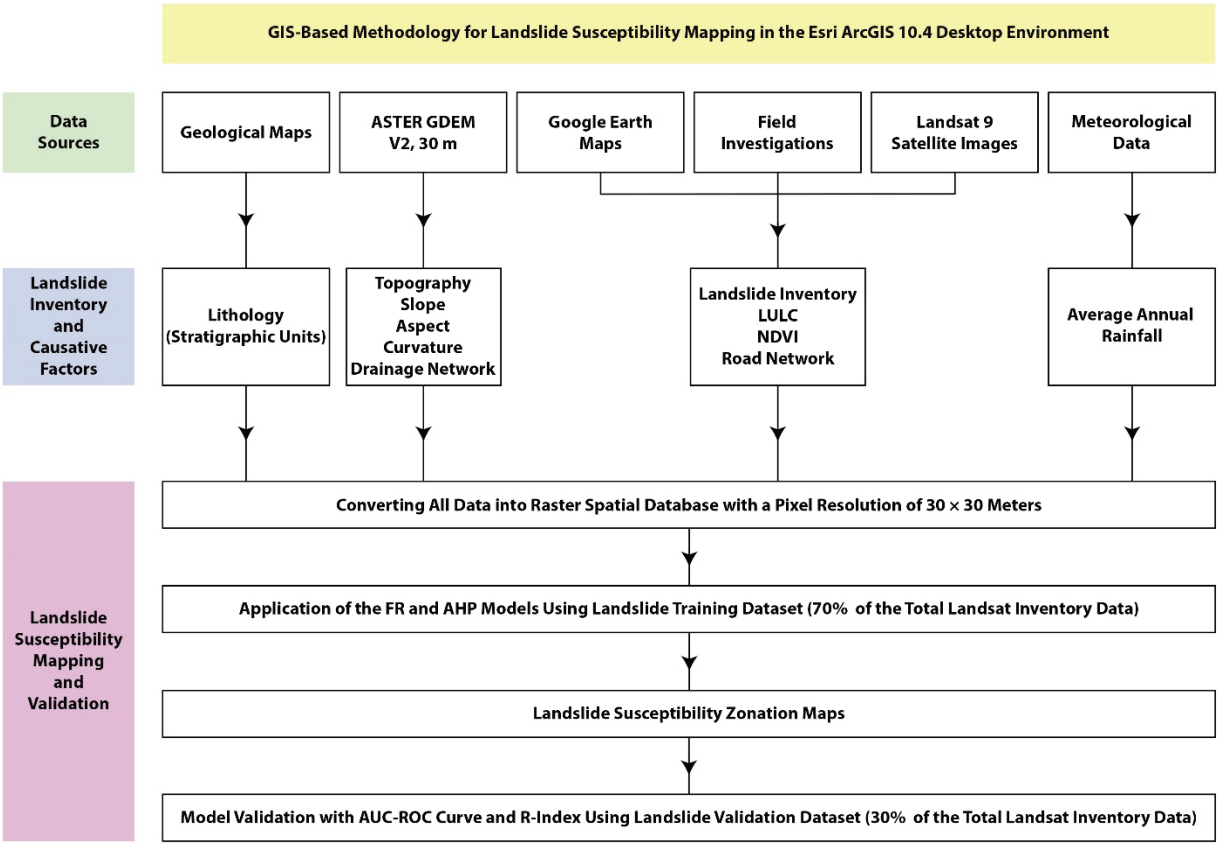

Figure 1 *Flowchart of the research methodology*

These factors, including elevation, rainfall, lithology, slope, curvature, aspect, LULC, NDVI, distance to roads and rivers, were categorized into different classes and weights for the FR and AHP models, respectively. The susceptibility map generated by the FR model for the study area depicted percentages for susceptibility as follows: very low (12.72%), low (20.90%), moderate (24.25%), high (25.23%), and very high (16.90%) (Fig. 2). Similarly, utilizing the AHP values, the study area was categorized into 5 hazard levels with percentages allocated as very low (12.01%), low (17.77%), moderate (31.11%), high (24.55%), and very high (14.55%). The landslide susceptibility maps clearly indicate that very low and low hazard zones are primarily occur in flat terrains or gently sloping plains characterized by competent massive rocks, shallow valleys, dense vegetation cover, light rainfall, and far away from riverbank s and roadways. Conversely, high and very high zones are clustered in steep slopes and rugged terrains with bare soils and extensively fractured rocks, highly weather, sparse vegetation, heavy rainfall, deep valleys, and near to human construction projects. Moderate susceptibility zones are predominantly interspersed between these aforementioned regions throughout the Bekhair core area.

Conclusions

1- The relationship between landslide occurrences and ten identified factors, including elevation, rainfall, lithology, slope, curvature, aspect, LULC, NDVI, distance to roads and rivers was assessed through the application of the FR and AHP methodologies in GIS Platform. The Bekhair core area was divided into 5 categories on the landslide susceptibility maps, indicating varying susceptibility degrees: very low, low, moderate, high, and very high. As a result, the study suggests focusing rehabilitation efforts on the high-risk landslide zones to efficiently address landslide challenges in the Bekhair anticline.

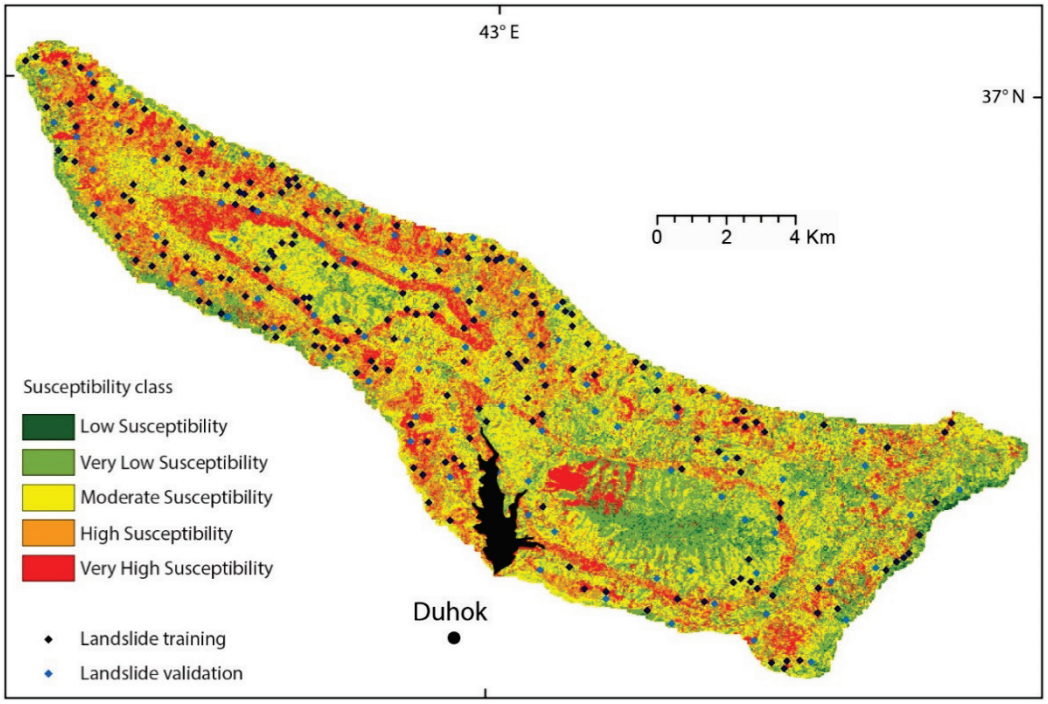

Figure 2 *Landslide susceptibility map for the Bekhair anticline's core, Kurdistan Mountains*

2- This study confirms that Kurdistan's landscape has been predominantly shaped by the interaction of tectonic structure, geomorphological processes, and climate variations. However, among the influencing factors, the lithology, slope, rainfall, and LULC were identified as the foremost influential factors, while elevation, distance to rivers and roads, and NDVI held secondary significance. Conversely, aspect and curvature were found to have relatively minimal impact.

References

Doski, J.A.H., McClay, K.R., 2022. Tectono-stratigraphic evolution, regional structure and fracture patterns of the Zagros fold-thrust belt in the Duhok region, Kurdistan, northern Iraq. Tectonophysics 838, 229506.

Forti, L., Perego, A., Brandolini, F., et al., 2021. Geomorphology of the northwestern Kurdistan Region of Iraq: landscapes of the Zagros Mountains drained by the Tigris and Great Zab Rivers. Journal of Maps, 17(2), 225–236. https://doi.org/10.1080/17445647.2021.1906339

Jassim, S.Z., Goff, J.C., 2006. Geology of Iraq. Dolin, Prague and Moravian Museum, Czech Republic, p. 341.

Varnes, D.J., 1978. Slope movement types and processes. In: Schuster, R.L., Krizek, R.J. (Eds.), Landslide analysis and control: Transportation Research Board Special Report, Washington, 11–33