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Factors Shaping the Landslide Trend in Nepal and their Impact on Human Lives and the Economy

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Abstract

This paper explores the status of landslide occurrence in Nepal, attributing it to a combination of factors such as geographical features, seismic activity, climate conditions, and anthropogenic factors like unregulated road construction. The landslides pose a serious threat to human lives and economic stability, particularly in high-risk areas like the mid-hills and mountain regions of Nepal. Seasonal variations in landslides have been influenced by monsoon activity, while poorly planned and constructed roads exacerbate the issue. The paper aims to highlight the vulnerability of Nepal's geography to landslides through case studies and existing literature. It concludes that landslides result from a complex interplay of geographical, climatic, and anthropogenic elements. To address the situation, the focus should be on sustainable infrastructure development, especially in mid-hills and mountain regions, by considering proper grading and drainage patterns during road construction. This approach can effectively mitigate anthropogenic factors and bring economic benefits to the nation while promoting a safer and more resilient future.

Keywords: Climatic, landslide, geography, anthropogenic, sustainable, economy

Introduction

The increasing trend of landslides and the resulting loss of life in Nepal can be attributed to a combination of factors, including geography, earthquakes, climate, and unregulated road construction. The uncontrolled expansion of road networks, especially during the rainy season, worsens the instability of slopes. Notably, landslides triggered by rainfall are more than twice as likely to occur within 100 meters of a road compared to those caused by earthquakes. This proliferation of informal roads is having a negative impact on the social and economic aspects of the region, undermining the very development goals these roads were intended to support and leading to significant loss of life. Nowadays, landslides are influenced not only by seismic activity, geology, geomorphology, and climate but also by the poor construction of roads, which is rapidly transforming the landscape and exacerbating the problem.(McAdoo et al., 2018).

Roads are a prerequisite for the development of rural areas in Nepal. They facilitate improved access to goods and services, quicker transit, and societal change. However, Nepal's poorly built mountain roads cause the risk of landslides and erosion, which affects people's lives and livelihoods (Sudmeier-Rieux et al., 2019). Various case studies have demonstrated that alterations in land use, land cover, and their associated changes affect soil erosion across different spatial and temporal dimensions (Tadesse et al., 2017 & Alkharabsheh, 2013). Also, an elevated likelihood of landslides exists in areas featuring soil highly susceptible to erosion (Abidin & Abu Hassan, 2005 & Khosrokhani & Pradhan, 2014).

Landslide events have various direct and indirect economic impacts. Direct economic impacts encompass the costs associated with cleanup, repair, and replacement of infrastructure, as well as search and rescue expenses. Estimating these costs for a specific event is relatively straightforward. Direct consequential economic impacts pertain to the disruption of infrastructure and the resulting loss of utility. This includes the costs of road closures, implementing traffic diversions, and the human costs of casualties and accidents. Indirect consequential economic impacts arise from the effect of landslides on access to remote rural areas, particularly those reliant on transportation-dependent activities. These impacts encompass constraints on incoming and outgoing goods, transportation of personnel and visitors, and long-term effects on local businesses.

Manufacturing, agriculture, and tourism sectors are particularly vulnerable to these impacts. Determining the extent of these impacts is challenging due to their dispersed nature and anticipation of compensation. However, understanding these costs is crucial for governments to allocate budgets for landslide risk mitigation and remediation efforts (Winter et al., 2018).

Methodology

The methodology for the article involved conducting a comprehensive literature review of national and international journals and articles/research and case studies to explore the impacts of geographical, climatic, and anthropogenic factors in light of landslide occurrences in Nepal. The study's primary objective was to synthesize existing research and investigate the complex interplay of these factors, emphasizing their implications for human lives and economic stability, particularly in high-risk areas like the mid-hills and mountain regions of Nepal. Relevant publications were sourced using various databases and keyword searches. Data extraction focused on geological, topographical, and climatic factors, as well as anthropogenic influences, with subsequent thematic analysis to address the research objectives. Ethical considerations centered on proper citation and acknowledgment of original authors, while acknowledging potential limitations, such as publication bias and data availability. The findings from this study contributed to a better understanding of landslide vulnerability in Nepal and provided insights into possible strategies for the prevention of adverse impacts.

Landslide trend in Nepal: Natural and Anthropogenic factors

Around the world, landslides pose a serious threat to both human lives and the national and rural economy, with particular high-risk locations concentrated in well-known mountain ranges like the Himalayas (Nadim et al., 2006 & Petley, 2012). In Nepal, where a thorough database of deadly landslides has been kept since the 1980s, a generally rising trend in fatal landslides is thought to be persistent (Petley, 2010). Although the seasonal variations in landslides appeared to be related to monsoon activity, poor road planning and construction were found to be major contributors to this trend. This highlights bigger issues with Nepal's and other mountainous regions' regional development (Sudmeier-Rieux et al., 2019).

In many rural areas of Nepal, the construction of local roads, commonly known as "dozer roads," is frequently initiated and carried out by bulldozer owners in partnership with politicians, based on community requests. Unfortunately, these roads are built hastily and without proper grading or drainage measures. This widespread and inefficient road construction, especially in middle hill and mountain regions, is exerting a growing strain on delicate ecosystems, squandering government resources, and raising the dangers for both road travelers and residents living alongside the roads (Singh, 2018).

Over the past two decades, rural road construction in Nepal has shifted from predominantly relying on manual labor to adopting a more equipment-based approach. Unfortunately, this equipment-based method often involves constructing unplanned roads without giving enough attention to implementing measures to protect against slopes and potential hazards (Hearn & Shakya, 2017). In Nepal, the shift to machinery-based road construction without considering sustainable development has led to negligence of grading, slope protection, and proper drainage systems.

This results in road failures and costly repairs during the monsoon season (Singh, 2018 & Sudmeier-Rieux et al., 2019). Similarly, Froude & Petley (2018) revealed that during road construction in Nepal, approximately 43% of landslides were triggered by construction activities. These landslides have severe consequences, impacting both lives and properties while also degrading the rural road networks which in turn, leads to a substantial rise in maintenance expenses (DFID, 2003).

Case Study 1: Landslide occurrence in relation to climate variables in the Far-Western Development Region of Nepal

According to Muñoz-Torrero Manchado et al. (2021), the landslide-climate correlation data of the Western Development Region of Nepal (Figure 1) shows that climate factors have a greater impact on rapid shallow landslides compared to deep-seated landslides. Shallow landslides show significant correlations with total monsoon precipitation (TP) and monsoon average temperature (T) ($r = 0.74$, $p = 3.99e{-}05$ and $r = 0.41$, $p = 0.045$, respectively), whereas deep-seated landslides do not exhibit such associations. Dry monsoons (PTP) lead to an increased occurrence of landslides in the following monsoon season ($r = -0.41$, $p = 0.049$). The highest landslide incidence was observed when warm monsoons coincided with humid conditions (TPPT), with both shallow ($r = 0.77$, $p = 4.19e{-}05$) and deep-seated landslides ($r = 0.42$, $p = 0.047$) displaying strong correlations. Long-term accumulated precipitation over a 10-day period (MAX10D) demonstrated the strongest correlation with shallow landslides ($r = 0.68$, $p = 0.00037$), while deep-seated landslides exhibit weaker correlations, reflecting their distinct hydrological characteristics.

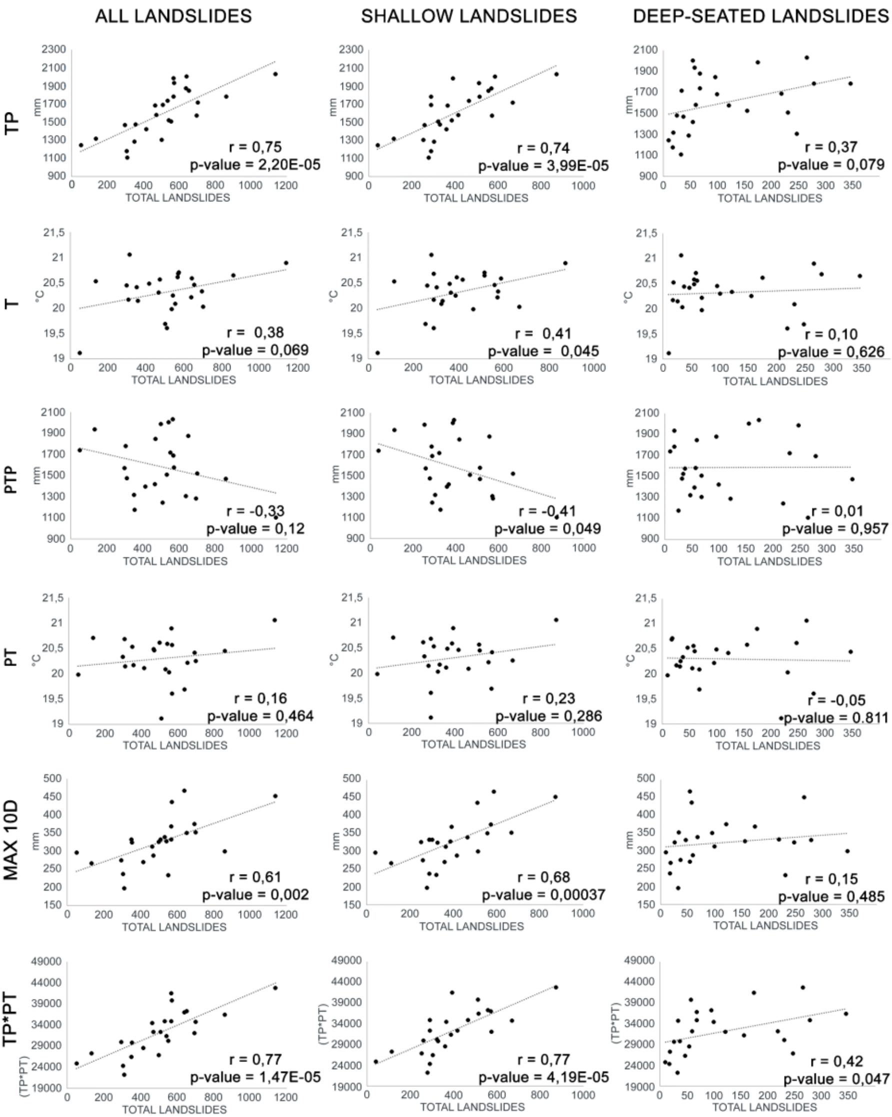


Figure 1: Pearson correlations between landslides and climatic variables (1992-2018) in Far Western Development Region of Nepal. Where, TP = monsoon accumulated precipitation; T = monsoon average temperature; PTP = previous

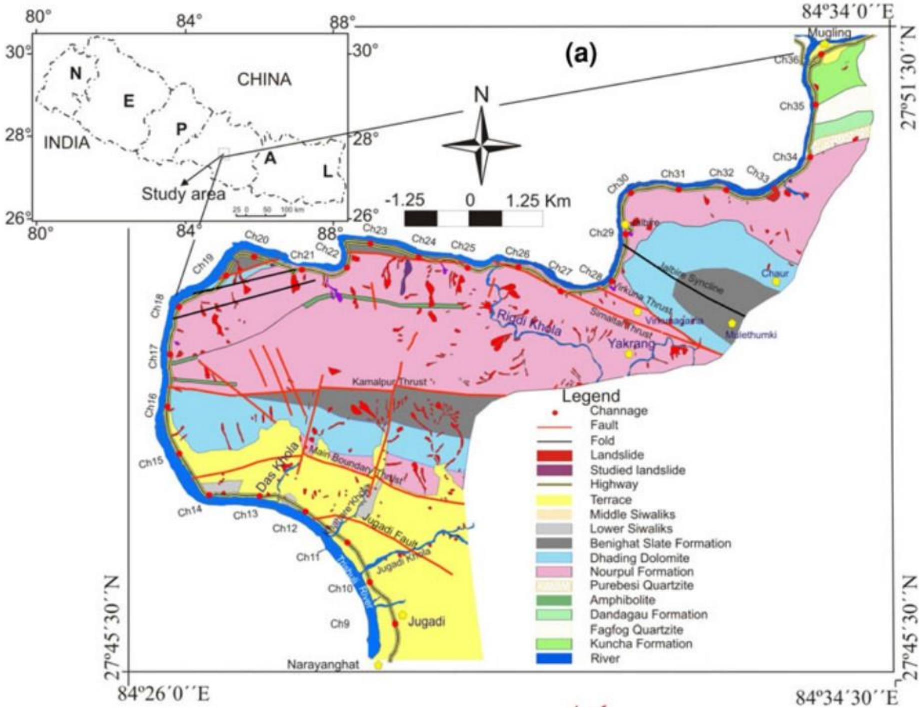
*monsoon accumulated precipitation; PT = previous monsoon average temperature; MAX10D = monsoon maximum 10 days accumulated precipitation; TPPT = monsoon accumulated precipitation * (previous monsoon average temperature) (Muñoz-Torrero Manchado et al., 2021).*

Case Study 2: Landslides in Mugling-Narayanghat Road Section

Regmi et al. (2013) investigated the Mugling–Narayanghat road section (Figure 2) and its surrounding area to study the link between geology, rock weathering, and mass movement, particularly landslides. The primary cause of landslides was found to be rainfall, but there were various underlying factors, such as geological structures, rock weathering, clay mineral formation, and river activity, which contributed to the area's susceptibility to landslides over a long period. Due to the complex geological setting in the region, establishing a direct relationship between landslides and rock weathering was challenging.

However, the study revealed that large and complex landslides were closely associated with deep rock weathering, along with the influence of geological structures like faults, joints, and fractures. On the other hand, rotational landslides were observed in weathered rocks, where the dip direction of the foliation plane played a crucial role. Shallow landslides occurred in areas covered by residual soil or colluviums, with relatively fresh rocks beneath them. Debris slides and flows were found in slopes covered with colluviums or residual soil, sometimes triggered by rock falls from higher slopes. Rock falls were primarily linked to the joint pattern and slope angle and were more common in less-weathered rocks.

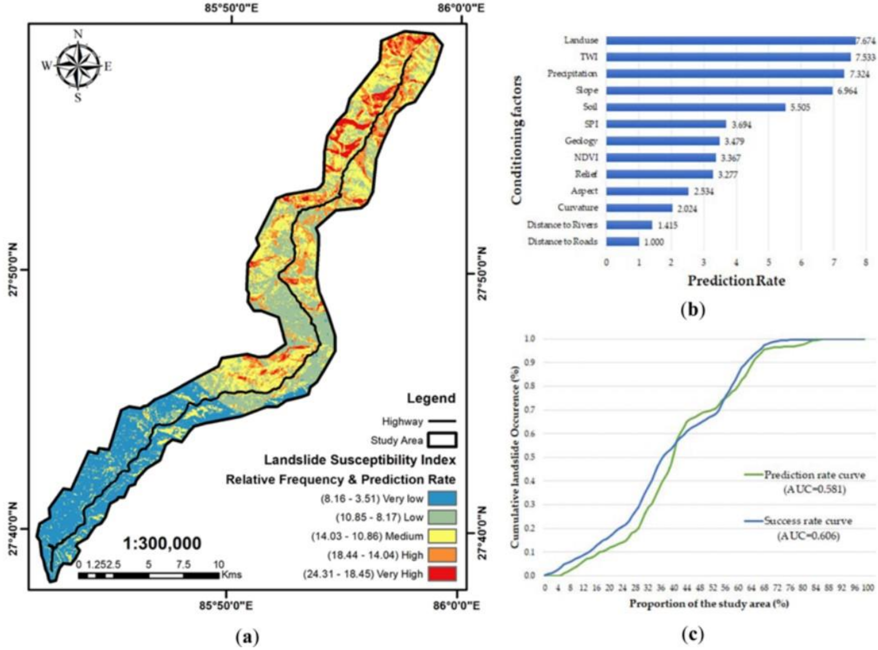
Figure 2: Geological map of the Mugling-Narayanghat road section (Regmi et al., 2013)



Case Study 3: Landslide Susceptibility Mapping along Araniko Highway

In a study by Acharya & Lee (2019), mapping the likelihood of landslides occurring along the Dolalghat-Kodari section of the Araniko Highway in Nepal was conducted. Two methods: Relative Frequency (RF) and Predictor Rate (PR) were used. The PR method was applied to the RF data to assess how well the factors they considered could predict landslide occurrences, resulting in a Landslide Susceptibility Index (LSI). A map that marked the locations of 314 landslides was created and the data was split into a 70/30 ratio for training and validating the model. Different factors that contribute to landslides were analyzed. The resulting susceptibility map, generated using the LSI, was categorized into five classes to indicate varying degrees of susceptibility. The Receiver Operating Characteristic (ROC) curve used to evaluate the accuracy of the map showed that the Area Under the Curve (AUC) for RF was 0.606 and for PR was 0.581 (Figure 3).

Figure 3: (a) Landslide Susceptibility Index (LSI) map (b) Prediction Rate (PR) of Conditioning Factors (c) ROC Curves (Acharya & Lee, 2019)



An AUC value above 0.5 indicates an acceptable model (Swets, 1988). The higher the AUC value, the better the model's prediction capability. For instance, an AUC value of 0.9 would signify a very good model, suggesting that 90% of the landslides are accurately predicted within the top 10% highest susceptibility area (Lee & Talib, 2005).

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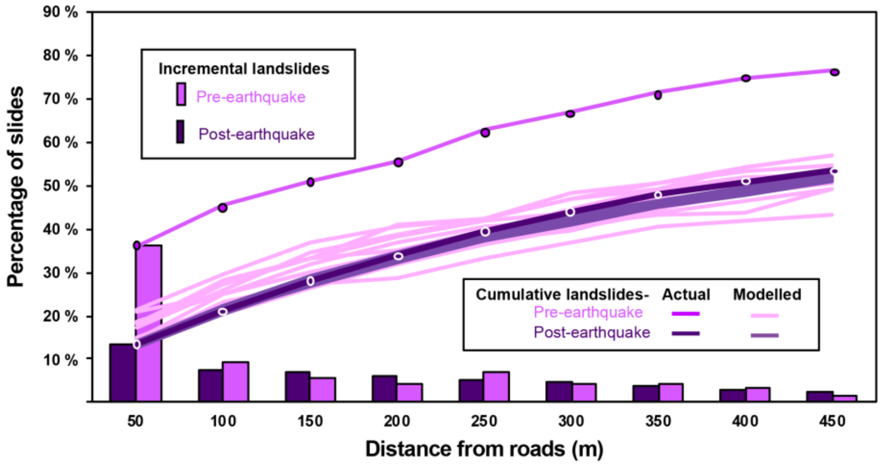
Case Study 4: Relationship between Roads and Landslides in the Sindhupalchok District of Nepal

To understand the impact of informal roads on the occurrence of landslides, McAdoo et al. (2018) investigated the proximity of roads to landslides that resulted from the 2015 Gorkha earthquake and compared with the proximity of roads to landslides caused by monsoon rainfalls along with analyzing a set of randomly located landslides to determine a potential cause-and-effect relationship. The results showed that landslides occurred more frequently in landscapes that were well-developed and agriculturally productive. Additionally, when it comes to landslides triggered by rainfall, they were over twice as likely to happen within a distance of 100 meters from a road compared to landslides caused by earthquakes (Fig. 4). Although change in slope of the cumulative number of slides with increasing distances from the road was expected corresponding to the critical distance where the mechanical influence of the road disturbance is reduced, the graph does not show such change which could potentially be as a result of resolution issues of the smaller slides (McAdoo et al., 2018).

Figure 4: Distance from roads of earthquake, monsoon, and randomly generated slides (McAdoo et al., 2018).



**Randomly located landslides within various buffer distances are represented in lighter shades of pre- and post-earthquake purple colors.*

Landslides and Mortality in Nepal

Over the past three decades, Nepal has experienced nearly 5,000 devastating climate-related disasters, resulting in the tragic loss of over 10,000 lives nationwide. Among these disasters, Landslides and floods proved to be the deadliest, accounting for 37% and 32% of the total fatalities, respectively (see Table 1). More than 800 individuals in these disasters were reported missing, and around 5,000 people sustained injuries during the disasters. It's important to note that many of those who were missing and some of the injured might have tragically lost their lives, but this information wasn't reflected in the official database. Additionally, there could be several other disaster incidents that went unreported. As a result, the numbers recorded in the database are likely an underestimate of the true scale of occurrences and fatalities caused by disasters in Nepal (Chapagain et al., 2022).

Table 1: Mortality by disaster types in Nepal 1992-2021

S. N.	Disaster types	Mortality	Mortality in % of total
1	Landslides	3692	36.66
2	Floods and heavy rains	3201	31.78
3	Thunderstorms	1780	17.67
4	Cold waves and frosts	848	8.42
5	Windstorms	273	2.71
6	Snowstorms and avalanches	223	2.21
7	Heatwaves	35	0.35
8	Hailstorms	20	0.2
	Total	**10,072**	**100**

Source: *Chapagain et al., 2022*

Economic Impacts of Landslides

In recent times, particularly in the 21st century, landslides have caused the loss of tens of thousands of human lives and resulted in an average of approximately $20 billion in economic losses each year. This amount accounts for roughly 17% of the total global disaster losses, which averaged $121 billion annually, between the years 1980 and 2013 (Klose et al., 2016). The average annual costs of different countries due to landslides are presented in Table 2. When looking at developing countries like China, India, and the Himalayan region, the economic costs of landslides are notably lower due to lower property values. In countries like Nepal, New Zealand, and Canada, most landslides and their resulting damages happen in rural areas, which leads to comparatively lower associated costs

Table 2: Average annual cost of landslides in different countries worldwide

Country	Average Annual Direct Costs (USD)	Average Annual Total Costs (USD)	Remarks
Canada[a]	–	$70 million–1.4 billion	
Japan	$1.5 billion	$4 billion	
Korea	$60 million	–	Based on poor record
Italy	–	$2.6–5 billion	Rough Estimate
Sweden	$10–20 million	–	
Spain	$0.2 billion	–	
Former USSR	$0.5 billion	–	
New Zealand		$26.3 million	90% of costs are sustained in rural

Country	Average Annual Direct Costs (USD)	Average Annual Total Costs (USD)	Remarks
			areas
Belgium[b]	$0.85 million	$4.48 million	
Germany[c]	$0.3 billion	–	
India	$1.3 billion		
China	$0.5 billion	–	Costs based on valuations in 1989
Nepal	**$19.6 million**	–	Includes flood damage, but likely incomplete
Brazil[d]	$45 million	$0.35 billion	
Worldwide		**$ 20 billion**	

Source: Sim et al., 2022

Conclusions and Recommendations

The increased frequency of landslides in Nepal and the consequent loss of life can be attributed to a combination of factors, including geographical features, seismic activity, climate conditions, and unregulated road construction. These landslides pose a serious threat to both human lives and economic stability, particularly in high-risk areas concentrated in well-known mountain ranges like the Himalayas. Seasonal variations in landslides seem to be influenced by monsoon activity, while inadequate road planning and construction practices play a significant role in exacerbating the issue.

Both environmental and human-made factors contribute to the vulnerability of Nepal's geography to landslides. By conducting case studies and thoroughly reviewing existing literature, we can conclude that the occurrence of landslides in Nepal is a complex interplay of geographical, climatic, and anthropogenic elements. The steep terrain of mid-hills and mountain regions in Nepal is highly susceptible to the impacts of frequent earthquakes and monsoon rainfall. Additionally, the construction of informal roads, lacking proper engineering design and practices, has further increased the occurrence of landslides in proximity to these roads, especially in rural areas.

While climatic factors such as weather patterns and earthquakes are beyond human control, addressing the situation requires a focus on sustainable infrastructure development. Especially in mid-hills and mountain regions, emphasizing proper grading and drainage patterns during road construction can be crucial. Allocating and utilizing the budget effectively at the governmental level for the construction of sustainable and environmentally friendly roads, considering the challenging geography and weather patterns of Nepal, is essential.

Through the implementation of preventive measures, the anthropogenic factors contributing to landslides can be effectively mitigated. This approach not only saves human lives and protects the environment but also brings overall economic benefits to the nation. By striving for sustainable infrastructure practices, Nepal can better cope with the challenges posed by landslides and pave the way for a safer and more resilient future.

Way Forward

Nature-based solutions (NBS) provide an optimistic and pragmatic way to deal with landslides in places like Nepal due to the terrain complexity. These solutions take into consideration the environmental aspects and bear the possibility to handle the specific challenges posed by the region's unique landscape. Nature-based solutions have also been shown to be extremely effective in reducing risks. These approaches acknowledge natural processes and ecosystems to tackle landslide issues while supporting the preservation of the environment and maintaining ecological harmony. NBS techniques proven effective to manage landslides are discussed below:

- *Afforestation and Reforestation:* One effective method to improve slope stability and minimize the risk of landslides in vulnerable areas is by planting trees and vegetation. The roots of trees play a crucial role in binding the soil, making it stronger and more cohesive. Additionally, the canopy of vegetation helps control water flow, preventing excessive erosion in these regions.

- *Soil Bio-engineering:* Using bioengineering techniques is a valuable method to avert landslides since they enhance slope stability and ensure ecological harmony. These approaches are particularly well-suited for implementation in developing countries due to their cost-effectiveness and environmentally friendly characteristics. Despite Nepal's long history with bioengineering practices, they have not been fully utilized to address the landslide issues effectively. Soil bioengineering techniques hold significant relevance in Nepal for mitigating landslide risks. These techniques are vegetation-based and integrate engineering practices with ecological principles. The core idea behind these methods is to harness the unique benefits of natural vegetation or combine them with living or non-living structures to enhance ecological balance and ensure slope stability. One of the key advantages of soil bioengineering is its cost-effectiveness, as it utilizes locally available materials and requires relatively low labour costs despite involving engineering practices. The use of soil bioengineering for landslide prevention is not a new concept in Nepal, as these methods were introduced more than 30 years ago. Common practices in the country include brush layering, palisades, vegetative stone pitching, live check dams, and fascines. By employing vegetation to reinforce and stabilize slopes, soil bioengineering not only contributes to biodiversity conservation but also positively impacts the overall ecosystem. It plays a crucial role in maintaining the balance between soil and water, and the combination of vegetation with various engineering structures fulfills both fundamental and engineering functions in ensuring slope stability (Raut & GUDMESTAD, 2018).

- *Slope Remediation Techniques:*

    1. Geometrical Method: This approach is quite straightforward and cost-effective, but it does necessitate having enough available space. It's a relatively simple method to improve slope safety by transforming steeper slopes into milder ones. This can be achieved by either trimming the slope or reducing the additional load on it. Another option is backfilling at the slope's base. By altering the steep slope's geometry to make it gentler through flattening or backfilling at the toe, the overall stability of the slope can be significantly enhanced. This method stands out for its simplicity and cost-effectiveness.

    2. Drainage Method: In landslide management, this method is commonly utilized in combination with other techniques. Its effectiveness relies on proper maintenance of both surface and sub-surface drains. The main contributors to slope instability are subsoil saturation and the build-up of pore water pressure. By implementing a well-designed surface and subsurface drainage system, the risk of these factors can be minimized, consequently enhancing slope stability. However, as a long-term solution, this method faces significant challenges due to the need for consistent maintenance of the drainage systems to ensure their continued functionality. While surface drains are relatively easy to maintain, the upkeep of subsoil drains poses considerable difficulty.

    3. Retaining Structure Method: This method is known for its flexibility, but it comes with a higher cost. It involves the use of retaining structures that can withstand the forces exerted by soil masses. These structures come in various types, such as gravity and cantilever retaining walls, contiguous bored piles, and sometimes soil nailing methods are also employed to stabilize slopes. Retaining structures encompass different options like gravity walls, cantilever walls, bored piles, caissons, steel sheet piles, ground anchors, and soil nails. While this method may be more expensive when compared to others, it remains a popular choice for remedial works, especially in challenging sites with space limitations (Kazmi et al., 2017).

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