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Investigation on Causes of Landslides and Mitigation Measures using SPSS

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This study investigates the causes and mitigation techniques for landslides, with an emphasis on the geological, environmental, and human-induced elements that contribute to slope instability. Severe rainfall, seismic activity, deforestation, and uncontrolled land use often trigger landslides, displacing soil, rocks, and debris and posing serious threats to life and infrastructure. The research looks at a variety of mitigation strategies, including technical measures like slope stabilization, retaining walls, and drainage systems, as well as vegetative options like growing ground cover and trees to improve slope stability. Furthermore, the report emphasizes the critical role of monitoring and early warning systems in identifying potential risks. Finally, the report emphasizes the need for land use planning, strict construction rules, and proactive management in mitigating landslide hazards. A multifaceted strategy that integrates these methods is crucial for reducing the effect of landslides while maintaining human and environmental health.

Keywords: Landslide, Slope, Stability, Mitigation.

1. Introduction

Landslides may occur in tropical and subtropical regions owing to variables such as strong monsoons, steep topography, and large deposits of alluvial, colluvial, and residual soil [1-3]. This geological phenomenon regularly occurs in steep or hilly places, causing major property damage and human casualties [4-9]. Only the cautious employment of countermeasures can ensure the safety of vulnerable persons and infrastructure. There is an essential need for research to understand the mechanisms that cause slope collapse as well as a fair evaluation of slope stability in order to design effective slope mitigation strategies. We must perform a detailed examination of the chosen landslide mitigation techniques to strengthen disaster resilience for those vulnerable to slope collapse. The local community's perception of the installed landslide mitigation measures holds significant importance in the field of disaster risk reduction (DRR). Our understanding of the landslide phenomenon has advanced as a consequence of our study of the processes and behaviors of slope materials under severe loads and rains. We use various methods to identify the features of landslides. These techniques involve analyzing landslide processes and the forces that cause them [10, 11], failure mode analysis and modeling [12-17], sensitivity and reliability analysis [18, 19], and developing suitable countermeasures and optimizing their field performance [20]. Socioeconomic studies on landslide challenges, in conjunction with physical science studies, assist in identifying the vulnerability of individuals living on risky slopes, thereby enhancing disaster risk management [21-26].

2. Causes of Landslide

2.1 Natural Causes of Landslide

1. Heavy Rainfall: Excessive precipitation saturates soil, reducing its cohesion.
2. Prolonged Wet Periods: Long-lasting rainfall destabilizes slopes by increasing pore water pressure.
3. Sudden Snowmelt: Melting snow introduces water into the soil, destabilizing slopes.
4. Earthquakes: Seismic activity shakes and loosens rocks and soil.
5. Volcanic Eruptions: Lava and debris flows destabilize surrounding slopes.
6. Tsunamis: Coastal waves erode slopes and cliffs, increasing instability.
7. Undercutting by Rivers: Rivers erode the base of slopes, reducing support.
8. Erosion by Sea Waves: Continuous wave action erodes cliffs and coastal slopes.
9. Frost Action: Freeze-thaw cycles weaken rocks and soil.
10. Wind Erosion: Winds remove finer materials, leaving loose, unstable particles.
11. Weak Rock Formation: Rocks like shale or clay-rich soils are prone to failure.
12. Overloading by Accumulated Materials: Snow, debris, or volcanic ash increase slope weight.

13. Weathering: Natural degradation weakens rocks and makes slopes unstable.

14. Landslide-Triggered Landslides: Movement in one slope destabilizes nearby areas.

2.2 Anthropogenic (Human-Induced) Causes of Landslide

1. Deforestation: Removing vegetation decreases slope stability by eliminating root reinforcement.

2. Mining and Quarrying: Excavation activities disrupt geological stability.

3. Road Construction: Improperly designed roads cut through slopes, increasing failure risks.

4. Unplanned Urbanization: Housing developments on unstable slopes increase landslide risks.

5. Overburdening by Infrastructure: Excessive load from buildings, dams, or roads destabilizes slopes.

6. Agricultural Activities: Poor farming practices such as over-irrigation lead to soil saturation.

7. Improper Waste Disposal: Dumping heavy waste materials destabilizes natural slopes.

8. Artificial Reservoirs: Water impoundment alters hydrology, triggering slides.

9. Improper Drainage Systems: Poorly designed drainage causes waterlogging on slopes.

10. Blasting and Explosions: Vibration from explosives weakens slopes.

11. Land Reclamation Projects: Altering natural landscapes disrupts slope balance.

2.3 Climatic and Environmental Causes of Landslide

1. Intense Cyclones and Storms: Extreme rainfall events rapidly destabilize slopes.

2. Droughts and Soil Drying: Prolonged droughts cause soil shrinkage, which destabilizes slopes when followed by rain.

3. Global Warming: Changes in precipitation patterns and melting glaciers exacerbate landslide risks.

4. Permafrost Thawing: Warming temperatures destabilize frozen slopes, causing landslides.

5. Vegetation Loss Due to Fire: Wildfires destroy root systems that stabilize soil, making slopes vulnerable to erosion.

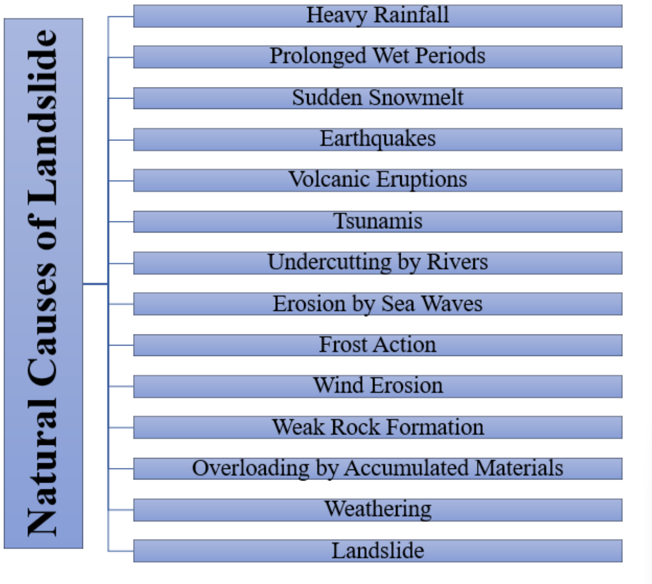

Fig. 1. Natural Causes of Landslide

Fig. 2. Anthropogenic (Human-Induced) Causes of Landslide

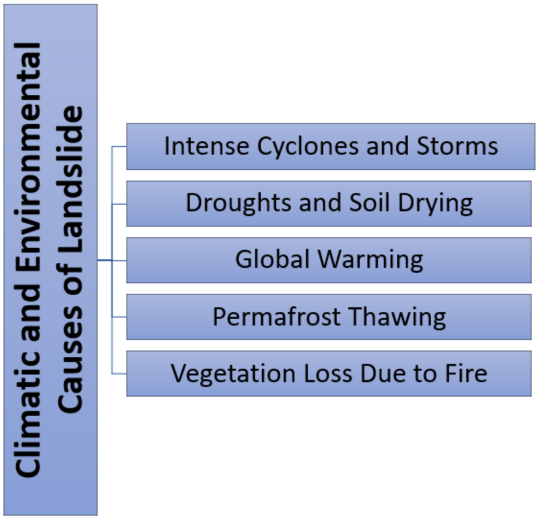

Fig. 3. Climatic and Environmental Causes of Landslide

3. Methodology

We conducted an online poll to investigate the causes of the landslides. A simple, thorough poll was possible. The poll is in two parts. The first section reviews poll results, while the second looks at environmental challenges. A Likert scale of 1 to 5 is appropriate for all assessments. The survey participants included business owners, planners, site engineers, builders, and quantity inspectors. Corporations, non-profits, and institutions received the poll. Some people didn't know what to do and gave unsatisfactory replies. We assessed 253 survey forms and discarded 18 due to incomplete information. We merged the replies to obtain the final findings. The poll had 324 answers. We analyzed all the data using structural equation modeling (SEM). PLS uses evaluation and structural equations. Internal models represent component linkages. Next, run SPSS factor analyses. We conducted a survey to identify the causes of the landslide. The poll respondents came from a variety of backgrounds and worked in manufacturing, construction, and transportation. The respondents provided their names, job titles, and years of experience before rating the significance and frequency of flood causes on a Likert scale. Asking open-ended questions enabled participants to explain landslides more completely and effectively. We evaluated the data using both qualitative and quantitative methods, such as factor analysis and descriptive statistics. This comprehensive methodology demonstrated how challenging project slips are and enabled more focused remedies.

4. Result and Discussion

4.1 Data Analysis

Table 1. Analysis of the Causes of landslides, including Factor Loadings and the Cronbach's Alpha, RII and Rank

Code	Social Factors	Factor loading	α	RII	Rank
Natural Causes of Landslide					
L1	Heavy Rainfall	0.7253	0.8958	0.9041	1
L4	Earthquakes	0.5353	0.8942	0.9021	2
L11	Weak Rock Formation	0.7052	0.8893	0.9001	3
L13	Weathering	0.7717	0.8424	0.8971	4
L8	Erosion by Sea Waves	0.6272	0.8833	0.8961	5
L7	Undercutting by Rivers	0.7275	0.8116	0.8921	6
L2	Prolonged Wet Periods	0.6302	0.8031	0.7891	7
L6	Tsunamis	0.7717	0.8032	0.7841	8
L5	Volcanic Eruptions	0.8017	0.7896	0.7821	9
L14	Landslide-Triggered Landslides	0.5404	0.8938	0.7791	10
L9	Frost Action	0.5215	0.7842	0.7731	11
L3	Sudden Snowmelt	0.7312	0.8855	0.7581	12
L10	Wind Erosion	0.7275	0.8833	0.7356	13
L12	Overloading by Accumulated Materials	0.6302	0.8116	0.6719	14
Anthropogenic (Human-Induced) Causes of Landslide					
L17	Road Construction	0.7134	0.8839	0.8922	1
L16	Mining and Quarrying	0.5234	0.8823	0.8902	2
L15	Deforestation	0.6933	0.8774	0.8882	3
L21	Improper Waste Disposal	0.7598	0.8305	0.8852	4
L23	Improper Drainage Systems	0.6153	0.8714	0.8842	5
L22	Artificial Reservoirs	0.7156	0.7997	0.8802	6
L18	Unplanned Urbanization	0.6183	0.7912	0.7772	7
L20	Agricultural Activities	0.7598	0.7913	0.7722	8
L24	Blasting and Explosions	0.7898	0.7777	0.7702	9
L19	Overburdening by Infrastructure	0.5285	0.8819	0.7672	10
L25	Land Reclamation Projects	0.5096	0.7723	0.7612	11
Climatic and Environmental Causes of Landslide					
L27	Droughts and Soil Drying	0.6053	0.8614	0.8742	1
L26	Intense Cyclones and Storms	0.7056	0.7897	0.8702	2
L28	Global Warming	0.6083	0.7812	0.7672	3
L29	Permafrost Thawing	0.7498	0.7813	0.7622	4
L30	Vegetation Loss Due to Fire	0.7798	0.7677	0.7602	5

4.2 Quality and Model-Fitness Indices

1. The path coefficient on average (APC) = 0.911

- (A route coefficient value of 0.90 or above is deemed acceptable and a good match.)

2. R^2 Value = 0.938

- R2 always has a value that is somewhere between 0% and 100% of the total.
- A model that has an R2 value of 0% does not take into account any of the variability in the response variables that comes from outside of the sample. It is possible to make predictions about both the regression model and the dependent variables by looking at their means.
- It is reasonable to conclude that a model with a fit statistic of one hundred percent adequately accounts for all outliers in the response distribution.
- If the R2 value is higher, it suggests that the regression model provides a better fit for the data.

3. Goodness of Fit Index

- (GoF) Value =0.224
- The integrity of fit (GOF) metric is used to guarantee that the model properly reflects experimental data. On a scale of 0 to 1, 0.10 (little), 0.25 (middle), and 0.36 (big) show general agreement with the method model. A good model fit indicates that a model is compact and viable.

4.3 Relative Importance Index

To aid in the review, SPSS was used to analyze the outcomes of eleven surveys. Table 3 displays the analysis's ranking of Navale Bridge accident-related causes and elements by predicted criticality as assessed by the Relative Importance Index (RII) using condition.

Where: W represents the respondents' weighting of each aspect, and its value may range from 1 to 5 (with 1 indicating "strongly disagree" and 5 indicating "strongly agree"). The letter A represents the highest possible weight, which in this case is 5, and the number N represents the total number of respondents.

4.4 Reliability Statistics

SPSS was used to determine sample size dependability. The values might be 0 or 1. This survey result is 0.811, which is more than 0.6 and very close to 1, suggesting that the sample size of the questionnaire is sufficient and reliable.

4.5 Factor Analysis Information Feasibility

The Kaiser-Meyer-Olkin (KMO) and Bartlett tests of sample adequacy supported factor analysis. Factor analysis questionnaire surveys using Bartlett's Test of Sphericity scales KMO 1 is more than 0.5, and the average is 0.725. This demonstrates the significance of factor analysis. This ensures variable homogeneity and the data validity of factor analysis. Factor analysis is relevant to the variables since Bartlett's Test of Sphericity obtained a p-value (Sig.)

of 0.05 at 95% significance.

Table 2. Key Factor Analysis using SPSS

Key Causes Identifies by Factor analysis using SPSS	
Natural Causes of Landslide	• Heavy Rainfall • Earthquakes • Weak Rock Formation • Weathering • Erosion by Sea Waves
Anthropogenic (Human-Induced) Causes of Landslide	• Road Construction • Mining and Quarrying • Deforestation • Improper Waste Disposal
Climatic and Environmental Causes of Landslide	• Droughts and Soil Drying • Intense Cyclones and Storms • Global Warming

4.6 Landslides Impacts

Landslides have devastating consequences on human lives, infrastructure, and the environment. The most immediate and severe impact is the loss of life, as landslides can bury homes, roads, and entire communities under debris within moments. Infrastructure such as roads, bridges, and buildings is often severely damaged or destroyed, disrupting transportation and communication networks. Additionally, landslides in agricultural areas can destroy crops, leading to food insecurity and economic losses for local communities.

From an environmental perspective, landslides can significantly alter landscapes by eroding soils, uprooting vegetation, and diverting watercourses. This leads to habitat destruction for flora and fauna, further destabilizing ecosystems. Sediment and debris transported by landslides often pollute water bodies, affecting aquatic ecosystems and water quality downstream. Large-scale landslides may also create natural dams, which, when breached, result in catastrophic flooding in adjacent regions.

Economically, landslides impose substantial costs on governments and communities due to disaster response, rebuilding, and mitigation efforts. Indirectly, they can disrupt trade routes, reduce tourism in affected areas, and hinder regional development. For vulnerable communities, these impacts often exacerbate poverty and displacement. Effective landslide management strategies, including hazard mapping, early warning systems, and sustainable development practices, are crucial to mitigating these multifaceted impacts.

4.7 Mitigation techniques of landslides

1. Slope Stabilization

- Retaining Walls: Strong walls can be constructed along slopes to prevent soil movement. These are typically made from concrete, stone, or steel.

- Terracing: Dividing a slope into steps reduces its angle and increases stability, allowing for more control over water runoff and reducing erosion.

- Soil Nailing: Involves reinforcing a slope with steel bars or nails, which are inserted into the slope to provide support and prevent movement.

2. Drainage Control

- Surface Drainage: Installing proper drainage systems (drainpipes, ditches, or berms) to divert water flow off the slope helps to reduce the buildup of water pressure and erosion.

- Subsurface Drainage: Using systems like perforated pipes (French drains) within the soil helps remove groundwater that could potentially weaken the slope.

- Interceptor Drains: These divert groundwater away from vulnerable areas to prevent saturation and instability.

3. Vegetative Solutions

- Vegetation and Groundcover: Planting deep-rooted vegetation on slopes can enhance soil cohesion and absorb excess water, which reduces soil erosion. Groundcover such as grasses, shrubs, or trees can significantly stabilize the slope.

- Hydroseeding: This is a process of applying a mixture of seed, mulch, and water to an area to quickly establish vegetation and reduce erosion.

4. Rockfall Protection

- Rocknets: Mesh or netting can be installed over rock slopes to prevent loose rocks from falling onto roads or structures.

- Rock Bolts and Anchors: These are used to secure large rocks or boulders to the underlying rock, preventing displacement.

5. Monitoring and Early Warning Systems

- Ground Monitoring Instruments: Using instruments like inclinometers and piezometers to monitor ground movement, soil saturation, and water levels can provide valuable data to identify signs of instability.

- Remote Sensing: Satellite imagery and ground-based radar can be used to track land displacement, soil moisture, and other signs of potential landslides.

- Early Warning Systems: Using monitoring data, these systems can issue alerts when conditions become conducive to landslides, allowing for timely evacuation and response.

6. Land Use Planning

- Building Regulations: Avoiding construction in high-risk areas is a proactive way to mitigate landslide risks. Where construction is necessary, design structures that account for landslide-prone areas.

- Slope Mapping: Conducting detailed landslide hazard mapping for an area helps inform urban planning and development, avoiding vulnerable locations.

7. Controlled Blasting or Excavation

- In some cases, removing unstable materials or carefully controlling the removal of rock or soil can reduce the risk of larger, more dangerous landslides. This is generally used on large, potentially unstable rock slopes or in quarries.

5. Conclusion

In summary, a variety of factors such as high rainfall, earthquakes, deforestation, and poor land use can cause landslides, which are a serious natural hazard. Fundamental reasons for landslides often involve a combination of geological, environmental, and human-related factors that diminish slope stability. Over time, the combined effects of these causes may lead to widespread movement of soil, rocks, and debris, posing a threat to life, property, and infrastructure. Identifying the causes of landslides is critical for implementing effective mitigation techniques.A variety of approaches mitigate landslides by minimizing triggering causes and improving slope stability. Engineering techniques such as slope stabilization, retaining walls, and drainage systems aid in the management of soil movement and water flow, whilst vegetation alternatives such as planting ground cover and trees increase slope strength by stabilizing soil. Additionally, frequent monitoring and the deployment of early warning systems provide critical tools for spotting possible threats, guaranteeing prompt evacuations, and reducing deaths.Effective mitigation needs not only the adoption of specialized solutions but also the integration of comprehensive land use planning and appropriate management. Restricting construction in high-risk locations and enforcing good building rules may assist in mitigating landslide hazards. Communities may mitigate the effect of landslides by integrating engineering solutions, monitoring technologies, and appropriate land management practices. Finally, a proactive and multifaceted strategy is required to protect both human life and the environment from the destructive effects of landslides.

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