Socio-Economic Impacts of Landslides and Applied Mitigation Techniques: A Case Study in Bagnaskali, Nepal

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Abstract: This study aimed to estimate the socio-economic impacts of landslides and identify mitigation techniques being applied for landslide control in Bagnaskali rural municipality, Palpa. Purposive sampling was conducted to focus the research on plots with frequent landslide occurrences. Out of the 20 identified landslide-prone sites, a random sampling method was used to ensure representative data collection with a 40% sampling intensity. Data were collected through direct observation, transect walks, and household surveys conducted in areas prone to landslides. Additionally, discussions were held with key informants, the technical team, and experts in the field to validate the collected data. In Bagnaskali rural municipality in the year 2020, six households reported damage, two cases of death occurred, 24 livestock fatalities were recorded, and there was damage to cultural heritage due to landslides, resulting in social losses. Affected communities also incurred compensatory losses ranging from NRs 10 to 50 lakhs due to the destruction of water resources, road blockages, and agricultural land damage. As mitigation measures for landslides, the municipality applied civil engineering techniques such as gabion walls, masonry, culverts, check dams, and reinforced concrete (RCC), as well as bioengineering techniques including plantation, wattling, and brush-layering. Civil engineering techniques were prioritized for mitigating landslides, with bioengineering serving as a supporting base. Plots where both civil and bioengineering techniques were employed together exhibited greater slope stability and reduced vulnerability. Therefore, it is recommended to use mitigation techniques that stabilize slopes and reinforce the soil to control landslide hazards effectively. To successfully reduce landslides and protect vulnerable communities, comprehensive policies, laws, and investments are required. Technical and financial assistance from governmental and non-governmental sectors is essential to minimize the impacts of landslides and implement the most effective mitigation techniques for landslide control.

Keywords: *Catastrophe, Mitigation techniques, Natural disaster, Vulnerable community*

Conflicts of interest: None
Supporting agencies: None

Received 28.04.2023; Revised 8.07.2023; Accepted 13.08.2023

Cite This Article: Shakya, A., Sigdel, P., & Pokhrel, S. (2023). Socio-Economic Impacts of Landslides and Applied Mitigation Techniques: A Case Study in Bagnaskali, Nepal. *Journal of Sustainability and Environmental Management*, 2(3), 170-178.

1. Introduction

The term landslide refers to several forms of mass-wasting that include wide range of ground movements, such as deep-seated slope failures, mudflows, and debris flows. Deep-seated slope failure is the washing away of the slope face in condition when shear strength of soil or rock within the slope exceeds the shear forces coming from the over-top weight of the slope (Eberhardt, 2008). Likewise, mudflows refers to flow of mud or sediments that is carried downslope along with water molecules (Jian L. e., 1983) and debris flow is a fast moving landslide that constitutes of mudflows and may even carry away rocks and debris along the flow (Iverson, 2005). A landslide is the result of slope failure, yet both natural and human activities are responsible for its occurrence. It may occur in several forms such as fall, topple, slide, spread, or flow (Varnes, 1978).

Landslides occur over a wide range of velocities and are recognized as the third most crucial natural disaster worldwide [(Zillman, 1999) cited in (Perera, 2018)]. Landslides mainly cause social, environmental and economic losses (Schuster, 2001) . It invites damage to social structures such as households, settlements, monuments, death tolls, and loss of livestock. Economic losses from landslides include compensation costs for its recovery and some even invite poverty as well. Economic losses from landslides have been increasing over the past years (Petley, 2005) mainly due to unsustainable human practices, increasing development, investment in the landslide-prone area and increasing frequency of its occurrence (Bandara, 2013). Hence, it is one of the most destructive natural disasters that invites a huge damage of property, structural damage and economic loss to even loss of lives.

Landslides are one of the most frequently occurring natural disasters in Nepal and are equally devastating as well. Landslide events nowadays are becoming more frequent and the failure to stabilize it is seen to be more common. Every year, Nepal suffers a tremendous loss from landslides but the actual amount of losses made from it has not been evaluated yet. Due to the limited numbers of studies that have been conducted to estimate the socio-economic losses from landslides, vulnerable communities are always compelled to bear a heavy compensation for it. Vulnerable communities may be compelled to leave their place of origin, settlements, and social belongings for their own safety (Alobo, 2016).

One of the most influential effects that landslide poses is upon the socio-economic aspect of vulnerable communities. They usually occur without any specific pre-signals or signs, giving people less time to evacuate. However, mitigation techniques can be applied that help to reduce the losses from the landslide. Mitigation techniques should be endorsed timely based on the need of the landslide event and preliminary survey of the site (Joshi et al., 2017). The type of mitigation technique applied for the landslide control determines its effectiveness. Such mitigation techniques can be minor to complex depending upon the nature of the landslide and their pattern of occurrence. Thus, this study clearly aims to analyze the nature of the most frequently occurring landslide and determine the actual losses faced as a result of the landslide. It also attempts to make an assessment of the mitigation techniques applied for its control.

Hazards are mitigated mainly through precautionary means—for instance, by restricting or even removing populations from areas with a history of landslides, by restricting certain types of land use where slope stability is in question, and by installing early warning systems based on the monitoring of ground conditions (Meng, 2021). The communities affected by landslides have sought to apply their own traditional mechanics and methods as a first-hand solution to landslide control which is later assisted by economic support from the government and other organizations. Yet, such steps for controlling landslides cannot sustainably fit in the future due to a lack of adequate research on actual losses from landslides, the nature of landslides, and their mitigation techniques. Also, the mitigation tools and techniques applied for its control are not effective in the long-term. Hence, it becomes very essential to make an assessment of the landslide event and their invited socio-economic losses. Thus this study aims to analyze the nature of frequently occurring landslides, determine the actual losses incurred, and assess the effectiveness of applied mitigation techniques.

Assessment of the socio-economic impacts of landslides is however difficult mainly due to the lack of available data and also because the studies conducted on its impact assessment are not adequate. Many places in Bagnaskali rural municipality are located in the remote areas which is why the supply of resources and research investigations are still lagging. Due to limited investigation and study of landslides in the area, actual causes of landslides and their losses are still a question to people. Proper fact-based pre-assessment of landslides and their socio-economic impacts would facilitate the generation of sustainable short run and long run solutions to vulnerable communities to mitigate and adapt landslide hazards. Therefore, assessment of the direct impact of landslides on the socio-economic system is crucial (Christopher, 2016).

This research aims to figure out the problems associated with landslides so that a more reliable mitigation practice could be adopted for its control in near future. Assessment of various mitigation techniques for landslide control are investigated to compare their effectiveness on the site. Without a proper assessment of the root causes of landslides and their impacts, any plan for landslide mitigation leads to policy failure and ineffectiveness mainly because the techniques and mechanisms applied are not being planned in the long-run. This research, thus, provides valuable insight and reliable data for planning and implementing an effective policy for landslide control.

2. Materials and methods

The study was carried out at Bagnaskali Rural Municipality that lies in 27.868165°N and 83.589448°E in Palpa district of Nepal. The municipality has an area of 84.3 sq.km or 32.5 sq. miles comprising total 9 wards with 28,847 number of residents (CBS, 2011).

The sampling design for this research involved a two-step process, starting with purposive sampling and followed by random sampling. The initial purpose of the purposive sampling technique was to select vulnerable landslide sites for a more concentrated study, focusing on areas with frequent landslide occurrences. This led to the identification of 20 landslide-prone sites, and a subsequent random sampling method was applied to ensure the collection of representative data. A sampling intensity of 40% was chosen as sufficient to capture the major characteristics of the landslide-prone wards. In total, eight landslide locations were surveyed, with 3-4 households selected randomly at each site for data collection.

Data collection incorporated both primary and secondary methods. Primary data were gathered through a range of participatory rural approach (PRA) tools, including direct field observation, household surveys involving approximately 3-4 households from each site, key informant interviews, and focus group discussions with landslide-vulnerable communities. Secondary data collection involved the use of various sources, such as books, research articles, official publications, theses, journals, and documents from the Soil and Watershed

Management Office (SWMO) in Palpa, as well as online resources.

The subsequent data analysis comprised both qualitative and quantitative methods. People's perceptions and qualitative data were subjected to a descriptive analysis approach, while quantitative data collected from the field underwent statistical analysis, including percentages and means. Information related to the nature of landslides and mitigation techniques was presented using visual aids like illustrations, tables, charts, and graphs. Furthermore, geographical data was studied and interpreted through ArcGIS 10.8. To ensure data accuracy and reliability in line with the research objectives, all collected data were meticulously reviewed for inconsistencies or errors.

3. Results

3.1. Assessment of landslide

Nature of landslide

Different types of landslides were classified according to Varnes classification, which included fall, topple, slide, spread, and flow. Falls involved the detachment and falling apart of geological materials, such as rocks or boulders. Topple referred to the forward rotation of units under the influence of gravity or forces exerted by adjacent units. Slides occurred when a distinct zone of weakness separated the sliding material from more stable underlying material. Spread denoted the lateral extension of slopes or flat terrain, often caused by liquefaction accompanied by shear or tensile fractures. Flow was characterized by the downward movement of debris, either alone or in conjunction with the cohesive force of water.

The results obtained from direct observations and household surveys revealed the annual occurrences of different types of landslides in the study area. Specifically, there were three instances of falls, three cases of flows, one instance of toppling, one case of sliding, and no occurrences of spreading. These numbers were represented as percentages, with falls at 37.5%, toppling at 12%, sliding at 13%, spreading at 0%, and flows at 37.5% among a total of eight surveyed landslide sites.

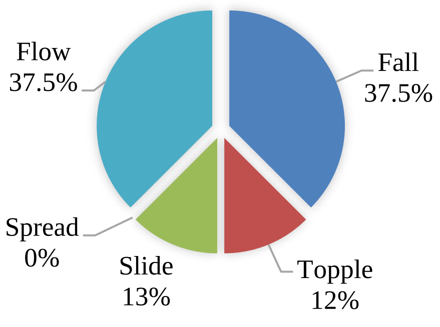

Figure 1: Nature of landslide

Frequency of occurrence

The frequency of landslide occurrences was assessed by categorizing them into specific frequency classes, which were defined as follows:

Very low: Occurring once in 4-5 years.
Low: Occurring once in 2 years.
Medium: Occurring once in a year.
High: Occurring 1-2 times a year.
Very high: Occurring many times a year.

The results of this assessment revealed that the majority of landslides fell into the category of high frequency of occurrence, meaning they occurred 1-2 times a year. Specifically, there were no landslides classified as very low or low frequency. There was one landslide categorized as medium frequency, and four landslides classified as high frequency. Additionally, three landslides were placed in the very high frequency category, denoting occurrences many times a year. This information highlights the distribution of landslides across different frequency classes in the study area, with a notable concentration in the high frequency category.

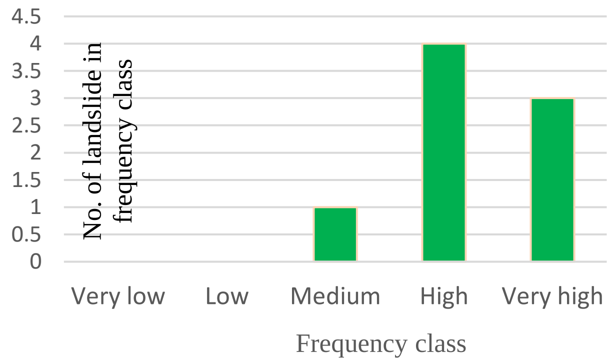

Figure 2: Frequency of landslide occurrence

Season of occurrence of landslide

Analyzing the number of landslides in relation to the month of their occurrence allows for insights into the predominant season of landslide events. The findings indicate that the most common season for landslide occurrences was observed between the months of June to August. This pattern was evident in 6 out of the 8 surveyed plots, signifying that the majority of landslides tended to happen during this period.

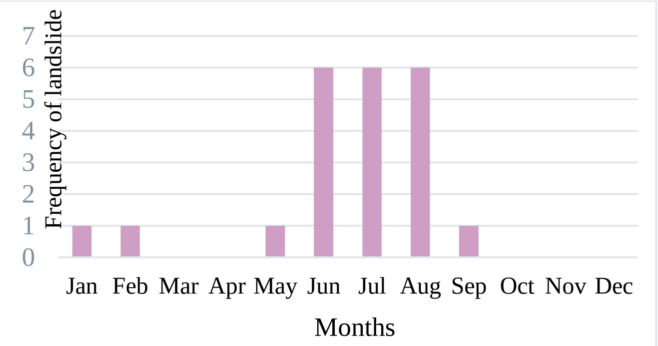

Figure 6: Season of landslide occurrence

3.2. Socio-economic impacts of landslide

List of socio-economic impacts from landslide

Table 1 shows the issues stemming from the landslide that were discussed during direct interviews with local households. These issues were subsequently categorized based on their nature, whether they were primarily social, economic, or a combination of both, as indicated in the table above. In the last column of the table, the estimated economic losses are presented. Notably, the highest economic loss was associated with the destruction of agricultural land, resulting in a substantial loss of NRs 1,58,50,000. This information underscores the significant economic impact of the landslide, particularly in terms of agricultural land damage.

Table 1: List and quantification of socio-economic losses from landslide

Issues from landslide as addressed by local people	Nature of damage (Impacts)	Loss in quantity	Monetary Equivalency (District Rate)
HH damage	Social + Economical	6 households	6*4,00,000 NRs
Loss of human lives	Social	2 death cases	NA
Livestock fatalities	Economical	24 livestock	24 * 50,000 NRs
Water source obstruction	Social + Economical	3 water canals, 1 public water storage tank	20,000 NRS Approx
Cultural heritage damage	Social + Economical	1 temple collapsed and 1 partially destructed	5,00,000 NRs Approx
Roadway blockage	Social + Economical	1 highway blocked case and 8 local pathways blocked in approx	100005 NRs Approx
Agricultural land destruction	Economical	150 ha approx	71,00,000 NRs Approx
		Total	NRs 15850000 approx

List of social losses from landslide

Table 2 illustrates data on different kinds of social losses faced by the vulnerable communities. The most common social damage was livestock fatalities which was observed among 50% of the plots surveyed. Likewise, the least affected social damage was the loss of human lives from landslides that happened within only 2/8 of the sample plots.

Table: 2 List of social losses from landslide

Landslide plot no. **Nature of social losses**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Loss of human lives	-	1	-	-	-	-	-	1
Livestock fatalities	5	7	6	-	4	-	-	2
Social structure damage	-	-	2	-	1	1	-	2
Cultural heritage damage	-	-	-	-	-	1	1	-

Economic losses from Landslide (according to people's perception)

The figure 7 shows economic losses from landslides in monetary terms (in NRs). Class A- from 1 to 10 lakhs, B- 10 to 50 lakhs, C- above 50 lakhs. Observed landslides were placed under the given classes based on the amount of money required for its compensation according to people's perception. Results showed that maximum number of landslides fell under class A and B i.e. 1 to 10 lakhs and 10 to 50 lakhs compensation amount.

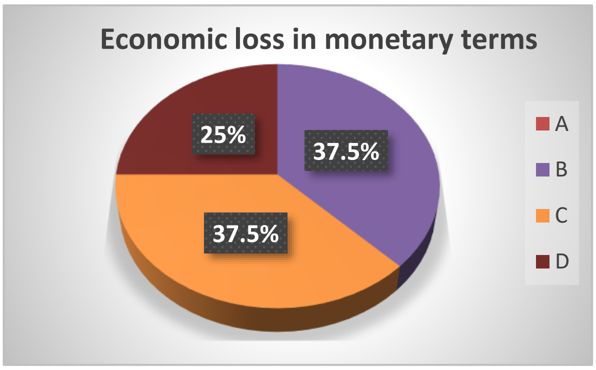

Figure 7: Economic losses from landslide

Losses in terms or monetary transaction
- A: 1-10 lakhs
- B: 10-50 lakhs
- C: >50 lakhs

3.3. Mitigation techniques

The figure 8 shows the mitigation techniques that were applied in Bagnaskali rural municipality representing the composition of civil engineering and bio-engineering techniques applied. Civil engineering techniques refers to the sole integration of concrete structures while Civil+ bio techniques refer to the combination of civil techniques along with vegetative plant structures added to support it. The study showed that civil engineering technique was applied among all field plots thus representing 100% composition of total bio-engineering along with civil engineering comprising 75% that was applied among 6 out of 8 plots surveyed.

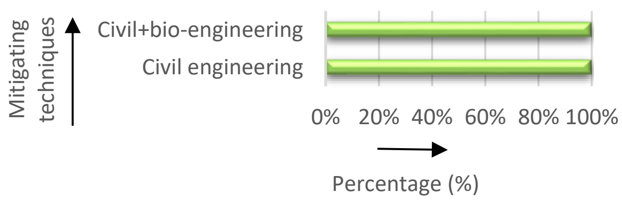

Figure 8: Applied mitigation techniques of landslide

Civil engineering techniques

The study showed that gabion wires, masonry walls, culvert, check dams and RCC were the major civil engineering techniques that were adopted in the study area as mitigation techniques. Among them, the most commonly applied civil engineering technique was gabion walls that was seen to be applied in 3 out of 8 plots followed by RCC that was applied at 2 out of 8 while others were applied at single plot.

Main purpose of this technique was to stabilize the landslide prone terrain and this technique was quite effective in the site to stabilize the landslide.

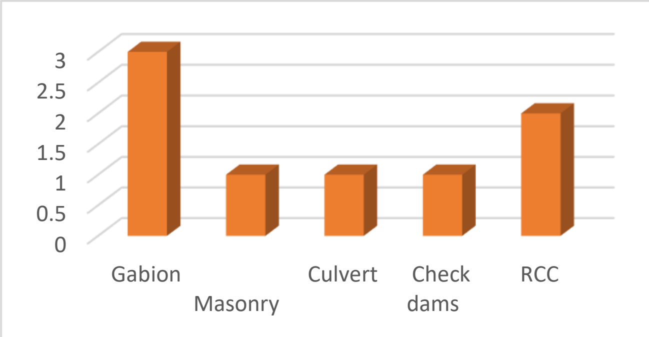

Figure 9: Applied civil engineering techniques

Bio-engineering techniques

Figure 10 demonstrates several kinds of bio-engineering techniques being applied at the study area. Plantation, watling and brush layering were the techniques applied. The main benefit of the bio-engineering method was that the materials for stabilizing slopes were cheaper and easily available. Among them, plantation was the most preferred option used for bio-engineering. Plantation of Amriso was comparatively easy and cost-effective. Hence, Amriso was highly prioritized among plantation techniques. Very few and rare were the cases of watling and brush layering were being applied.

Bio-engineering along with civil-engineering technique

The result from the figure 11 shows the combined application of civil along with bio-engineering techniques at the study area. It shows dominance of Gabion+ Amriso and RCC+ Amriso+ Napier techniques which is seen to be applied at 5 sites out of 8 sites surveyed. The main aim of integrating bioengineering structures to concrete engineering structures is to provide strength and longevity to the structures so that it can become sustainable in the long run. In most of the landslide prone sites, the combined bio+ civil engineering structures resulted in creating stable slopes that reduced the chances of landslide occurrence.

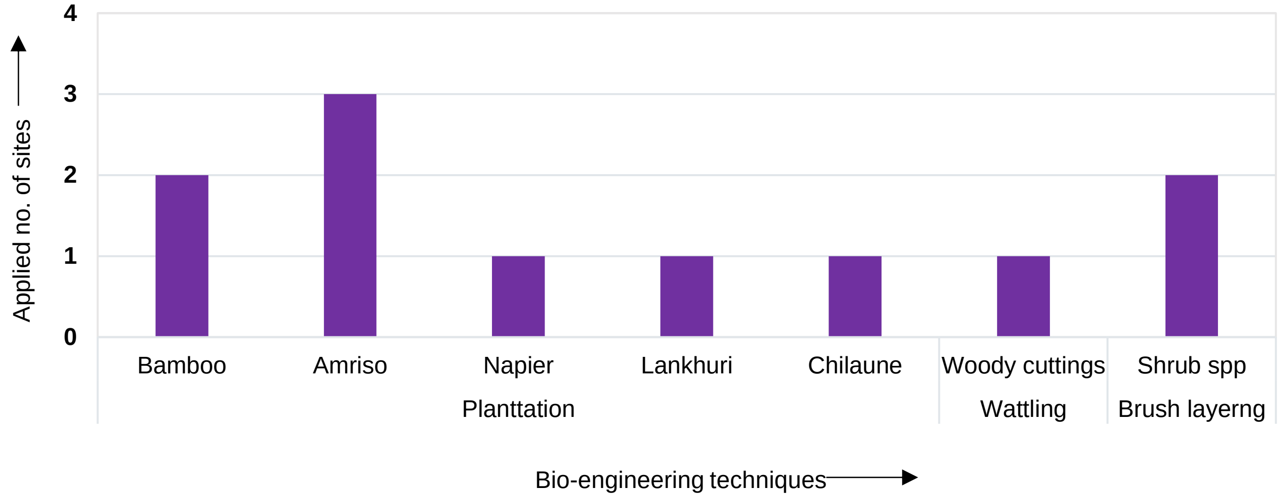

Figure 10: Applied bio-engineering techniques

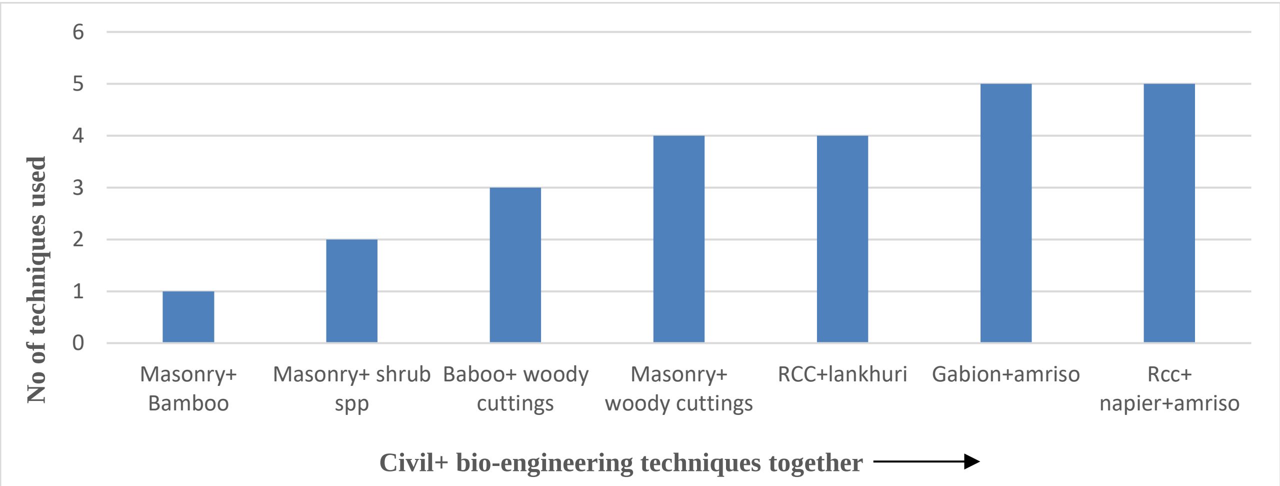

Figure 11: Application of Bio-engineering along with civil-engineering technique

4. Discussion

Several studies have shown that landslides are one of the most destructive and probably the most vulnerable natural disasters occurring worldwide. From 1998 to 2017, an estimated 4.8 million people were affected and 18,000 deaths were caused by landslides (WHO, 2023). A study from the United Nations' Food and Agriculture Organization in 2011 states that Nepal has been one of the countries with highest fatalities from landslides.

Landslides do not only destroy the landforms and cause land degradation but also possess threat and challenges to the communities affected. It leads to soil erosion and nutrition loss, contamination of water sources affecting local ecosystems and biodiversity etc. Communities vulnerable from landslides are often compelled to leave their place of origin and compromise with heavy social and economic losses as it destroys homes, buildings, roads, and bridges, leading to the disruption of transportation networks and communication systems.

Falls and flows are the dominant forms of landslide prevalent in Bagnaskali rural municipality with their highest frequency of occurrence from Ashad to Bhadra months in Nepal. More than 90% of landslides in Nepal occur during the monsoon between June and September, peaking in July and August (Bhusal, 2020). These results from Bhusal, 2020 are in accordance with this study. Loss of lives and damage of social and cultural heritage are the social losses addressed from the study area while the economic loss seems to be a more critical issue than social loss. Heavy compensatory amount upto NRs 50 lakhs have been invested for mitigating landslide.

Both civil and bio-engineering techniques have been applied to minimize and control landslides. Civil engineering structures were applied to the slopes that had solid soil structure that could hold the weight of the structures whereas bio-engineering structures were applied to shallow seated unconsolidated soil structure to provide rigidity and strength to the soil. Gabion walls, masonry walls, RCC walls, drainage structures/culverts are the common civil engineering techniques being applied and bio-engineering techniques include plantation, wattling, brush layering etc.

A study shows that soil bioengineering technique have been extensively used in recent year because they are cost-effective, flexible, and applicable in remote areas by using locally available materials and because they require low-cost labor in comparison to more elaborate civil engineering works (Li & Eddleman, 2002; Wu & Feng, 2006; Li et al., 2006; Evette et al., 2009; Rey & Burylo, 2014). Bioengineering offers an environment friendly and highly cost and time effective solution to the slope instability problems in mountainous and hilly areas (Singh A. K., 2010). In contrast, this study showed that civil engineering structures are the most commonly used techniques than bioengineering techniques. This was a site-specific scenario due to lack of technical knowledge on soil bioengineering techniques or due to the easy access and availability of civil engineering structures such as gabion wires, stones for gabion filling, cement, concrete, etc. In contrast to study from (Dhital, 2013) which says in recent years, soil bioengineering techniques are extensively used due to their cost-effectiveness, using locally available materials and low-cost labor in comparison to more elaborate civil engineering works, civil engineering techniques were more preferred than bioengineering techniques at Bagnaskali rural municipality. The contrasting result was mainly due to the lack of technical knowledge of bioengineering at the study area. Though materials for bio-engineering were easily available at Bagnaskali, local residents were not familiar with those types of mitigation techniques. Rather people found it easier to apply civil engineering techniques as they were less laborious than self-establishment of bio-engineering structures.

Despite having one of the highest mortality rates per capita in the world, the government of Nepal has failed to address the risk of landslides as indiscriminate road construction and climate change exacerbate the situation. (Bhusal, 2020). It is essential for the government to prioritize landslide risk reduction and provide necessary support to protect vulnerable communities. One of the significant challenges faced by the government of Nepal is the rapid and unplanned road construction, improper road alignment, cutting slopes without appropriate stabilization measures, and inadequate drainage systems that contribute to increased soil erosion and instability, leading to landslides.

Thus, the government must impose tight standards and norms for development works, ensuring that environmental and geological analyses are carried out before such projects are undertaken which is a crucial part for extracting the appropriate solutions to landslides. Without the support and intervention of the government, assessment of the impacts of landslides and effective mitigation techniques becomes difficult to formulate.

5. Conclusion

Landslides stand as one of the most devastating natural disasters globally, inflicting substantial social damage and incurring multimillion and billion-rupee losses for recovery efforts. In Bagnaskali rural municipality, Nepal, falls and flows emerged as the prevailing forms of landslides, predominantly striking during the rainy season from July to August. The social toll encompassed the loss of two lives, 24 fatalities among livestock, destruction to six households, and damage to two cultural heritage sites. Remarkably, substantial compensatory investments, reaching up to NRs 50 lakhs, have been allocated to mitigate landslide risks.

Mitigation techniques have proven effective to a certain extent in controlling landslides by stabilizing slopes and imparting mechanical strength to the soil. Among the civil engineering techniques employed, gabions were the most prevalent. Meanwhile, within the realm of bioengineering, amriso plantation emerged as the predominant approach in the study area. Interestingly, combining civil engineering and bioengineering techniques resulted in the most successful and dominant mitigation strategies. Bioengineering techniques were typically applied as a complementary foundation following civil engineering interventions. In general, the simultaneous use of both civil and bioengineering techniques contributed to the enhanced stability of slopes.

Governments play a pivotal role in mitigating the destructive impacts of landslides and ensuring the safety and well-being of their populations. This entails harnessing expertise, enacting suitable regulations, investing in infrastructure, and fostering awareness. Effective reduction of landslides and the protection of vulnerable communities necessitate comprehensive policies, legal frameworks, and substantial investments.

For future research, it is advisable to investigate the effectiveness of specific mitigation techniques, delve into the socio-economic ramifications of landslides in greater detail, and explore the long-term stability of slopes treated with combined civil and bioengineering methods. These inquiries will contribute to a more robust understanding of landslide dynamics and mitigation strategies for the benefit of vulnerable regions.

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