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# Introductory Chapter: Importance of Investigating Landslide Hazards

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## 1. Introduction

Natural disasters, like earthquakes, volcanic eruptions, intense rainfall, and anthropogenic factors, such as deforestation, contribute to slope failure, either by decreasing resisting forces or increasing driving forces of the soil mass [1]. Landslides are strongly related to steepness of the slope, soil moisture/water content of the soil layer, climate factors that increase the water content of the soil, and other anthropogenic factors and can be triggered by earthquakes, volcanoes, and floods. However, most of the slope failures are preceded by intense rainfall and wet antecedent soil moisture conditions [2–4]. Often aggravated by rapid and uncontrolled development, landslides, either large or small, which happen every year in mountainous regions around the world [5, 6].

To better understand and manage the potential landslides, it is essential to know the location and size of potential slope failures [7]. However, it is a difficult task to predict precise size and location of the possible landslides. Since slope failure is a complex phenomenon, it requires an in-depth understanding of slope failure mechanisms and monitoring techniques.

It is necessary to collect/obtain high-resolution spatial information of the soil layer, topography, hydrologic conditions, geotechnical characteristics, and land use/land cover types to investigate landslide, including mapping, detection, monitoring, analysis, prediction, and others. Since slope failures commonly occur in the hilly region, especially in steep terrain, so it is rather challenging to obtain high-resolution data in conducting landslide studies [8, 9].

It is always recommended to obtain in-situ measurements for an accurate landslide study. However, such in-situ measurements are time-consuming and require complex data collection efforts even on local scales [2, 6]. Recently, remote sensing data and spatial analysis tools are widely used in landslide studies, including landslide detection, assessment, hazard, mapping, and inventories [10–12]. Remote sensing data makes it possible to conduct landslide studies, not only at inaccessible terrain but also at regional to global scale, which otherwise is not possible using in situ measurements.

## 2. Importance of information of historic landslides

Data archives of national projects, besides constitute a sort of historical encyclopedia, they also represent a potential operational support tool useful and functional for planning and managing territorial and mitigation policies for landslide risks.

The awareness that territorial planning and emergency plans can provide significant information from historical data series on localities and areas previously affected by hydrogeological disasters have recently stimulated the international

scientific community to systematically collect data on landslides and floods [13]. Landslides, statistically, represent, after earthquakes and other external driving forces of natural disasters, which cause the most significant number of victims and damages built-up areas, infrastructures, environmental, historical, and cultural assets.

In particular, those which cause the most damage are fast-moving landslides (rockfalls, rapid mudflows, and debris flows), as well as those which involve large volumes of rocks or soils. Several landslide investigation projects, economically supported by public agencies, tended to focus mainly on phenomena that caused significant or evident damages (preferably occurring in urban areas or correspondence with linear infrastructures). They often neglected some landslides, even a substantial entity, which had not affected or interacted with built-up areas, communication routes, or infrastructures.

Historical memory helps play a fundamental and decision-making role that can be recovered and used through integrated methodological approaches. The collection of historical data aimed at knowledge and mapping of the instabilities allows us to complete and improve the information obtained with normal geological-geomorphological analysis, better defining fundamental aspects for assessments of danger and vulnerability of the region.

### **3. Global landslide information**

Knowledge of past landslides of a region, in terms of the occurrence of the event, controlling factors, and trigger conditions, are the main needed factors to evaluate spatial and temporal probabilistic hazard [14]. Therefore, the use of published and unpublished historical sources (federal, municipal, provincial, and state archives, publications, newspapers, press reviews, technical reports, photographs, and videos) can provide essential frameworks to understand the impact of hazard events over time in the areas monitored and evaluated during the new surveys.

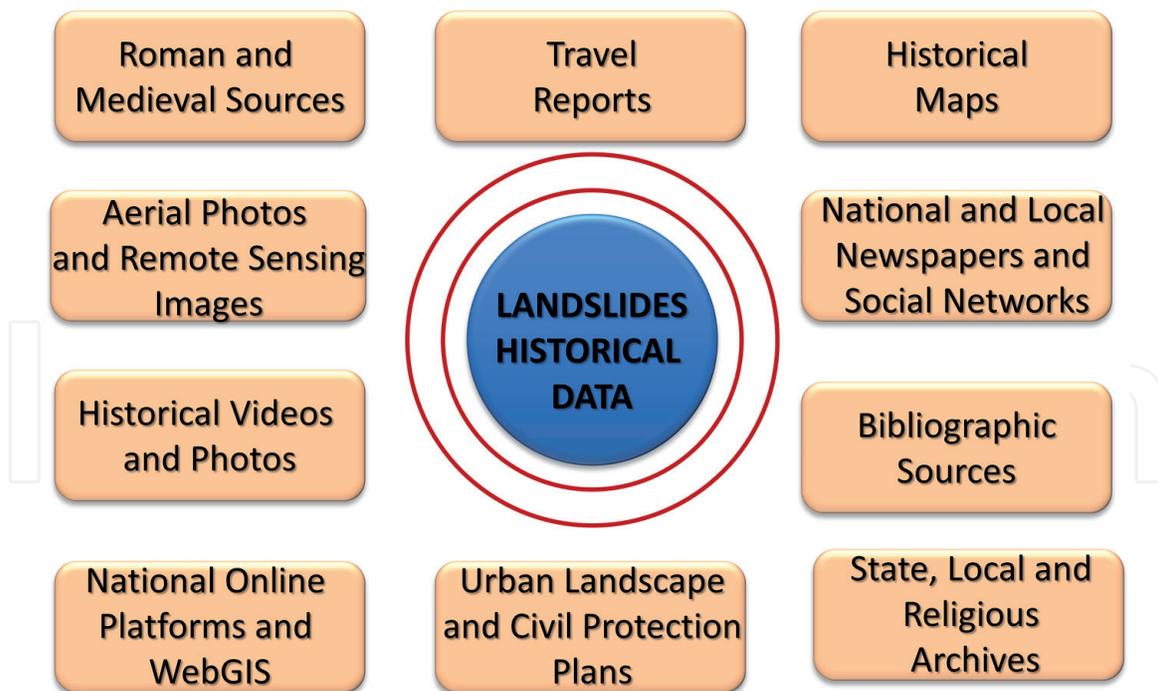
Historical information can be grouped into four categories:

1. Direct recorded changes or natural events, such as droughts, floods, landslides, and erosion rates;
2. Indirect data used to determine causes or explain patterns, such as historical rainfall series;
3. Other data that provides additional information, such as geological maps;
4. phenomenological data that may change with time (e.g., the response of aquifers to wet seasons).

The types of information available from local archive data of ancient inscriptions, annals, historical chronicles, private funds, ecclesiastical funds, newspapers, iconographies, magazines, monographs, old postcards, cartographies, and videos (**Figure 1**) are broad and may differ from place to place.

The data obtainable from these sources is extensive and vital but requires control and validation of the news and associated information, such as geographical (e.g., location, municipality, street) and temporal ones (exact day, time, etc.) or climatic conditions (rainfalls mm/h, local measurement stations, etc.).

The historical-environmental analysis uses documentary information to reconstruct impact scenarios of natural events of the past on the environmental and



**Figure 1.**  
*Synthesis of the remarkable diversity of historical documents potentially available to carry out geologic hazard analysis by integrating the present-day scenarios and data.*

anthropic context of the time [15]. A fundamental method of interpreting historical information is to bring it back to its cultural, political, and economic context. The degree of reliability of data is, in fact, directly proportional to the knowledge, more or less in-depth, of this context.

## 4. Factors affecting landslides

There are numerous internal and external forces, natural and anthropogenic factors that trigger landslides [16–19]. The primary natural and anthropogenic factors that triggered landslides are outlined below.

### 4.1 Natural factors

*Topography* - Steep terrain

*Gravity* - slope failure due to gravitational forces

*Geological*- weathered/sheared/susceptible materials

*Morphological*- fluvial/glacial/wind erosion of slope toe, tectonic, volcanism

*Heavy and Prolonged Rainfall* -

*Hydrological*- rise in the groundwater table, flooding, rapid snowmelt

*Earthquakes* - ground vibrations created during Earthquakes

*Climate* – cause series of natural disasters (e.g., drought, floods, storm, hurricanes, etc.)

### 4.2 Anthropogenic factors

*Deforestation* – enhance soil erosion and surface runoff

*Overloading Slopes* – increase surcharge load

*Mining and Quarrying Activities* – increase instability

*Construction* – increase instability

The driving forces of landslides are physical/geological, morphological, and human in nature. Globally, the prominent causes of landslides are geological in nature and rainfall-induced. Landslides occurring majorly in mountainous and coastal terrains have also occurred in plains, which can be such as failures of the roadway and building, in addition to quarries and open-pit mines. These are sometimes the resultant effects of heavy rainfalls, volcanic eruptions, earthquakes, and droughts. Some areas are susceptible to landslides due to human activities affecting vegetation and topography. This also happens in places where wildfires occur.

Landslides are unpredictable. For example, landslides can occur due to human activities or non-human activities that affect slope stability [20]. Geological factors may account for 43% of landslides. This includes the impact of gravity on the topography of sloped areas, water pressure, weak soil formation, etc. The morphological causes, such as volcanic pressure, underground erosion, climate factors, vegetation elimination, crest accumulation. Human activities, such as excavation, irrigation, mining, deforestation, and slope encroachment, also enhance slope instability [21, 22]).

Kazmi et al. [21] investigated 11 landslide events in Malaysia and summarized water movements, weak safety management, heavy downpours, inadequate slope protection, damaged drainage, flawed design, and construction were some of the underlying factors that triggered landslides. Singh and Singh [23] found urbanization as a contributing factor for the risk of landslides and hazards. They discussed one of the most famous landslide events in the history known as Frank Slide. The Frank Slide of Turtle Mountain of Canada occurred in 1903 and generated 82 million tons of limestone. The primary cause of this landslide was the geology of the mountain because weak rock and stones were covered by limestone rock. Another factor was the weather event prior to the landslide, which was more snowy than usual, which allowed snowmelt and rain to permeate the mountain. The resistance forces of the rocks were more weakened beyond bearable limits. Pal et al. [24] reviewed several other landslide events and found intense rainfall as a common triggering factor for these landslide events. Since the causes of landslides across the world are multi-faceted, more advanced researches are necessary to investigate the triggering factors of landslide events.

## **5. Landslide investigation: recent trends and techniques**

Landslide investigation has been promoted by the International Decade of Natural Disaster Reduction (IDNDR, 1990–2000) proclaimed by the United Nations, when working groups on landslides were established (e.g., International Landslide Research Group (ILRG)). In addition, recent advances in landslide investigations include real-time monitoring, modeling, prediction, and assessment, which are helping communities and end-users to be better prepared to face potential landslide threats [25]. During the past three decades, tremendous developments have been made to investigate landslides. The investigation of Landslides has been carried out using surface and subsurface methods comprising qualitative and quantitative approaches. Although the wide range of applied geophysical techniques were used in landslide investigations, primarily these are grouped into two main classes: remote sensing techniques, which can be used to characterize the Earth's surface, and sub-surface techniques, which characterize geological surface by using non-destructive approaches [26]. In addition, an integrated approach combining satellite, airborne, and ground-based sensing, is widely used to investigate landslides [27, 28]. The wide range of remote sensing data from various optical

and microwave synthetic aperture radar (SAR) sensors and the increased temporal and spatial resolution provides new opportunities to investigate landslides at a range of scales [26, 29].

Some other advancements for landslide investigation are the use of in-situ geophysical techniques and electrical resistivity tomography (ERT), which can be used for landslide detection [27]. The interferometric techniques, which include Multi temporary interferometry (MTI) and advanced synthetic aperture radar differential interferometry (DInSAR) techniques, can be used to extract information on ground surface deformations. Also, interferometry SAR (InSAR) data combined with Unmanned Aerial Vehicle (UAV) images and aerial photography can be used to investigate slow-moving landslide [30]. Recently, application of UAV is growing to monitor rapidly occurring landslides and mapping in inaccessible terrains [31, 32].

Machine learning techniques are also getting popular in evaluating and detecting landslides [33, 34]. In addition, the use of artificial intelligence (AI) technique is growing to investigate landslides, such as landslide susceptibility mapping, characterization, and prediction [35].

Currently, remote sensing technologies are used in landslide monitoring, mapping, hazard prediction and assessment, inventory and detection, and other investigations. Some of the key technological advancements for investigating landslides outlined by Petley [26] are as follows:

*Digital imaging* – Digital photogrammetry to capture image of landslides.

*Optical satellite sensors* – Many commercial satellites are providing high spatial resolution data to study landslides (e.g., GeoEye-1 (0.4 m); Quickbird (0.6 m)).

*Google Earth* – An important tool for visualization and analysis.

*Radar satellite sensors* – Radar techniques allow to accurately determine the small landslide movement.

*Terrestrial laser scanners (TLS)*- The TLS, a ground-based LiDAR, mainly used to collect field data on steep unstable terrains.

*Airborne LiDAR* – A little expensive to collect data; however, it is widely used to collect high spatial resolution data to study landslides.

*Engineering geophysics* – This geophysical technique is widely used and applied to evaluate the sub-surface environment of landslides in 3D and in real-time.

## 6. Concluding remarks

Landslide, a catastrophic disaster, has been on the rise due to the impact of natural and anthropogenic, such as climate and land use/land cover change, and growing population. Landslides are common around the world, especially in mountainous regions. Since landslides are a severe threat to lives and properties, it is essential to understand the physical processes, causes of landslides, movement characteristics, and potential risk factors. It is also vital to study landslides, which helps understand landslide mapping, prediction, monitoring, and risk assessment to reduce the impact of landslides. However, such in-depth landslide investigations require advanced technologies, robust methods, models, and high resolution spatial data, which includes in-situ and/or remotely sensed measurements globally.

While a high resolution data is required for landslide investigation, the potential landslide area is mostly inaccessible, which limits for in-situ measurements. Although recently, the application of satellite for landslide studies is growing, high spatial and temporal resolution satellite data are still limited on a global scale. Regardless of recent advancements in landslide studies, more research efforts, advanced

technologies, and tools, high resolution spatial and temporal data, and effective management, awareness, and policy are needed in landslide research. It will help address the impact of future human activity, climate change, land use/land cover change on landslide hazards from local to the global scale.

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