

# Integrated Python Workflow for Landslide Susceptibility and Geological Hazard Mapping in South-East Albania

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## Abstract

South-East Albania is characterized by complex geological settings, steep topography, and intense climatic variability, making the region particularly vulnerable to landslides and related geological hazards. This study presents an integrated, fully Python-based workflow for landslide susceptibility and geological hazard mapping, combining spatial analysis, statistical processing, and interactive visualization. A Digital Elevation Model (DEM) was used to derive slope and aspect parameters, while lithology, land cover, and drainage proximity layers were standardized and integrated using a weighted overlay approach based on the Analytic Hierarchy Process (AHP). The resulting Landslide Susceptibility Index (LSI) was classified into five susceptibility levels (very low, low, moderate, high, very high). Using Python libraries such as *rasterio*, *geopandas*, *numpy*, and *matplotlib*, terrain parameters were computed and standardized, while thematic layers were reclassified according to their relative influence on slope instability. The results highlight areas of elevated landslide susceptibility in mountainous and structurally complex sectors of South-East Albania, demonstrating the effectiveness of Python-based geospatial scripting for geological hazard assessment and decision-support applications in spatial planning and risk mitigation.

**Keywords:** Landslide Susceptibility, Geological Hazards, Python, DEM Analysis, Slope and Aspect, GIS, South-East Albania

## Introduction

Landslides represent a persistent geological hazard in South-East Albania, driven by steep terrain, complex lithological conditions, and variable climatic influences. These factors increase the vulnerability of infrastructure and settlements, while effective landslide susceptibility mapping remains essential for hazard assessment and spatial planning. However, many existing approaches rely on fragmented GIS workflows that reduce reproducibility and limit methodological transparency. Landslide susceptibility mapping has been widely studied using statistical, heuristic, and machine learning approaches (Carrara et al., 1999; Guzzetti et al., 1999). Traditional GIS-based methods often rely on semi-manual workflows that reduce reproducibility and transparency. Heuristic weighted overlay methods and AHP-based models remain widely applied in regional susceptibility assessment (Saaty, 1980; Van Westen et al., 2003).

Recent studies in Albania (Muceku et al., 2014; 2018) have addressed slope stability and hazard zonation; however, most approaches rely on conventional GIS platforms with limited scripting integration. A clear methodological gap exists in implementing fully reproducible, code-driven susceptibility workflows tailored for regional geological conditions in South-East Albania. This study analyses landslide susceptibility in South-East Albania using an integrated Python-based geospatial workflow. The research examines the spatial influence of key environmental and terrain-related factors, including slope, aspect, lithology, land cover, and drainage proximity. All thematic layers are processed and standardized within a single open-source scripting environment, allowing consistent data handling and analytical control.

The objective of this research is to evaluate the applicability of Python scripting for geological hazard mapping through a reproducible and transparent methodology. By implementing a weighted overlay approach, the study assesses the effectiveness of a unified, code-driven framework for generating interpretable landslide susceptibility maps suitable for conference-level scientific communication and practical hazard assessment.

## Data and Method

The area of interest was South-East Albania, a region characterized by rugged mountainous topography, structurally complex lithological units, and active geomorphological processes. The study area includes zones with steep slopes and dense drainage networks, where landslide occurrence represents a significant geological hazard affecting infrastructure, settlements, and land-use planning.

The landslide susceptibility assessment was implemented through a structured, five-stage geospatial workflow developed entirely within a Python scripting environment. The procedure integrates terrain analysis, factor standardization, multi-criteria weighting, index computation, and classification into susceptibility zones, following principles commonly adopted in heuristic landslide modeling approaches (Aleotti & Chowdhury, 1999; Van Westen et al., 2003).

In the first stage, terrain parameters were derived from the Digital Elevation Model (DEM). Slope gradient (in degrees) was calculated using raster-based gradient functions, while aspect was derived from directional derivatives of elevation values. Slope is widely recognized as one of the most influential conditioning factors in landslide occurrence, as increasing slope angles directly affect shear stress and gravitational instability (Guzzetti et al., 1999). Aspect was included to account for differential solar exposure and soil moisture variability, which may influence weathering intensity and vegetation cover.

In the second stage, all conditioning factors were standardized to a common ordinal susceptibility scale ranging from 1 (very low) to 5 (very high). Slope values were classified into five intervals (0–5°, 5–15°, 15–30°, 30–45°, >45°), reflecting increasing instability potential with steeper gradients. Lithological units were reclassified according to their mechanical strength and weathering susceptibility, assigning higher scores to weak, clay-rich, or flysch formations. Land-cover classes were ranked based on their stabilizing or destabilizing influence, with sparse vegetation and bare soil receiving higher susceptibility values. Drainage proximity was calculated through buffer analysis, with shorter distances to streams associated with higher susceptibility due to erosion and toe undercutting effects. The reclassification scheme follows heuristic multi-criteria approaches commonly applied in regional landslide susceptibility mapping (Aleotti & Chowdhury, 1999).

In the third stage, factor weights were determined using the Analytic Hierarchy Process (AHP) developed by Saaty (1980). A pairwise comparison matrix was constructed to evaluate the relative importance of each conditioning factor. Slope was assigned the highest weight (0.35), followed by lithology (0.25), drainage proximity (0.20), land cover (0.15), and aspect (0.05). The normalized eigenvector method was used to derive the final weights, and the consistency ratio (CR) was calculated to verify the logical coherence of the comparisons. A CR value below 0.1 confirmed acceptable consistency, in accordance with the methodological criteria proposed by Saaty (1980). The application of AHP in landslide susceptibility studies has been widely documented as a transparent and interpretable weighting strategy (Van Westen et al., 2003). The fourth stage involved the computation of the Landslide Susceptibility Index (LSI). The index was calculated as a weighted linear combination of standardized factors:

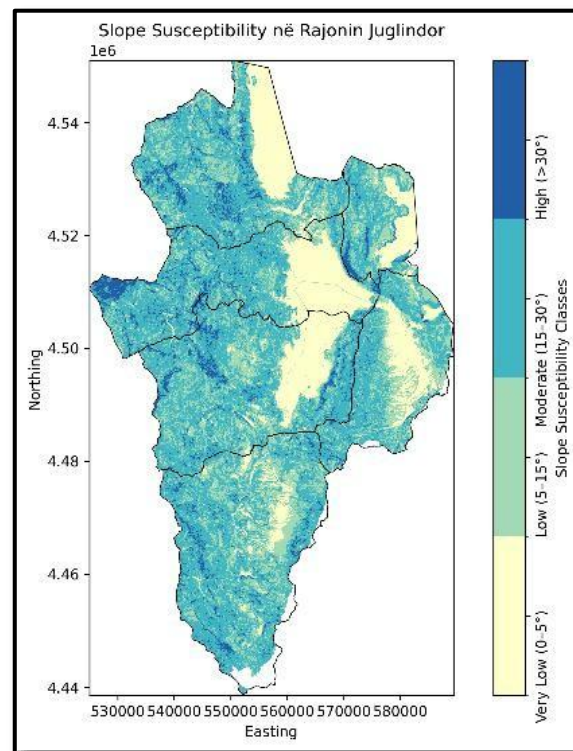
$$LSI = \sum (W_i \times X_i)$$

where  $W_i$  represents the weight assigned to factor  $i$  and  $X_i$  represents the standardized susceptibility class of that factor. This weighted overlay approach allows integration of heterogeneous datasets into a single continuous susceptibility surface, consistent with established GIS-based heuristic methodologies (Carrara et al., 1999; Guzzetti et al., 1999).

In the final stage, the continuous LSI raster was classified into four susceptibility zones—low, moderate, high, and very high—using the natural breaks (Jenks) optimization method. This classification approach minimizes within-class variance and maximizes between-class differences, producing spatially coherent susceptibility zones suitable for hazard interpretation and spatial planning applications.

Overall, the workflow combines established heuristic susceptibility modeling principles with a fully reproducible Python-based implementation, enhancing methodological transparency while maintaining consistency with classical landslide hazard assessment frameworks described in the literature (Aleotti & Chowdhury, 1999; Van Westen et al., 2003).

All raster layers were converted to floating-point arrays and aggregated pixel-by-pixel using matrix-based weighted linear combination in Python (NumPy), ensuring full computational transparency of the susceptibility index calculation.



**Fig. 1.** Slope Susceptibility Map for South-eastern Albania.

## Results

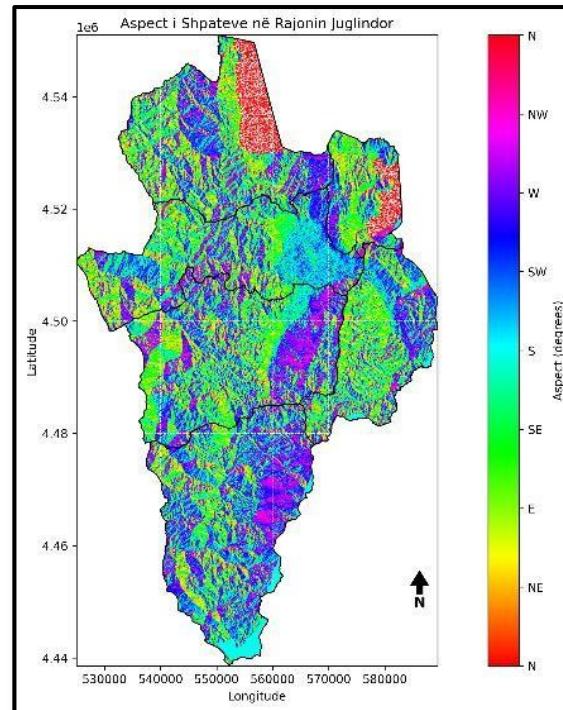
The analysis produced a detailed landslide susceptibility map for South-East Albania, highlighting areas with varying levels of slope instability. Terrain analysis from the DEM revealed that the steepest slopes are primarily concentrated along the mountain belts, with slope values exceeding critical thresholds for landslide occurrence (Fig. 1). Aspect analysis indicated that south-facing and southeast-facing slopes are more susceptible, likely due to a combination of sun exposure and soil moisture dynamics (Fig. 2).

The integration of lithology and land-cover data showed that areas underlain by weak or unconsolidated rocks, such as flysch and clay-rich formations, combined with sparse vegetation, exhibited higher susceptibility. Proximity to drainage networks further increased the likelihood of slope failures, particularly along narrow valleys and riverbanks.

The weighted overlay method allowed the combination of all contributing factors into a

landslide susceptibility index, classifying the study area into low, moderate, high, and very high susceptibility zones. The results indicate that the **most critical landslide-prone areas are located in mountainous sectors and along drainage corridors**, while lower susceptibility zones coincide with gentler slopes and more stable lithologies.

Overall, the workflow successfully identified spatial patterns of landslide risk, demonstrating that **Python-based geospatial analysis can produce reproducible, interpretable, and interactive susceptibility maps** suitable for hazard assessment and spatial planning.



**Fig. 2.** Slope Aspect Map for South-eastern Albania.

## Conclusion

We conclude that landslide susceptibility in South-East Albania is strongly controlled by slope steepness, lithology, land cover, and proximity to drainage networks. Steep slopes, weak or unconsolidated rock formations, sparse vegetation, and areas near rivers show the highest landslide potential.

The integrated Python-based workflow proves to be an effective, reproducible, and transparent approach for geological hazard mapping, allowing the combination of multiple spatial factors into a single susceptibility index. The resulting maps provide clear guidance for identifying high-risk zones, supporting hazard assessment, land-use planning, and disaster risk reduction strategies.

We recommend that future studies incorporate temporal factors such as rainfall events and land-use changes to further refine susceptibility predictions and enhance the applicability of the models for early warning and mitigation purposes.

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