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Editorial

Landslide Hazard and Environment Risk Assessment

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1. Introduction

Landslides are among the most widespread and frequent natural hazards that lead to fatalities, socioeconomic losses, and property damage globally [1,2]. These phenomena also play essential roles in landscape evolution and occur in relation to peculiar predisposing factors (i.e., morphology, lithology, geological setting, land use, climate, etc.) and to triggering events (i.e., extreme rainfall events, earthquakes, wildfires, etc.) [3–6]. According to Varnes [7] and Cruden [8], a "landslide" can be defined as the movement of a mass of rock, debris, or earth downward and outward of a slope under the influence of gravity. The range of landslides is particularly wide, making them one of the most diversified and complex natural phenomena with impacts on territories in all geographic areas. The definition of their affectable areas and recurrence is complicated since they are linked to complex mass movements and to the difficulty in deriving historical data. Instead, discriminating the spatial distribution of potentially unstable areas can be easier by assessing the likelihood of landslides occurring in a region based on the local environmental conditions [9]. Spatial occurrence can be inferred from numerous approaches such as inventory-based mapping, deterministic and probabilistic techniques, heuristic approaches, statistical analysis, and multi-criteria decision-making analysis [10–12]. As a result, it is crucial to follow stepwise approaches mainly involving geomorphological field activities, remotely sensed analysis, numerical modelling, and innovative GIS techniques in order to provide correct landslide hazard assessments and zonation and to support best practices for long-term risk mitigation and reduction.

Given the above scenario, the overall goal of this Special Issue was to present innovative approaches for the analysis and mapping of landslide dynamics, mechanisms, and processes. In the collected papers, readers will find a compendium of scientific contributions providing a sample of the state-of-the-art and forefront research in landslide hazard assessment. Each article offers valuable advancements in scientific approaches for landslide susceptibility mapping and slope stability at the local and regional scales, highlighting new ideas and innovations in analysing various mass movements (e.g., DGSDs, snow avalanches, shallow landslides, and complex and historical landslides).

2. Overview of the Special Issue

This Special Issue reports scientific improvements in landslide hazard and environmental risk assessment with contributions written by authors from Italian regions and other countries, facilitating the interest of an international audience of readers. In detail, it contains 12 peer-reviewed papers focused on (i) methodologies for landslide susceptibility mapping, (ii) slope stability and environmental risk management in mass movement-prone areas, and (iii) multidisciplinary approaches for landslide analysis in different geomorphological/morphostructural environments.

2.1. Methodologies for Landslide Susceptibility Mapping

Zhou et al. [13] developed a landslide susceptibility map at the national level in Kenya. First, a hierarchical evaluation index system containing ten landslide contributing factors

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and their subclasses was established to produce a susceptibility map. Then, the weights of these indexes were determined through pairwise comparisons. The landslide inventory and landslide causative factors used in this study were collected from various sources. Triangular fuzzy numbers (TFNs) were widely employed to scale the relative importance based on experts' opinions. The entire Kenyan territory was divided into five susceptibility levels, highlighting regions in which further studies were conducted to improve planning and land resource management.

Tavoularis et al. [14] developed a landslide susceptibility map for the entire area of the Attica region (Greece) using the Rock Engineering System (RES). This semi-quantitative heuristic methodology was applied through an interaction matrix. Ten parameters, selected as controlling factors, were statistically correlated with the spatial distribution of slope failures. The generated model was validated using historical landslide data, field-verified slope failures, and a prototype technique developed by the Oregon Department of Geology and Mineral Industries. The resulting data allowed for the construction of an updated geodatabase and the definition of susceptibility levels, representing the basic steps in producing upcoming landslide hazard and risk maps.

Polykretis et al. [15] developed a hybrid landslide susceptibility model for the vicinity of the Pinios artificial lake (Ilia, Greece). In a GIS-based framework, the model was defined by integrating two different statistical analysis models: the multivariate Geographical Detector (GeoDetector) and the bivariate information value (IV). A landslide inventory of 60 past landslides and 14 conditioning factors was incorporated in the model and used to compose the spatial database. The resulting data confirmed the performance of GeoDIV in the definition of the spatial distribution of zones of potential landslides over the study area. The produced LS map represents a basis for regional or local authorities to develop both general (long-term) and emergency (short-term) strategies.

Abraham et al. [16] focused on the factors affecting landslide susceptibility mapping. Five different Machine Learning (ML) algorithms were used to investigate the Wayanad district in Kerala (India), involving different sampling strategies and training datasets. The results show that Naïve Bayes (NB) and Logistic Regression (LR) algorithms are less sensitive to the sampling strategy and data splitting. In contrast, the performance of the other three algorithms—Random Forest (RF), K Nearest Neighbors (KNN), and Support Vector Machine (SVM)—is considerably influenced by the sampling strategy. Hence, as shown in the final H-index plots, both the choice of algorithm and the sampling strategy are critical in obtaining the best-suited landslide susceptibility maps.

2.2. Slope Stability and Environmental Risk Management in Mass Movement-Prone Areas

Segoni and Caleca [17] proposed a new set of environmental indicators for the fast estimation of landslide risk at national scale. Italy was chosen as a test case. Landslide susceptibility maps and soil sealing/land consumption maps were combined to derive a spatially distributed indicator (LRI—Landslide Risk Index). Using GIS techniques, LRI was aggregated at the municipal scale to define the Average Landslide Risk index (ALR) and the Total Landslide Risk index (TLR). The proposed indexes cannot substitute a detailed quantitative risk assessment; nevertheless, they can provide a preliminary overview of the spatial distribution of landslide risk, offering valuable information to each Italian municipality in planning sustainable urban growth.

Moradi et al. [18] presented a multi-method approach of site characterization combined with field observation and a hydromechanical model. A failure-prone hillslope near Bonn (Germany) was chosen as a study site. The field investigation allowed for constructing a three-dimensional slope model with geological units derived from drilling and refraction seismic surveys. Mechanical and hydraulic soil parameters were derived from laboratory analysis; water dynamics were monitored through geoelectrical monitoring. The work presents a potential workflow to improve numerical slope stability analysis through multiple data sources and outlines the usage of such a system for a site-specific early warning system.

Emeka et al. [19] focused on the effect of hydroseeded vegetation for slope reinforcement. The article introduces vegetation establishment as a low-cost, practical measure for slope stability through the ground cover and the root of the vegetation. The study was conducted within the UPM, a government tertiary institution in Serdang, Selangor, Peninsular Malaysia. Twelve conditioning factors were used through the Analytic Hierarchy Process (AHP) model to produce a landslide susceptibility map. Four seed samples, namely ryegrass, rye corn, signal grass, and couch, were hydroseeded to determine the vegetation root and ground cover's effectiveness in stabilizing a high-risk susceptible slope, suggesting variable landslide control benefits.

Fazzini et al. [20] performed a multidisciplinary analysis of detailed climatic and geomorphological data integrated with GIS techniques to advance the snow avalanche hazard assessment. Mass movement phenomena widely affected the Prati di Tivo area (Abruzzo Region, Central Italy) with its well-developed tourist facilities. The resulting data properly defined the main steps for developing a risk mitigation protocol. It involved the provision of new data about the geomorphological setting of the study area and the definition of a technical-scientific basis for civil protection plans required to increase the knowledge of citizens and interested stakeholders about proper land management considering multi-hazard scenarios (i.e., snow avalanches and landslides).

2.3. Multidisciplinary Approaches for Landslide Analysis in Different Geomorphological/Morphostructural Environments

Demurtas et al. [21] focused on the evolution of deep-seated gravitational slope deformations in East Sardinia (Italy). Their article highlights the connections between Plio-Pleistocene tectonic activity and geomorphological changes in Pardu and Quirra River valleys. The use of LiDAR, high-resolution uncrewed aerial vehicle digital photogrammetry (UAV-DP) and geological–geomorphological surveys enabled a depth morphometric analysis and the creation of interpretative 3D models. Multi-source and multi-scale data showed that the state of activity of the DGSDs is closely related to uplift and geomorphological processes. It is recorded by geomorphological indicators, such as fluvial captures, engraved valleys, waterfalls, and heterogeneous water drainage.

Aringoli et al. [22] focused on a geomorphological hazard analysis in an active tectonic area. The Sibillini Mountains (Central Italy) sector was chosen as the study area for the complex tectonic-structural setting, recent seismic sequences, and evident traces of huge landslides. An aerophoto-geological analysis and geomorphological survey verified the link between gravitational occurrences and in-depth tectonic-structural elements. The resulting data show the relationship between tectonic structures, critical hydrogeological conditions, and high-relief energies versus huge gravitational movements. Moreover, these relationships could also play a significant role in differentiating the risk associated with seismic and hydrogeological events.

Materazzi et al. [23] contributed to evaluating the best procedure to be implemented for Landslide Hazard Assessment (LHA), comparing the results obtained using two different approaches (geomorphological and numerical). The area chosen for the analysis is located in a high hilly sector of the Adriatic side of the Central Apennines (Italy), characterized by monoclinal reliefs and cuesta morphologies formed by differential tectonic movements in a recent uplift area. Although preliminary, the results clarify the two different methods' role, usefulness, and limits. Moreover, they demonstrate how a combined approach can certainly provide mutual advantages by addressing the choice of the best numerical model through direct observations and surveys.

Esposito et al. [24] focused on the relationships between the morphostructural/geological framework and landslide types in the hilly piedmont area of the Abruzzo Region (Central Italy). A detailed analysis of three selected case studies was carried out to highlight the multitemporal geomorphological evolution of each landslide phenomenon. Historical landslides were analysed using an integrated approach combining literature data and landslide inventory analysis, relationships between landslide types and lithological units, detailed photogeological analysis, and geomorphological field mapping. The resulting data defined some advances in the understanding of the spatial interrelationship of landslide types, morphostructural setting, and climate regime in the study area.

3. Conclusions

Landslides are global geomorphological phenomena that occur in all geographic regions in response to many predisposing and triggering factors. Directly and indirectly, they impact territories, causing fatalities and huge socioeconomic losses due to environmental degradation and rapid population growth. Consequently, to support sustainable territorial plannings and operative activities, there is a clear need for valid land-use policies, and best long-term risk mitigation and reduction practices. The contributions to this Special Issue represent valuable scientific advances in geomorphological field activities, satellite remote sensing, landslide susceptibility mapping, and numerical modelling, offering practical support for mapping and monitoring of landslide dynamics at both the local and regional scales. All landslide types have been considered, from DGSDs to complex and historical landslides, from rockfalls to debris flows, and from slow-moving slides to shallow landslides. The results described in each article allow for the definition of mitigation activities needed to manage permanent settlements, recreation infrastructures, buildings, and ski facilities. Each paper provides a scientific and methodological basis used to support the idea that landslide hazard assessments must be accurately defined to help local administrations, decision-makers, and interested stakeholders in land planning, emergency planning, and protecting the environment and human life.

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