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Editorial

Landslide Monitoring and Mapping

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1. Special Issue Aims

Landslides are a major natural hazard, a worldwide problem with direct and indirect consequences, causing fatalities, colossal socio-economic damage [1,2] and environmental degradation [3]. The word *landslide* defines a multifaced typology of events characterized by different materials and velocities of movement, having various impacts on society and causing multiscale damage to man-made structures [4]. Population growth and continuous urban expansion often force populations to migrate towards landslide-prone areas, which are also expanding due to global climate change effects and uncontrolled anthropogenic pressure. This dramatic increase in the number of geo-hydrological disasters highlights the importance of being proactive in developing technologies for identifying, modeling, and characterizing landslide-prone areas. This is possible by taking advantage of a continuous exchange of knowledge between the authorities in charge of environmental risk management and the scientific community [5,6]. Studying landslides and their state of activity is key to identifying areas that could be affected by damaging events in the near future. Several tools and techniques to achieve this goal have been developed, and they differ in accuracy, precision and time delay. Several well-known and cutting-edge remote sensing approaches are used to monitor the territory to identify geomorphological variations or ongoing deformations. In addition, traditional and ever more sophisticated instruments are being installed in situ to monitor and characterize landslide-prone areas to forecast and ultimately model deformations. These applications will also allow more correct land use policies and best practices to be developed for long-term risk mitigation and reduction. The derived information can be useful to risk management actors, land managers, or local stakeholders in making conscious decisions on civil protection matters and properly allocating funds [7].

This Special Issue collates scientific papers that cover the following topics: (i) traditional and ground truth approaches, (ii) remote sensing techniques, (iii) combinations of ground- and satellite-based techniques, and (iv) innovative computing platforms to manage and process huge volumes of data. These methods and technical advances can be used for the following applications: (i) mapping landslides over large areas, (ii) monitoring land phenomena using traditional instruments and methods, (iii) estimating landslide susceptibility and landslide risk, (iv) defining local- and regional-scale applications for landslide post-event rapid mapping, and (v) evaluating the interactions between landslides and other hazards (triggering, increased probability, and catalysis/impedance).

2. Overview of the Published Paper

The first edition of the Special Issue, “Landslide Monitoring and Mapping” (with the second edition concluded a few months ago and the third forthcoming) collates eleven articles: two reviews, three technical studies, and six research articles.

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2.1. Spatial Distribution and Issues Covered

The articles published in this Special Issue encompass research from Europe, Central Africa [8], and South America [9]. Additionally, a global review on the role of the root reinforcement in slope stability models was included [10] (Figure 1a). More specifically, Italy was one of the most researched countries, with three examples focusing on the Alpine Arc [11], the Nuvole di Morra landslide in the Municipality of Città di Castello (Umbria Region, Central Italy) [12], and the Valle d'Aosta Region [13]. Another article detailed the Vögelsberg landslide in Austria [14]. Five articles each addressed the problem of mass movements in the Harz Mountains in Germany [15], Florina prefecture in Greece [16], Bujumbura Hillslope in Burundi [8], the Vercors Massif in France [17] and the Upper Gudbrandsdalen in Norway [18].

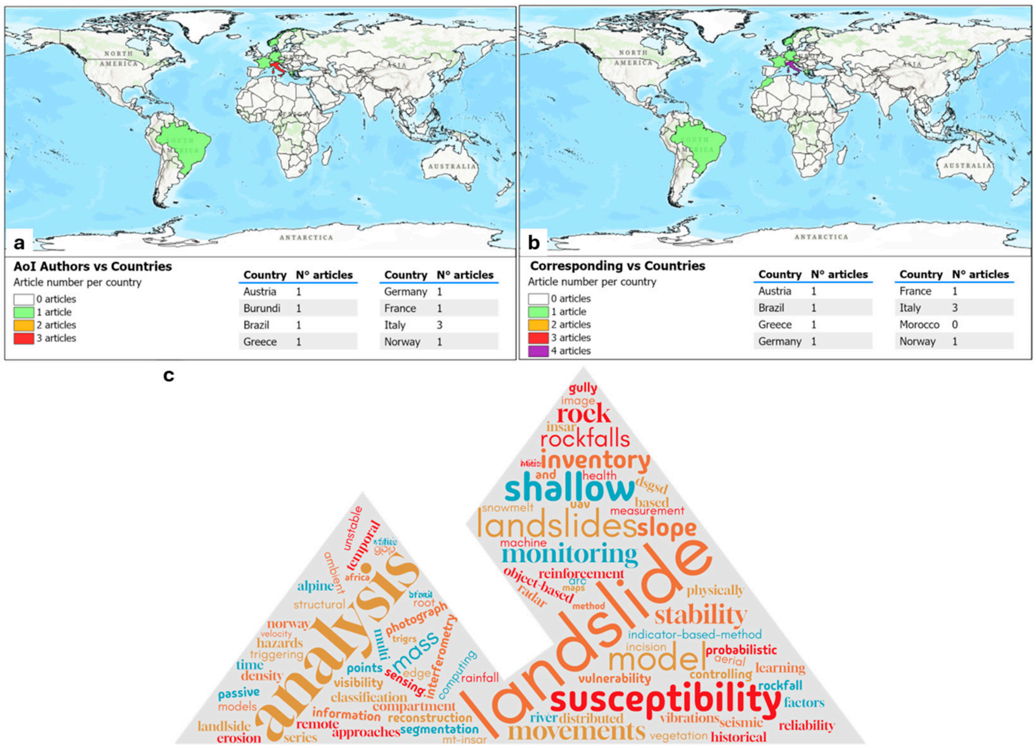

Figure 1. Areas of interest versus countries (**a**), nationality of the corresponding author affiliations versus countries, (**b**) and word clouds of the keywords (**c**) from the articles published in this Special Issue.

Almost all areas of interest were investigated by corresponding authors from the same country with the following exceptions: a global review on root reinforcement presented by an team of Italian authors, a study on the analysis and characterization of landslides in Burundi published by Moroccan authors, and a team of African and Belgian researchers (Figure 1b).

An analysis of the keywords from the published studies reveals a wide variety of terms with low frequency (Figure 1c). The few words that were repeated in different articles as keywords are "landslides" and "shallow landslides" as well as "landslide inventory", "rockfalls", and "mass movements". All other keywords were only found once since most of the terms refer to the techniques and methods applied.

2.2. Article Content

The research published in this Special Issue are focused on different themes: (i) characterization and modeling for understanding and forecasting events in landslide-prone areas in different climatic settings, (ii) tools for the generation of radar satellite visibility, (iii) innovative edge-computing solutions for monitoring unstable rock compartments and rockfall vulnerability methods, (iv) demonstrative studies on the potential use of UAV data for landslide mapping and investigation, and (v) approaches for determining velocity for shallow landslides and rockfalls at a large scale. In addition, a review of worldwide papers published during the period of 2015–2020 dealing with root reinforcement and an overview of landslide susceptibility mapping in Brazil were included.

As detailed in the first review [10], over the course of 5 years of monitoring, the research focus on the mechanical role of the root system in slope stability models has increased. Thirty-nine scientific studies were collected and analyzed, and the modeling of root systems was found to be the most common research focus (61.5%). It is worth noting that vegetation strongly affects the behavior of soil, mainly in shallow landslides, and from a mechanical and hydrogeological perspective, it plays a crucial role in the stability of slopes. Additionally, vegetation has a positive impact on increasing the level of security against hydrogeological hazards for people, structures, and infrastructure. The role and the level of influence of vegetation and roots in slope stability remains an open-ended issue among the scientific community, and modeling their role is a real challenge. The review concludes that the challenging research in the field of slope stability models, which includes the role of roots, is experiencing a progressive expansion of applications at different scales, but the estimation of root reinforcement at the regional scale represents one of the main limits for its complexity in modeling and in comparative analysis with the other soil components and conditions.

The second review published in this SI focuses on landslide susceptibility mapping in Brazil [9], where the methods and input data used for 33 articles (research articles and proceeding papers) were analyzed, considering both English and Portuguese articles. The majority of this research (57.6%) focuses on the southern and south-eastern regions of Brazil. It demonstrated a high heterogeneity of adopted methods and input variables, suggesting a necessity to homogenize datasets on a national scale for more comparable or reproducible results.

Studies on models of rainfall-induced landslides are widespread among the scientific community. In this SI, a physical-based model, Transient Rainfall Infiltration and Grid-based Regional Slope stability (TRIGRS), is applied in a case study of the upper Gudbrandsdalen Valley in southeastern Norway [18]. The authors aimed to establish a reliable and reproducible procedure to identify input parameters for an investigation across large areas by testing the TRIGRS on the June 2011 and May 2013 landslide events.

A forecasting model was also presented by Volpe et al. [12], who focused their attention on the evaluation of potential slope instability after rainfall events and assessed the relevance of the impact of appropriate probability density functions (pdfs) on the probability of Failure (PoF) estimation. This scientific postulate was demonstrated through the application of a physical-based probabilistic model in the study area of Nuvole di Morra village (Città di Castello municipality, Central Italy), which is affected by landslides and where detailed geotechnical data were available. The authors concluded that, in terms of PoF, a concrete definition of pdfs is necessary when different and random parameters are applied.

An interesting study on the Vibration-Based Structural Health Monitoring (VB–SHM) monitoring technique, which relies on a modal analysis of structures, was presented by Bottelin et al. [17]. The goal was to evaluate the feasibility of monitoring unstable rock compartments by analyzing the cost-benefit ratio of the proposed technique. The authors applied the innovative VB-SHM approach to analyze a portion of the Vercors Massif (composed of limestone and marl) in southeastern France using a three-component seismic system during the bolting of a limestone rock column. The test yielded positive result for the case study, suggesting a preliminary survey for applications at other sites to investigate potential characteristic resonance effects.

An estimation of the rockfall susceptibility and the vulnerability of the road network in the Harz Mountains in the Central Uplands of Germany was presented [15]. Vulnerability was assessed using an indicator-based method, while susceptibility used a bivariate statistical approach. The two results show discrepancies: vulnerability exhibits high values on the south-west and north sector of the road network, while high susceptibility was identified for 23% of the western part of the Harz Mountains.

The research collected in the SI focusing on Africa shows a much more accurate record of landslide processes with respect to the previously available literature [8]. It could have high relevance for land management and disaster risk reduction strategies. An updated landslide inventory was developed for the populated hillslopes around Bujumbura, in Burundi. In total, 1286 landslides and gullies with landslides of different types and states of activity were identified, demonstrating that more than 20% of the landscape is affected by various slope failures. Several deep-seated landslides were identified as being triggered by various causes, such as earthquakes and changing climate conditions.

Karantanellis et al. [16] analyzed different segmentation and classification scenarios using integrated Object-Based Image Analysis (OBIA) on Unmanned Aerial Vehicles (UAV) data. Their study, which focused on the old lignite open pit site in Florina prefecture, north-western Greece, demonstrated that UAVs can support landslide mapping investigation due to the frequency, cost, and spatial resolution of the collected images and timely acquisition after the occurrence of landslide events. In the case study, the combination of UAV data, a Structure from Motion (SfM) approach, and machine learning allowed two rotational landslides to be recognized and mapped and their thematic sub-zones to be characterized.

Marinelli et al. [13] presented a study focusing on the estimation of fast landslides (shallow landslides and rockfalls) in the Valle d'Aosta Region (NW Italy) using an approach developed in a Geographic Information System (GIS) environment and based on morphometric parameters. The approach was based on the Heim method [19] and applied to the whole region. It required only the landslide polygons and a Digital Elevation Model to extract morphometric information and landslide velocity. A validation of the model was derived from the Gravitational Process Path model [20].

Aside from the diffusion of the InSAR (Interferometric Synthetic Aperture Radar) technique for mapping and monitoring landslides worldwide, only two studies focused on this remote sensing approach. The first study [11] presented GIS tools for the preliminary investigation of radar satellite visibility across large areas. The main innovation of this study, in addition to developing ArcGIS tools to semi-automate the procedure for generating visibility maps, was the introduction of shadow and layover masks, derived in the Sentinel Application Platform (SNAP) [21] and a Corine Land Cover (CLC) mask. The tools were tested along the Alpine Arc of Italy. The software used was made available by the authors and can be found in the Supplementary Materials of the manuscript [11].

The second study [14] focused on the kinematic and geometric characterization of slow-moving landslides by using Multi temporal-InSAR (MT-InSAR) data from the Vögelsberg rockslide and Wattens municipality in Tyrol (Austria), which reoccurred in 2016, causing several damages. For this purpose, MT-InSAR time-series data were decomposed in North, East and Up directions using the Breaks For Additive Seasonal and Trend (BFAST) [22]; the results were also correlated with the Automated Geodetic Tracking Total Station (ATTS). The earth and rock mobilized volume as well as a sliding surface were approximated with a 3D model applying the Vector Inclination Method (VIM) [23].

3. Future Expectations

In the next edition of these Special Issues (Vol. II and Vol. III), the expectation is to receive manuscripts that focus on the following topics:

- modelling new technologies to identify and monitor slope instability and deformations, as well as back analysis, to understand the triggering causes and evolution along time for avoiding further damaging or catastrophic events;
- the application of more precise and sophisticated sensors and additional upcoming space and UAV missions, (including radar, multi-spectral, hyper-spectral, and HR sensors), combined with the possibility of reducing the revisiting time and processing

time, as well as the gap between acquisition and availability of data, will help to enhance the identification and forecasting of possible events.

- the significant use of Citizen Science (the active participation of the public in scientific research through data collection) and Internet of Things (a network of interconnected devices and sensors that communicate and share data wirelessly).

With the increased availability of modern data at higher spatial and temporal resolutions, we might soon expect a regular integration of physical-based and numerical-based studies to improve the precision of simulations and predictive modeling.

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