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An Overview of Landslide Management: Scope, Difficulties, Limitations with Future Directions and Opportunities

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Absract

This study thoroughly examines the challenges, limitations, and future directions encountered in landslide management in the literature. Similar to other disasters, landslides pose significant threats to the normal flow of life, infrastructure, and the environment, necessitating effective management strategies. The reduction and/or prevention of damages caused by landslides are achievable through both physical and non-physical methods. In this context, this study discusses and extensively explores the scope of damage reduction efforts while delving into landslide management. Furthermore, this study highlights various challenges faced in landslide management, such as limited resources, technical expertise, and data availability, while offering sustainable approaches for landslide disaster management within the insights of landslide management approaches. Additionally, it proposes a comprehensive approach that combines effective landslide management, mitigates the impacts of these natural disasters, and integrates community participation with policy support. Moreover, it emphasizes the importance of landslide management studies considered as "alternative management strategies" that merge various tools and approaches to provide a more comprehensive solution and are regarded as alternatives to existing traditional approaches.

Keywords: Disaster, Management Landslide Hazard, Landslide Management, Landslide Risk, Landslide Susceptibility

1. INTRODUCTION

Landslides are one of the most common natural disasters worldwide, affecting millions of people each year. Between 1998 and 2017, landslides caused over 18,000 deaths and affected an estimated 4.8 million individuals (URL 1). In addition to the loss of life and property, landslides also result in significant environmental damages, such as soil erosion, deforestation, and habitat destruction (Derin Cengiz and Ercanoğlu, 2022). Given the frequency and severity of landslides, effective management of landslide risks is crucial for safeguarding human lives and reducing the destructive impacts of landslides. Landslide management expresses the set of efforts and strategies aimed at reducing the risk and impact of landslides and includes a wide range of approaches, such as hazard assessment, monitoring and early warning systems, emergency response planning, and mitigation measures. Effective landslide management requires a comprehensive understanding of the physical, social, and economic factors that contribute to landslide risk, as well as to implement appropriate preventions that are arranged to specific contexts and needs. The scope of landslide management is broad and encompasses a range of activities and strategies. Generally, landslide management aims to reduce the risk of landslides

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through various preventions such as improving land-use planning, taking prevention measures, to improve support slope stability, and promoting public awareness and education. Additionally, it involves monitoring landslide activity and providing early warning to communities at risk of landslides. This comprehensive approach helps to mitigate the damaging effect of landslides by reducing the loss of life and property damage.

Despite the importance of landslide management, there are various challenges that can hinder its effectiveness, especially in low-income and developing countries where resources are limited, and the lack of reliable data and information for landslide hazard assessment and decision-making can lead to uncertainties. This can make it difficult to implement comprehensive landslide management strategies.

While landslide management often focuses narrowly on engineering and technical solutions (such as slope stabilization and drainage improvements), it can be considered as a limited approach as it fails to address the social, economic, and environmental factors contributing to landslide risks. In addition to these challenges, one of the limitations in current landslide management approaches is the tendency to prioritize short-term reactions over long-term planning. This can result in a focus on emergency response and mitigation measures rather than understanding the underlying causes of landslide risks. Moreover, existing approaches to landslide management often prioritize practices that may lead to inadequate risk communication, exclusion of vulnerable communities from decision-making processes, and unsustainable utilization of natural resources, relatively neglecting social and economic considerations. Despite these challenges and limitations, there are successful landslide management projects that provide examples of effective approaches to reduce landslide risk. By implementing comprehensive and integrated landslide management strategies encompassing social, economic, and environmental aspects, sustainable landslide management can be achieved.

2. SCOPE OF LANDSLIDE MANAGEMENT

Landslide management essentially encompasses technical and non-technical approaches, as well as preventive measures taken before a landslide event and activities during and after landslides, including prevention, mitigation, and/or intervention strategies that can be employed. The primary objective of landslide management is to reduce risks and thereby minimize the detrimental effects on people, properties, and the environment. To achieve this goal, it requires a comprehensive and integrated approach that involves multiple stakeholders and addresses different stages of landslide hazard management, ranging from risk assessment and planning to emergency response and recovery. In this context, the scope of landslide management can be divided into several main approaches, including:

- Landslide susceptibility mapping: The initial step in landslide management involves identifying and mapping landslide-prone areas, which entails collecting and analyzing data related to factors causing and triggering landslides. Landslide susceptibility mapping is a fundamental requirement and a critical stage as it aims to identify the most vulnerable areas against future landslides based on local physical conditions or predispositions (Fell et al., 2008; Vojteková and Vojtek, 2020).

- Hazard identification and mapping: This process involves identifying and mapping areas that pose a threat to human life due to landslides, defining the probability of landslide occurrence for specific regions, areas, and/or timeframes (Glade, 2001). In this regard,

landslide hazard maps are essential steps in landslide management and serve as valuable sources of information for land-use planning.

- Risk assessment and management: Landslide risk assessment and management entail determining and interpreting the level of risk, deciding whether it is acceptable or not, and identifying and implementing appropriate measures to reduce the risk when the level is deemed unacceptable (Ho et al., 2000; Dai, Lee, and Ngai, 2002).

- Emergency response and recovery: Effective emergency response and recovery plans are crucial for minimizing the damaging effects of landslides on people, properties, infrastructure, and the environment. Despite mitigation efforts, landslides can still occur and cause destructive impacts. Therefore, intervention and recovery strategies are critical steps. These processes include the establishment of early warning systems, the development of evacuation plans, the provision of emergency shelters and supplies, rescue operations, assistance to affected communities, and the restoration of infrastructure, among many other practices aimed at mitigating these hazards.

- Institutional and governance arrangements: Effective landslide management encompasses the development of policies and regulations (taking into account the physical characteristics of the region, socioeconomic context, political and institutional environment, etc.) that promote sustainable land-use practices. It involves coordinating the actions of various institutions and organizations (government agencies, private sector organizations, non-governmental organizations, volunteers, academic institutions, and local communities), enhancing the capacity of local communities to manage landslide hazards, and addressing different stages of landslide hazard management through transparent institutional and governance arrangements that involve multiple stakeholders.

3. DIFFICULTIES IN LANDSLIDE MANAGEMENT

Landslide management is a complex and multifaceted field that involves numerous challenges, including physical, social, economic, and political factors, similar to other random variable disasters.

Some of the key challenges in landslide management include:

I. Lack of data and information (inadequate availability of comprehensive and reliable data on landslide hazards and their impacts for each region),
II. Limited resources (including significant financial and technical resources, as well as trained personnel and technical expertise, which can be limited, particularly in low- and middle-income countries),
III. Complex and dynamic hazards (due to the presence of various factors such as geology, topography, vegetation, weather patterns, etc.),
IV. Rapid urbanization and land-use changes (changes in land use, rapid urbanization, alteration of natural environment, increase in population and infrastructure in landslide-prone areas, etc.),
V. Limited public awareness and participation (involving active engagement processes of stakeholders, including local communities, government institutions, private sector organizations, and civil society groups),
VI. Climate change (including changes in rainfall patterns, increased frequency and intensity of extreme weather events, fluctuations in soil moisture levels, etc.),
VII. Political and institutional factors (institutional and governance regulations, etc.).

It requires the collaboration of expert teams with advanced theoretical knowledge and practical skills in different fields for various types of disasters and different stages of disaster management (Varol and Kaya, 2018; Kaya, 2022). In this context, landslide management will benefit from increased investments, the development of effective land-use planning and regulations, the creation of public awareness and participation, as well as addressing the underlying social, economic, and political factors influencing landslide hazards, and fostering collaboration among various sectors and stakeholders. This multidisciplinary and integrated approach will ensure effective landslide management.

4. CASE STUDIES

Some case studies highlighting the scope, challenges, and limitations of landslide management in the literature are discussed below:

Oso Landslide, Washington, USA

The Oso landslide, which occurred on March 22, 2014, in Oso, Washington, is one of the devastating landslides resulting in significant loss of life and property (URL 2, Figure 1). The landslide debris blocked the North Fork Stillaguamish River and caused the destruction of approximately 40 buildings and structures. It also resulted in the loss of 43 lives (URL 2). The factors contributing to the landslide included intense rainfall and the presence of a glacial deposit weakening the soil, among other geological factors (URL 3). This tragic event highlights the importance of landslide management, especially in areas with complex geology and topography, and emphasizes the challenges it entails. Following this disaster, the government and local communities focused on implementing various prevention measures to manage future landslide risks, including the development of landslide inventory maps, hazard assessments, and mitigation measures such as slope stability and land-use planning. The roots of the Oso catastrophe stemming from previous landslides (URL 2) demonstrated the importance of inventory and sensitivity mapping for landslide management (Gökçeoğlu and Ercanoğlu, 2001). In this context, the Oso landslide highlighted the significance of comprehensive approaches in landslide management, including hazard assessment and mitigation measures, as well as the importance of sustainable management approaches and proactive measures. It also underscores the need for collaboration and coordination among stakeholders, including governments, communities, and practitioners, in developing effective landslide management strategies.

Figure 1. A view from Oso Landslide (Wartman, et al. 2016)

Sidoarjo Mudflow, Indonesia

A mud volcano in the Sidoarjo district, East Java, Indonesia, has been spewing hot mud and gases (URL 4). The Sidoarjo Mudflow, also known as the "Lusi eruption" started on May 29, 2006. Its muck is inundating an ever-increasing area in the region (URL 4). The Sidoarjo Mudflow, a massive flow of hot mud, has since buried several villages and caused significant damage to properties and infrastructure (Fig. 2). Different opinions exist about the cause of the disaster. There are many scientists supporting the "drilling hypothesis" which contends those drilling activities caused the disaster. On the other hand, there are views attributed to the "earthquake hypothesis" in the literature, suggesting that the eruption of the mudflow was triggered by an earthquake that occurred in the nearby city of Yogyakarta two days earlier (URL 4). Understanding and managing the Sidoarjo Mudflow, which displaced thousands of people, has been challenging due to the complex nature of the eruption and the intense human activities in the region. The mudflow has caused significant population displacement and complicated land-use planning. Additionally, the impact of the eruption on livelihoods (such as damage to industries like agriculture and tourism) has led to significant economic consequences.

The Sidoarjo Mudflow disaster in landslide management has indicated the need for a multidisciplinary and comprehensive approach, particularly in areas with high population and human activities. It has also highlighted the necessity for effective communication and collaboration among stakeholders to develop sustainable management strategies that consider the socio-economic impacts.

Figure 2. A view from Sidoarjo Mudflow (URL 5)

Maoxian Landslide, China

The Maoxian landslide occurred in Xinmo village, located in Mao County, Sichuan Province, China. It took place on June 24, 2017, and resulted in the loss of 83 lives (Hu et al., 2018). It was a fast-moving flow-like rockslide characterized by strong rock fragmentation and basal sliding (Fig. 3) (Hu et al., 2018). The Maoxian landslide is a landslide disaster that highlights the challenges of landslide management in remote and mountainous regions. Due to the remote nature and limited infrastructure of the area, providing access and assistance to the affected communities has been extremely difficult.

The case study of the Maoxian landslide emphasizes the importance of preparedness and resilience in landslide management, particularly in high-altitude and mountainous areas (Fan et al., 2017). Nonetheless, monitoring and prevention of similar collapses in mountainous areas must be carried out to protect human lives and infrastructures (Fan et al. 2017). This case study also highlights the need for proactive prevention measures at landslide management such as early warning systems and the development of emergency response plans.

Figure 3. A view from Maoxian Landslide (URL 6)

Sierra Leone Landslide, Africa

The case study of Sierra Leone Landslide, which occurred on August 14, 2017, highlights the impact of climate change on landslide risk. A 6-kilometer mudslide occurred in Regent Area, Western Area District of Sierra Leone (Fig. 4), following a torrential downpour that lasted 3 days (Musoke et al. 2020). More than 300 houses along River Juba were submerged; 1141 people were reported dead or missing and 5905 displaced (Musoke et al. 2020).

The Sierra Leone Landslide is a tragic example of the impact of climate change on disasters. The region has experienced a significant increase in precipitation in previous months, which is thought to be linked to climate change (URL 7 and 8). The heavy rains caused the saturation of the soil, leading to the landslide. Managing the Sierra Leone Landslide has been a significant challenge for the government and communities. This landslide was the worst disaster that occurred in Sierra Leone in decades, and it overwhelmed the government's response capacity. Since 40% of Sierra Leone's population live in urban areas comprising poorly constructed slums, disaster-related health risks also remain a key concern in the country (URL 9).

The Sierra Leone Landslide case study highlights the need for developing effective landslide management strategies that consider the impact of climate change. It also underscores the importance of investing in preparedness and response capabilities to manage the risk of landslides effectively. It has come to light by this disaster again that affected communities also need international support to help cope with the socio-economic implications of major disasters like the Sierra Leone Landslide.

Figure 4. A view from Sierra Leone Landslide (URL, 10)

Koyulhisar (Kuzulu) Landslide, Turkey

On 17 March 2005, a catastrophic landslide occurred in the North of the Kuzulu district of Koyulhisar (Turkey) (Yilmaz et al. 2006). This landslide caused widespread loss of life, and damaged to buildings, and lifelines, so fifteen people died and five were injured, 21 houses were covered and damaged severely (Yilmaz et al. 2006). Landslide area is highly mountainous and wooded, and is located in the North Anatolian Fault Zone (NAFZ). The landslide initiated as a collapse, and developed into debris avalanches in the valley (Fig. 5) and the landslide area is highly mountainous and wooded, and is located in the North Anatolian Fault Zone (NAFZ) (Yilmaz et al. 2006). A second landslide occurred on March 22, 2005 and some of the houses that survived after the first landslide were completely buried under the ground as a result of this event (Ulusay, Aydan and Kılıc, 2007).

After the landslide, the work of many rescue teams with construction equipment did not yield any results; As the landslide continued during the search operations, the teams risked being underground several times (URL 11). Despite all the efforts of the teams, the work was stopped because the risk of landslide continued in the region and the accumulated land mass reached 20 million cubic meters (URL 11).

This demonstrates that the potential of landslides to turn into unpredictable multiple disasters. Moreover, a future earthquake, which may occur in the region, may result in a complete failure of the unstable mass remaining at the source area (Ulusay, Aydan and Kılıc, 2007). This disaster highlighted that disaster preparedness, planning, and risk management need to be improved in Turkey, particularly in areas prone to landslides and other natural hazards.

Figure 5. A view from Koyulhisar (Kuzulu) Landslide (Yilmaz et al. 2006).

5. LANDSLIDE RİSK MANAGEMENT

There are new and innovative methods considered as alternatives to the existing traditional approaches in landslide management, referred to as "alternative management strategies." These alternative management strategies offer a new vision in landslide management, playing a significant role and providing a range of advantages. Existing management approaches sometimes overly rely on a single technology or method, which can limit achieving effective results. Alternative strategies combine various tools and approaches to provide a more comprehensive solution.

Considering the increasing population pressure and pressures on resources, environmental sustainability and conservation of natural resources have become increasingly important. The preservation and restoration of natural ecosystems provide ecosystem services such as increased biodiversity, erosion reduction, and improved soil stability. The use of these strategies aims to overcome the limitations of traditional management approaches, achieve more effective results, promote the sustainable use of natural resources, and ensure the benefit of future generations. Additionally, community participation and involvement of local stakeholders are vital elements in adopting alternative management strategies. Utilizing local knowledge and experiences facilitates the successful implementation of strategies and encourages active participation of local communities in the management processes.

Alternative management strategies have gained significant attention and importance in the literature, and research has shown their effectiveness in reducing landslide risks and their potential for conserving natural resources. Therefore, implementing these strategies is a crucial step towards more sustainable and effective landslide management. These strategies represent an important focus for future studies, as they contribute to the conservation of resources and the development of more holistic and sustainable landslide management approaches.

The use of a "nature conservation-focused" or "ecosystem-based" approach is important among sustainable alternative management strategies that are in harmony with nature. In this regard, this study particularly emphasizes these two approaches. The nature conservation-focused approach highlights the utilization of natural processes and ecosystem services in landslide management. This approach, by focusing on the functions of the natural environment, envisages the use of natural systems and processes to reduce landslide risks and includes a range of practices such as preserving natural vegetation, promoting erosion-reducing agricultural practices, and ensuring sustainable use of water resources. This perspective implies a preference for natural solutions rather than relying on traditional engineering structures.

5.1. Nature Conservation-Focused Approach

The preservation or restoration of natural vegetation, sustainable agricultural practices, and water management strategies are important in reducing landslide risks. With this perspective, the "Nature Conservation-Focused Approach" encompasses three main focal points:

A. Preservation and restoration of natural vegetation,
B. Promotion of erosion-reducing agricultural practices, and
C. Ensuring sustainable use of water resources.

The preservation and restoration of natural vegetation is an effective strategy in reducing landslide risks (Sandholz, Lange, and Nehren, 2018). Vegetation can reduce soil erosion and the likelihood of landslides. Replanting or seeding erosion-preventing plant species in eroded lands, conserving forest areas, planting native tree species to enhance soil stability, and implementing afforestation projects in erosion-prone areas can reduce soil erosion and decrease landslide probabilities. In other words, by improving soil stability, increasing water retention capacity, and reducing landslide risks.

Traditional agricultural methods can be associated with farming activities that cause soil erosion. However, sustainable agricultural practices such as terracing, erosion barriers, sustainable drainage systems, organic fertilizer use, and the preservation of natural grain cover can enhance soil stability, reduce erosion, and thus decrease landslide risks.

The sustainable use of water resources, which involves the efficient utilization and management of water, is an important approach to controlling soil erosion and landslides. The conservation of water ecosystems and the maintenance of ecosystem services provided by water resources, leading to increased water absorption capacity and the prevention of floods and landslides.

Wetlands or forests with high water absorption capacity can absorb and store rainfall, reducing excessive runoff. This approach enables the reduction of landslide risks through the resources, natural processes, and functions provided by ecosystems. Additionally, it helps create a natural barrier to prevent soil erosion. Ecosystem services refer to the benefits provided by natural ecosystems, including their resources and functions. Furthermore, natural ecosystems support biodiversity, provide habitat, and ensure the healthy continuity of ecosystems, playing a critical role in reducing landslide risks alongside sustainable use.

Various studies have shown that ecosystem services are an effective strategy in reducing natural disaster risks, such as landslide management and mitigating soil erosion.

6. CONCLUSIONS

As mentioned in the article, there are 2 groups of factors that increase the risk of landslides: economic vulnerability and environmental vulnerability. While poverty, unemployment, and debt can be listed under economic vulnerability; quarrying, which leaves the land barren and susceptible to landslide, deforestation, and the type of soil in the area are the environmental vulnerabilities.

In order to reduce these risk factors, the following methods can be used:

1. Conducting a ground analysis before constructing, so that a suitable foundation can be made.

2. Public training: Public training activities would increase the community awareness of the hazard and what they can do to mitigate against risks. It is significant to mention that not only public awareness and education, but also emergency preparedness and response are extremely essential for capacity building and training.

3. Building retaining walls in areas that are prone to landslides.

4. Enforcing policies regarding the use of proper building codes when constructing structures.

5. Providing incentives and financial help to individuals with special needs, so that they would have the finances to build more resilient buildings (URL-12).

The assessment of landslide hazard, vulnerability, and risk; multi-hazard conceptualization; landslide prevention measures, research and development of early warning and monitoring are necessary for systematic and coordinated management of landslide hazards.

Additionaly, for regulation and enforcement, measures such as reinforcement of floor slabs and external walls in existing buildings, installation of drainage pipes for rainwater, slope drainage, and also planting of slopes that are vulnerable to landslides with deep-rooted trees and shrubs are considered to be highly necessary and crucial.

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