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Landslides: Challenges and Mitigation Strategies

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ABSTRACT

Landslides are among the most significant natural hazards worldwide, causing extensive financial and human losses and destroying natural resources annually. Therefore, comprehensive investigation of these hazards is an unavoidable requirement for future human life. A landslide is a natural disaster that claims human and animal victims every year. In addition to loss of life, landslides cause millions of dollars in financial damage globally. According to NASA records, the highest numbers of landslides occurred in Brazil, India, China, Peru, Afghanistan, Nepal, Indonesia, and the Philippines between 1900 and 2011, resulting in heavy human and financial losses (USGS, 2014). A landslide is the movement of a portion of earth materials and is a general term for the downward movement of rock fragments and detached masses under the influence of gravity. This process operates on sloping lands and may cause the destruction of houses and facilities, blockage of roads and rivers, and in some cases, when its volume is enormous, it can create a disaster. Afghanistan, due to its high mountains, rugged relief, severe physical erosion, and its location in the Mediterranean–Indonesian seismic belt—especially in the central and northeastern regions—has a high potential for fall and landslide processes. The present study aims to identify the types of landslides, their triggering factors, control methods, and mitigation strategies. This research employs a library-based methodology, including descriptive and analytical approaches. The findings indicate that recognizing the type of landslide and its triggering factors is the first and most important step in reducing associated risks. Furthermore, the implementation of geotechnical, physical, and biotechnical measures can significantly mitigate landslide hazards. The study concludes with recommendations for relevant authorities to allocate specific budgets for landslide hazard assessment and mitigation across Afghanistan.

KEYWORDS

landslide, hazard potential, control, slope, geological characteristics, mitigation

ARTICLE INFORMATION

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1. Introduction

Geologists, engineers, and other specialists often have unique and somewhat different definitions of landslides. This diversity in definitions reflects the complex nature of many disciplines related to the study of the landslide phenomenon. There is still no single definition of a landslide, because specialists in each discipline have defined this phenomenon according to their own field of work.

For example, from a geological perspective, the movement of materials on slopes, or a landslide, is a mass movement process that occurs under the influence of Earth's gravity and a number of accelerating factors at the base of slopes and inclines. However, from a structural engineering perspective, a landslide is a technical problem for which geotechnical measures must be taken to eliminate and control it (Mohammad & Waezi, 2020).

Landslide and rockfall are examples of the movement of a portion of earth materials and are general terms for the downward movement of rock fragments and detached masses under the influence of gravity. This process operates on sloping lands and may cause the destruction of houses and facilities, blockage of roads and rivers, etc., and in some cases, when its volume is enormous, it can create a disaster. Among the factors that create and activate this phenomenon are severe erosion along rivers and waterways, high slope of sediments on the sides, lack of strong bonding between rock particles, heavy rainfall, and increased water between rock pores in sediments. Human activities such as excavation and road construction, construction activities on sloping areas, cutting

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trees and vegetation cover, infiltration of water from sewage wells, artificial irrigation, etc., can also activate and accelerate landslides (Moore, 1989).

A landslide includes all processes of material movement on sloping and unstable slopes. This process can occur at various scales, from a small area to very large areas. The occurrence of landslides is not always free of financial and human losses; it is always associated with harmful losses. For this reason, various and numerous factors can currently be considered as triggering factors for landslides. At present, developing countries, especially those exposed to this natural disaster, have invested and continue to invest heavily in studying landslide-prone slopes. Mapping areas at risk of landslides is one of the important and fundamental tasks of geological engineers. Various methods exist worldwide for this purpose, including the new method of remote sensing, whose basis is the use of electromagnetic waves and satellite imagery (Bolt, Horn, Macdonald, & Scott, 1977).

Landslides occur more frequently in areas with higher annual rainfall, or on sloping areas lacking vegetation. A landslide is the unwanted displacement of rock masses on the slopes of steep areas that lack vegetation cover. When soil or materials on sloping areas become saturated with rainwater and snow, the internal bonds between particles are destroyed, and depending on the slope of the area, under the influence of gravity or earthquake activity, they move and are displaced from their original location. In other words, it can be said that landslides occur due to the interaction and combined activity of environmental factors in mountainous and steep regions (Sahak, 2016).

Landslides can occur under the influence of various factors, for example: geological factors (type of lithology of the area, distance from tectonic fractures), hydrological factors (distance from the sea, amount of rainfall in the area), topographic factors (elevation of the region, slope angle, slope direction, curvature of layers), land-use factors (land cover of the area), and other factors (distance from roads, temperature of the region), etc.

To control and reduce the risks caused by landslides, the first and most important step is recognizing the type of landslide. As mentioned above, landslides can occur under the influence of different factors; therefore, according to the understanding and recognition of the type of triggering factor, preventive and mitigation methods can be applied and implemented to control and reduce landslide risks in a given location (Fakhri, 2019).

1.1 Research Objectives

The objective of this scientific article is to identify the types of landslides and also the methods of controlling and reducing the risks caused by them. The following objectives are included in order:

1. What is a landslide?
2. Types of landslides
3. Triggering factors of landslides
4. Necessary measures to reduce risks caused by landslides
5. Effects or consequences of landslides

1.2 Importance of the Research

Given that today natural hazards have become a fundamental and major problem for human societies, and humanity suffers irreparable losses and damages in this regard, it is necessary to study and investigate this natural disaster in detail and comprehensively, so that financial and human losses can be prevented as much as possible. For this reason, assessing landslide potential without knowledge and study of landslides, their types, and their triggering factors is not possible, and necessary measures cannot be taken to reduce the risks caused by landslides.

1.3 Research Questions

The questions we seek to answer through this article are as follows:

1. What process is referred to as slope movement or landslide?
2. Which factors and elements play a role in causing landslides?
3. The hazard potential of which type of landslide is greater?
4. Can the hazard potential of landslides be reduced or minimized using geotechnical methods?
5. How severe are the losses and damages caused by landslides?

1.4 Research Methodology

Research methodology refers to the method of research. In terms of conducting and completing a research project, methodology consists of three processes or three parts: library method, field method, and laboratory method.

Since the subject of this article is Landslides: Challenges and Mitigation Strategies, the library research method has been used. The library research method involves reviewing reports, scientific works, and books written and published on the subject under study. The library method itself is divided into two parts: descriptive and analytical. The descriptive part includes the study of reports, information, books, articles, and scientific dissertations, while the analytical part involves the analysis, evaluation, descriptive analysis, and quantitative analysis of the collected documents. Both parts have been used to complete this article.

2. Types of Landslides

A landslide is a type of movement of a mass or soil on a sloping or inclined surface. In this section, different types of landslides are described along with illustrations. Understanding and recognizing the types of landslides is an important and highly necessary matter for road construction and building projects, because by knowing the type of landslide, subsequent measures can be taken to reduce the risks caused by it.

2.1 Rock Fall

Rock fall involves the detachment and falling of rock, soil, or both, which are displaced downward on a steep slope under the influence of gravity.

- **Location:** Rock falls usually occur on a steep or vertical slope, or in coastal areas. The volume of falling material can vary greatly, from the fall of a single rock mass to a massive fall of mixed rock and soil materials.
- **Speed of movement:** Rock falls occur very rapidly, because rock masses on steep slopes are displaced with the slightest disturbance and move downward very quickly depending on their volume.
- **Triggering factors:** Cutting steep slopes, excavation, construction, soil removal, and creating vibrations along steep slopes.
- **Direct and indirect effects:** Rock falls can be life-threatening. They directly impact houses and cause fatalities, but in many cases, the indirect effects of rock falls include the destruction of transportation roads, buildings, railways, and power lines.
- **Necessary measures to reduce risks from rock falls:** Construction of protective walls, blasting rock masses, marking and signposting areas prone to rock falls, and preventing house construction in such locations (Kyoji, 2005).

2.2 Slides

A slide is the downward movement of soil or a rock mass that occurs on a sloping surface.

- **Location:** A slide occurs when the sliding materials are homogeneous or uniform and are displaced on sloping surfaces depending on their volume and the influence of gravity. Slides are among the most common movements and displacements of materials and occur on slopes with an inclination of 20–40 degrees.
- **Speed of movement:** Very slow, on the order of 0.3 meters over five years.
- **Triggering factors:** Heavy rains, melting of snow and glaciers increase the volume of materials, which then move down the slope due to the slope angle and gravity. It should be noted that earthquakes are also sometimes a factor in causing slides.
- **Direct and indirect effects:** They can cause damage and financial losses to buildings, structures, and road routes. However, due to the low speed of slide occurrence, they do not pose a serious threat to life. In some places, if the volume is large, they can create dams along water flow paths.
- **Necessary measures to reduce risks from slides:** Water drainage pipes should always be inspected and evaluated, because loose soil and materials are easily triggered by water and cause slides. Therefore, drainage locations should always be checked. In areas where sliding is possible, protective walls should be built; planting seedlings also helps reduce the occurrence of slides (Kyoji et al., 2005).

2.3 Lateral Spreads

Lateral spreads usually occur on very gentle slopes and relatively flat terrain, especially when a firm layer lies over a weak and unstable layer. This movement occurs suddenly along a fracture in a small area and slowly moves away from the fracture location. Such fractures are usually caused by subsidence.

- **Location:** They occur in areas with higher seismic activity. Lateral spreads occur in areas covering a small extent.
- **Speed of movement:** The speed depends on the accelerating factors; accordingly, it can occur slowly or rapidly.
- **Triggering factors:** Saturation of the weak lower layer by rainwater, water from melting snow and glaciers, changes in groundwater levels, plastic deformation of unstable materials (salt), and adding loads beyond the stability limit.
- **Direct and indirect effects:** They can cause significant damage to roads, buildings, and railways. The speed depends on saturation by water.
- **Necessary measures to reduce risks from lateral spreads:** Before construction and road-building activities, the site should be mapped according to its lithological characteristics. In areas where materials are very loose and unstable and are easily saturated by water, becoming fluid-like, construction should be prevented (Kyoji et al., 2005).

2.4 Debris Flows

Debris flows are a form of rapid material movement consisting of soil, gravel, loess, and water. This type of landslide occurs when the above materials mix with water and take on a fluid state.

- **Location:** Debris flows, composed of mud, soil, gravel, and water, can occur in steep valleys.
- **Speed of movement:** The speed depends on the triggering forces and also on the slope of the area. In areas with steep slopes, the speed of debris flows is high, while in areas with low slopes, their speed is low. The presence or absence of vegetation also plays a role in speed (with vegetation, the speed is lower; without it, the speed is higher). Debris flows are

among the fastest movements of materials on steep slopes, with speeds reaching 35 miles per hour or 56 kilometers per hour.

- **Triggering factors:** Debris flows usually occur as a result of heavy rainfall and the melting of glaciers and snow.
- **Direct and indirect effects:** Due to their high speed, debris flows can transport large rock masses with them, making them very dangerous. They can carry a large amount of mixed material downward and cause the destruction of buildings. In addition to destroying buildings, they can affect water quality. In many places, debris flows impact roads, causing destruction or blockage.
- **Necessary measures to reduce risks from debris flows:** Generally, debris flows cannot be prevented. However, construction in such locations should be seriously prevented. If construction is to be carried out in these areas, walls should be built to divert the flow path. Residents should also be informed about such locations (Kyoji et al., 2005).

2.5 Lahars (Volcanic Debris Flows)

The word "lahar" is an Indonesian word referring to volcanic debris flows. These are flows that occur on the slopes of volcanoes.

- **Location:** They occur in almost all volcanic regions of the world. Lahars can cover areas of up to hundreds of square kilometers, and as their speed increases and surrounding materials are added, their area expands.
- **Speed of movement:** Lahars can be very fast (more than 35 miles or 56 kilometers per hour), especially when they combine with water or meltwater from snow and glaciers, which increases their speed.
- **Triggering factors:** Water is among the most important triggering factors for lahars. One of the most dangerous types of lahars is the sudden eruption of volcanic materials in snow-covered areas, because these materials are hot and cause snow to melt rapidly. The melted material, along with snow, rock debris, and water, moves very quickly down the slopes of volcanoes, which is very dangerous and deadly.
- **Direct and indirect effects:** These effects can be very large and destructive, especially when accompanied by volcanic flows and meltwater from snow and glaciers. Due to the high water content and the steep slope of the area, these materials can cause great damage to buildings, houses, roads, and rivers.
- **Necessary measures to reduce risks from volcanic debris flows:** There are no necessary measures to prevent or avoid this type of flow, except that construction should not be carried out in the path of such flows (Kyoji et al., 2005).

2.6 Debris Avalanche

A debris avalanche is a type of flow that is very intense and rapid, occurring on an unstable sloping surface.

- **Location:** It occurs worldwide in unstable sloping environments and also in areas that have been drained.
- **Speed of movement:** Very fast, with speeds reaching up to 100 meters per second.
- **Triggering factors:** Generally, this type of flow is divided into two sub-types: hot and cold. Cold avalanches usually originate from an unstable slope when weathered and unstable materials are present on steep slopes. Hot avalanches occur as a result of earthquake activity or volcanic activity.
- **Direct and indirect effects:** Because these flows are fluid-like and have high speeds, they are very dangerous and deadly. They can destroy houses, facilities, roads, and streets during occurrence, and also disrupt groundwater flows.
- **Necessary measures to reduce risks from debris avalanches:** Avoiding construction in volcanic valleys or steep volcanic areas is the only way to be safe from these hazards. In areas where such an event is possible, warning systems should be installed. It should be noted that there is no way to prevent this type of flow (Kyoji et al., 2005).

2.7 Earth Flow

Earth flow can occur in areas with low to moderate slopes. Earth flow usually occurs in loose soils or clay soils. Clay soil is among the very weak and unstable soils that are easily saturated by water and move very quickly in a fluid-like manner.

- **Location:** Earth flow usually occurs in areas where fine-grained materials and clay soil are widespread.
- **Speed of movement:** Its speed is lower compared to other landslides.
- **Triggering factors:** The most important accelerating factor is the saturation of soils by rainwater and water from melting snow and glaciers. It should be noted that excavation and construction activities are also among the accelerating factors.
- **Direct and indirect effects:** Like other landslides, it causes damage and losses to all facilities and houses.
- **Necessary measures to reduce risks from earth flow:** The most important method to prevent earth flow is to reduce or prevent soil saturation by water. Therefore, areas where drainage is carried out should be carefully monitored. Excavation in these locations should also be prevented (Highland & Bobrowsky, 2008).

3. Landslide Risk Reduction Measures

3.1 Pre-Landslide Measures

a. Do not build houses near sloping areas, mountain edges, water flow paths (temporary rivers and floods), or near erosional valleys.b. Test or examine the soil of the intended area before construction.c. Plant trees in sloping areas.d. Construct canals and protective walls in areas where there is a risk of mud and debris flow (Margottini & Canuti, 2013).

3.2 During-Landslide Measures

1. If there is no opportunity to take refuge in a safe place, stay inside the building or take shelter beside or under a sturdy table.
2. Moving out of the path of mudflow and landslide is the best action.
   c. Inform neighbors who are at risk
3. Be cautious while driving, because earth walls along roads are more exposed to landslide risk.
4. If you live near a stream or water canal, watch for any rise or fall in water level and for changes in water condition turning into mud. Such changes may indicate a slide in the upper part of the water flow path; therefore, be ready to move quickly and save yourself immediately without taking anything (Margottini & Canuti, 2013).

3.3 Post-Landslide Measures

1. Listen to radio and television news for the latest emergency information.
2. Go to the injured and trapped people near the landslide site, help them, and guide rescuers to their location.
3. Help your neighbors who need assistance, especially the elderly, children, and disabled individuals.
4. Check infrastructure such as water, electricity, etc., as well as damage to roads and railway lines, and if any damage is observed, immediately inform the responsible centers. Reporting potential hazards helps to cut off main water and electricity lines as soon as possible, thereby preventing many potential damages and risks.
5. Consult a geotechnical expert to assess the level of landslide risk in your area or to design appropriate methods for reducing its risk. An informed and specialized person in this field can guide you in adopting the best method for preventing or reducing landslide risk without creating further hazards.
6. Avoid living in areas where there is a possibility of landslides, because there is also a risk of subsequent slides (Sahak & Najaf, 2019).

4. Landslide Control Methods

4.1 Sealing and Cement Injection in Joints and Fissures

One of the most common methods for preventing landslides is this method. To use it, the main water infiltration channels in the sliding mass must first be identified, and then, by constructing waterways and tunnels, the water is directed to another path. Cement injection into joints and other fissures, and sealing or plastic-coating of joints, may be very effective; this was done at the spillway of Kool in the Vanj area of Badakhshan Province, Tajikistan (Fakhri, 2019).

4.2 Retaining Structures

The main objective of all designs is to prevent the movement of sliding masses. To construct successful retaining walls, it is necessary to know precisely the amount of force against which a stability barrier must be created.

4.3 Iron and Concrete Nails, and Use of Bolts and Nuts

This method is common in areas with large, integrated rock masses. After identifying the sliding mass or body, it is drilled and pinned to a larger and more stable body behind it to prevent its sliding.

4.4 Netting (Use of Wire Mesh)

This method is mostly used in areas with scattered rock masses or gravel (stone chips). First, iron-concrete nails are driven into places with greater strength and stability, and then round bars (rebar) are laid in a grid-like pattern over the bare sloping surface (Sahak & Najaf, 2019).

5. Effects and Consequences of Landslides

The occurrence of landslides affects human-made facilities both directly and indirectly. Residential houses built on unstable slopes may experience minor damage to complete destruction in the event of a landslide, because a landslide is caused by the instability of the soil layer, leading to the destruction of foundations, walls, and surface and subsurface facilities. Landslides can affect residential areas on a large regional scale (Milano & Oslo, 2010).

Debris flow is considered among the most destructive types of landslides, because this type of landslide involves the movement of a mass of material as a thick fluid down a sloping surface. Such landslides often occur without prediction, are very fast, and due to their high speed, are very powerful in terms of destructive force, completely destroying whatever lies in their path. However, landslides with lower movement speeds have lower destructive power. It should be noted that whether the speed of a landslide is high or low, it generally causes human and financial losses (Margottini & Canuti, 2013).

Among the most common landslides that claim human lives every year are those that occur along transportation and communication roads. In many cases, in addition to human casualties, they cause the destruction of road routes and blockage of roads (financial losses).

With the increasing global human population, people are increasingly exposed to landslide hazards. Humans tend to move to new lands that in the past seemed very dangerous in terms of natural hazards, but due to population growth, these areas have remained among the habitats for the growing population (Highland & Bobrowsky, 2008).

6. Recommendations

Given the importance and sensitivity of the subject (landslides) in today's world, the following recommendations are made to the relevant departments working in the field of combating natural disasters:

1. Humanity is facing increasing risks of natural disasters, which daily cause financial and human losses worldwide. Therefore, it is recommended that this phenomenon be studied and investigated properly and comprehensively.
2. The occurrence of landslides or slope movements is an instantaneous and unpredictable process, but by studying the geological characteristics of an area, the existence of its hazard potential can be mapped. Therefore, it is recommended that extensive studies be conducted and large-scale mapping be carried out in areas geologically exposed to the risk of this phenomenon.
3. Various factors play a role in causing landslides in a region. Therefore, it is recommended that these factors be studied and identified in areas with landslide potential, and necessary measures be taken to reduce the risks caused by landslides.
4. In areas with landslide hazard potential, it is recommended to use the most effective and economical geotechnical, physical, and biotechnical methods compatible with the region's conditions and sloping terrain, and to take preventive measures before landslide occurrence.
5. Human activities such as house construction and excavation of layers for road construction reduce the stability of layers and decrease their resistance to slope movements. Therefore, it is recommended that unregulated construction of houses and facilities and road construction without considering the slope of layers and the type of sediments be seriously avoided.
6. Losses caused by slope movements are very large and irreparable. Therefore, it is recommended that relevant departments allocate a specific budget to combat slope movements throughout Afghanistan.

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