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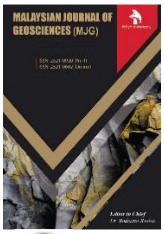

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RESEARCH ARTICLE

LANDSLIDE OCCURRENCES AND COMMUNITY-BASED RISK REDUCTION ALONG THE STATE HIGHWAY-12 ADJACENT TO LESSER HIMALAYAS: RESEARCH INSIGHTS

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ABSTRACT

The Kalimpong district of West Bengal stretches overlesser Himalaya which is highly susceptible to landslides along the SH-12. The research offers valuable insights into the relationship between natural hazards and human systems in this area and also investigates the affected institutions and communities to manage landslide.The present research attempts to explore the important factors responsible for slope instability and the critical examination of attributes underscores the complex interplay of geological, topographical, and environmental factors which mainly includes the steepness of the slope, low strength of rock, porosity and permeability of rocks and active soil erosion. Additionally, to investigate the community-based adaptation practices (CAP) to prevent landslide occurrences, Analytical Hierarchical Process (AHP) has been applied. For stakeholders and decision makers it emphasizes the critical need for comprehensive understanding and proactive mitigation strategies to mitigate their potentially devastating impacts on human settlements and infrastructure.

KEYWORDS

Landslide, Slope instability, Lesser Himalaya, Adaptation practices

1. INTRODUCTION

As defined and the UNESCO IAEG Commission on landslides and other mass movements "landslide hazard" refers to the likelihood of a damaging landslide event happening in a specific area over a certain timeframe (Varnes, 1984). This definition includes ideas about geographical factors and recurrence, addressing where and when such a damaging landslide event (i.e., hazard) is expected to take place (Reichenbach, 1999). However, they revised that definition by adding the aspect of potential event magnitude, thereby redefining landslide hazard in a particular area based on three parameters which are the temporal, spatial and magnitude of probabilities of landslide occurrences (Guzzetti et al., 1999). Landslides of various types and sizes typically experience different frequencies of occurrences. Smaller landslide incidents generally take place more often than larger ones. Different landslide types and sliding mechanics have distinct triggers (such as varying intensities, duration and prior conditions of rainfall; earthquakes with different magnitude) that occur with differing recurrence intervals. The occurrence of landslides in response to rainfall is usually non-linear. For minor slides from natural slopes and excavated areas, there is frequently a 'threshold' level of rainfall below which minimal or landsliding is observed, followed by an increased frequency of landsliding once the rainfall exceeds that threshold (Finlay et al., 1997 and De, 2017). In case of larger landslides, it is the interplay between the intensity of rainfall and the preceding rainfall accumulated over time, intensity and pre-earthquake rainfall triggers the activation of landslides (National Landslide Risk Management Strategy 2019). The occurrences of landslides are affected by multiple factors, specifically geology, proximity to the fault, landscape, vegetation cover and rainfall. Landslides happen on both natural and artificial slopes due to elements that initiate soil movement. Regulating alterations in land use on slopes are critical since they may result in reduced land stability, which in turn increase the likelihood of landslides during rainy season(Wang et al., 2017 and Setyawan, 2021). The moisture content of the soil increases as the pore water pressure increases because of continuous precipitation which in turn increases the infiltration and decreases the soils shear strength which loosens the compactness of the slope (Abrahamand, 2019 and Roy et al., 2019). Due to these above-mentioned alterations, deformations take place along the slope, leading to progressive failure of slope materials and this threatens life and property (Baum and Godt, 2010 and Sharma, 2008).The Kalimpong district of West Bengal is locally administered and falls under the jurisdiction of Gorkhaland Territorial Administration. The Kalimpong district has a long history of landslides starting from 1899, 1950, 1968, 1976, 1991, 1993, 2003, 2004, 2005, 2006, 2009, 2011 and 2015 (District disaster management plan Kalimpong 2017, 2019 and District survey report of Kalimpong district 2022). The mountain regions of Kalimpong are naturally susceptible to landslides due factors like incessant rainfall and heavy rainfall, seismic occurrences, weathering and toe erosion by rivers (Petley 2012 and Sarkar et al. 2013).Kalimpong Hills is a part of active Himalayan system. The huge amount of compression caused by the continental plates convergence in this area has resulted in extensive deformations in lithological units. Schist planes, cracks, joints and thrust planes are present in the region hence making it a fragile lithology. This fragile lithology loses its compactness and unity during rainfall leading to slope instability and eventually slope failure causing landslide. Kalimpong is a tourist attraction spot which led to the urbanization of the district.

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Rapid populationgrowth and increase in human settlements have caused deforestation. Forest was cleared and were replaced by Tea gardens leading to the loss deep-rooted stability and compactness of the soils. Development of modern infrastructure facilities like communication lines were constructed, roads, buildings and dams for hydro-power generation have added to the fragility of the slopes (Roy et al., 2022 and Bera et al., 2020). Changes in pattern of rainfall has impacted the rice production. Climate conditions like less predictable weather pattern, increase in temperature and short duration intense rainfall has added to the problems of the people. Due to such changes the people have become more vulnerable to landslides in Kalimpong. The erratic changes in weather have led to the loss of agricultural lands of farmers due to landslips and also impacted the agricultural livelihood of the farmers(McGowran, 2024 and Gerrard, 1994). Hence it also becomes important to focus on the adaptation practices to adapt to the natural hazard like landslide. It is very important that local institutions and administration need to advocate as key enablers of the adaption practices as the local administration and institutions play a significant role in determining the access to resources that the households depend on and which eventually shapes the household's ability to manage and combat risks (Ojha et al., 2021 and Sudmeier-Rieux, 2012). Human activities including deforestation and slope excavation for making roads and increase in construction sites, among others have become significant cause of landslides due to the stress of urbanization and population growth (Dai et al., 2001). The study focuses on the slope instability in the arterial and transportation network along the SH-12 of Kalimpong district, as landslides along the arterial roads cause major issues that disrupt traffic between the hills and the plains, which cause operational impact on the tourists, the transportation of goods and livelihood of the local people of Kalimpong.

2. Methodology

To fulfill the objectives, the methodology is categorized into three phases, firstly information related to the study area; second, framing the required database for the study and finally, the selection of methodologies to analyze and interpretation the findings.

2.1 Study Area Information

The Kalimpong district was formed by the division of Darjeeling district on 14th February 2017. Kalimpong district falls on the northern part of west Bengal and is bounded by Bhutan on the east, Darjeeling district on the west, Sikkim in the north and Jalpaiguri in the south. The district consists of three blocks namely Kalimpong Block-I having 18gram panchayats, Kalimpong Block-II having 13gram panchayats, Gorubathan having 11 gram panchayats and Kalimpong municipality. Major roads mainly are NH-10 running from Birikdara under

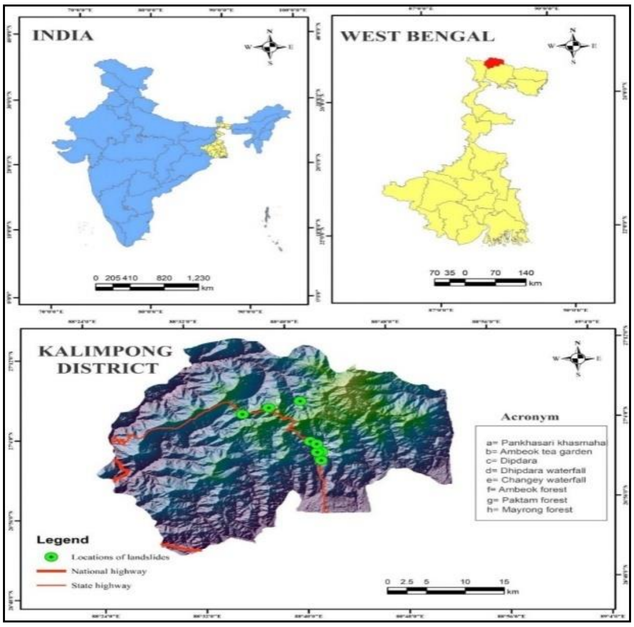

Figure 1: Location Map of the study area

Kalimpong-I block, which continues to Rangpo border and the SH-12 runs from Teesta to Bhutta Bari under Gorubathan Block via Algarah-Lava (District disaster management plan Kalimpong 2019). The topography of the district is characterized by significant elevationvariations. The highest and lowest elvation of the district are recorded 3177meters and 137 meters respectively from above sea level. The district drained by several Major riversnamely Teesta and Jaldhaka, along with smaller rivers including Lish, Geet, Chel, Neora, Relli, Riyang, Rangpoo Chu, Rishi Chu, Jaldhaka, Ni Chu and Murti (District survey report of Kalimpong district 2022).Over 80% of the population in Kalimpong rely on farming for their livelihood. The district is very prone and susceptible to landslide because of poor and inadequate water retention capacity of the soil combined with steep slope land. Moreover, the district falls under the seismic zone IV making it prone to earthquakes. The geological structures of the district reveal that metamorphic rocks dominate a significant portion of the region. To the South of the district, unaltered sedimentary rocks can be found (CGWB 2023). The Kalimpong district's Darjeeling hills are composed of Precambrian slates, schist, phyllite, quartzite, gneisses, lower Gondwana and Siwalik sandstones, along with recent to sub-recent alluvium (Cajee, 2018). The soil pattern of the district is majorly of two types namely Brown Forest soil of hill slopes and terai soil. The district has a total area of 1053.12 sq. km. and total population of 251642 (census, 2011). The study aims to assess the extent of damage caused by landslide, identify vulnerable areas and evaluate the impact on road infrastructure. Detailed observations were conducted regarding the slope stability, drainage conditions and existing preventive measures with the help of checklist. The eight critical landslide-prone points were, PankhasariKhasmahal, Ambeok Tea Garden, Dipdara, Dhipdara Waterfall, Changey Waterfall, Ambeok Forest, Paktam Forest and Mayrong Forest. These points were selected to provide a comprehensive understanding of the landslide occurrences and community-based risk reduction.

2.2 Database

The database consists of the framework required for field survey study by assessing the necessary literature reviews for setting different factors responsible for landslides, required methodology for it, along with the data to support it and to prepare the check list and Focused Group Discussion (FGDS) questions for field visit.

Table 1: Database for field survey

Sl. No.	Purpose	Methodology	Data Source	Reference
1.	Domineering Factors	• Landslide Hazard Evaluation factors under Bureau of Indian Standards. • Brunton Compass • Theodolite	• Check list survey	• BIS, 1998 and Anbalagan, 1992 • Saibal Ghosh, 2009

Table 1 (cont): Database for field survey				
2.	Relation between Landslide Occurrences and Local Human System	• FGDs	• Field survey	• Mukherjee, N. (1993). • Mukherjee, N. (2002).
3.	Community based Adaptation Practices	• FGDs and AHP	• Field survey for perception study.	• R.W. Satty, 1987 • Hamed Taherdoost, 2017 • T. L. Satty, 2008

2.3 Methods and Application

The study is based on primary data collected during the field visit to Kalimpong district along the landslide affected sites of the State Highway-12. Three Focused Group Discussion (FGDs) were carried out in 3rd mile, two in 6th mile and two in Pankhasari Khasmahal. The Bureau of Indian Standards formulated guidelines were used to prepare the check list was used for surveying the landslides occurred along the SH-12. This standard offers a Landslide Hazard Evaluation Factor (LHEF) rating system, a generalized heuristic approach of fixed weighting or ranking of a collection of pre-defined geo-factors (Ghosh et. al., 2009). Further Analytical Hierarchy Process (AHP) method was used to assess the landslide hazard at four levels by defining the problem. Determining the goals, constructing the pair wise comparison matrix, assigning the weights and obtaining the overall priority (Satty, 2008). The factors taken are as sensitivity, critical stress moment and adaptation practices (Pardeshi et. al., 2013).

A specialized, multipurpose compass, the Brunton Compass is used in geology, surveying, and navigation to measure azimuths, bearings and structural geological elements like the strike and dip of rocks formation with accuracy. Geologist, engineers and outdoor professionals utilize it extensively.

Theodolite are precise optical tools used in engineering, building and surveying to measure angles both vertically and horizontally. It is essential tool for geographer, geologist, civil engineer and land surveyors, guaranteeing precise alignment and placement in tasks like building bridges, roads and surveying lands. Accuracy and efficiency have increased as theodolites have progressed from mechanical vernier models to digital and electronic equivalents. For improved usefulness, contemporary theodolites incorporate data storage and electronic distance measuring (EDM), much like total station.

The Bureau of Indian Standard (BIS) provides guidelines for Landslide Hazard Evaluation under IS 14496:1998 (Part 2) - *Guidelines for preparation of Landslide Hazard Zonation Maps*. This standard outline key factors for assessing landslide susceptibility and risk. The Landslide Hazard Evaluation rating system is based on specialist expertise in the investigation of geofactors and how they contribute to landslide; as a result, the numerical values of rating are mostly determined by qualitative evaluation. The LHEF is done based on the geofactors such as: Lithology; Structure; Slope; Relative Relief; Land use and land cover; and Hydrological conditions.

Table 2: LHEF ratings of different causative geofactors (BIS, 1998 and Anbalagan, 1992)

Geofactor	Description	LHEF	Category	
Lithology		0.2		Quartzite and Limestone
	Rock type	0.3	Type1	Granite and Gabbro
	Type – 1**	0.4		Gneiss
	Highly weathered (4);	1.0		Sandstone and minor beds of clay stone
	Moderately weathered (3);	1.3	Type2	Poorly cemented sandstone with minor
	Slightly weathered (2)			clay /shale
	Type –2**	1.2		Slate and phyllite
	Highly weathered (1.5);	1.3	Type3	Schist
	Moderately weathered (1.25);	1.8		Shale with inter bedded clayey and non-clayey
	Slightly weathered (1.0)	2.0		Highly weathered shale, phyllite and schist
	Soil type	0.8		Older well compacted alluvial fill material
		1.0		Clayey soil with naturally formed surface
		1.4		Sandy soil with naturally formed surface (alluvial)
				Debris comprising mostly rock pieces mixed with
		1.2		clayey / sandy soil (colluvial)–older well compacted
				Debris comprising mostly rock pieces mixed with
		2.0		clayey / sandy soil (colluvial)–younger loose material
Structure		0.20	>30°	
	Relationship of parallelism	0.25	21°–30°	
	Between the slope and	0.30	11°–20°	
	Vulnerable discontinuity	0.40	6°–10°	
		0.50	<5°	
	Relationship of dip of	0.3	>10°	
	Vulnerable discontinuity	0.5	0°–10°	
	and inclination of slope	0.7	0o	
		0.8	0°–(-10°)	
		1.0	<-10°	
	Dip of vulnerable	0.20	<15	
	discontinuity	0.25	16°–25°	
		0.30	26°–35°	
		0.40	36°–45°	
		0.50	>45°	
	Depth of soil cover	0.65	<5m	
		0.85	6–10m	
		1.30	11–15m	
		2.0	16–20m	

Table 2 (cont): LHEF ratings of different causative geofactors (BIS, 1998 and Anbalagan, 1992)				
	Escarpment / cliff	2.0	>45°	
	Steep slope	1.7	36°–45°	
Slope	Moderately steep slope	1.2	26°–35°	
	Gentle slope	0.8	16°–25°	
	Very gentle slope	0.5	≤15°	
	<100 m	0.3		
Relative relief	101–300 m	0.6		
	>300m	1.0		
Land use and Land cover	Agricultural land /populated flat land	0.60		
	Thickly vegetated forest area	0.80		
	Moderately vegetated area	1.20		
	Sparsely vegetated area with less ground cover	1.50		
	Barren land	2.0		
Hydro-geological conditions	Flowing	1.0		
	Dripping	0.8		
	Wet	0.5		
	Damp	0.2		
	Dry	0.0		

** Numerical values within parenthesis are correction factor for weathering

Focused Group Discussions (FGDs) are a qualitative research technique that examines participants' attitude, experience and views of a certain subject. A professional moderator facilitates participatory discourse in a small group of six to twelve participants through guided conversation. Through open-ended questions that accommodate a range of a viewpoints, focused group discussions (FGDs) yield deep, comprehensive insights. For the purpose to topic analysis, sessions are filmed and transcribed. This approach is especially helpful for creating hypotheses, comprehending group perspectives, and guiding the creation of policies or programs. FGDs provide useful qualitative data, but In order to reduce bias and guarantee equitable participation from every member of the group, they need to be expertly facilitated.

The Analytic Hierarchy Process (AHP) is a technique to calculate qualitative and quantitative multiple elements to select the best alternative involving a decision-making behavior. The AHP is utilized in this work to give weights to various indicators in order to evaluate landslide occurrences and the possible adaptive strategies to combat this event using the pair-wise comparison matrix of multi-criteria analysis.

Step 1: Developing a Model

Level 0 is the goal of the analysis. Level 1 is a multicriteria that consists of several factors. And the last level is the alternative choices based on the values of level 1.

Step 2: Derive priorities (weights) for the Criteria

Table 3: The Fundamental Scales of Relative Importance for Pair Wise Comparison	
The Fundamental Scale	
Importance Scale	**Definition**
1	Equally Important Preferred
3	Moderately Important Preferred
5	Strongly Important Preferred
7	Very Strongly Important Preferred
9	Extremely Important Preferred
2,4,6,8	Intermediate values between two adjacent judgements
1/3, 1/5 ,1/7, 1/9	Values of inverse comparison

Source: (*Satty, 1980*)

Based on the selected criteria and weights given to each criteria a pair comparison matrix will be calculate.

Table 4: Pair Wise Comparison Matrix				
Pair-wise comparison Matrix				
	X_1	**X_2**	**X_3**	**X_4**
X_1	1	$1/a$	$1/b$	$1/c$
X_2	a	1	d	e
X_3	b	$1/d$	1	f
X_4	c	$1/e$	$1/f$	1

Step 3: Consistency Check (Weights assigned correct or not?)

A crucial step in confirming the coherence and reasonableness of the assigned criterion weights is consistency validation. The Consistency Ration (CR), which evaluates the dependability of the decision make in the pair-wise comparison matrix statistically, is used for validation. The Consistency Index (CI), which measures the judgement matrix's departure from an ideal consistency state and is described as follows:

$$\boldsymbol{ConsistencyIndex} = \frac{\lambda_{\max} - \boldsymbol{n}}{\boldsymbol{n} - \boldsymbol{1}}$$

Where, $\lambda_{\max}$ represents the principal eigen value of the matrix, and n is the number of criteria.

The Random Index (RI), a common reference value depending on matrix size, is then used to normalize CI in order to develop the Consistency Ration (CR):

$$ConsistencyRatio = \frac{\text{Consistency Index}}{\text{Random Index}}$$

Table 5: Random Index (RI)

N	1	2	3	4	5	6	7	8	9	10	11	12
Random Index	0	0	0.58	0.9	1.12	1.24	1.32	1.14	1.45	1.49	1.51	1.48

Source: Satty, 1980

An appropriate degree of consistency is shown by a CR scoreless then 0.10, which suggests that the weights assigned establish logical. To improve the robustness of decision-making, the pair-wise comparison matrix must be revaluated if CR> 0.10, as this indicates severe inconsistency.

3. Results and Discussion

3.1 Domineering Factors

The factors analyzed below play a vital role in initiation and occurrences of hazard like landslide. So, it becomes essential to study the factors like weathering, past legacies of landslides, relief, drainage, soil, identification of rocks present in the area and influence of man-made features.

3.1.1 State of weathering

All of the studied landslide areas had moderate joint density, 35% of the landslide had moderate type of dip and 65% had steep/vertical type of dip, all the landslides had strong bed over weak bed present in the slide areas, the hardness of the slide materials was moderate in nature, 20% of the slide areas had medium kind of texture materials while 80% of the slide areas had coarse type of textured materials , degree of weathering was moderate in all the landslide areas, 40% of the landslide had moderate compressive strength and 60% of the landslides had low compressive strength and 65% of the landslides had low and 35% had moderate porosity and permeability.

3.1.2 Legacies from the Past

The landslide areas visited had past history which was visible during the field visit as 85% of the landslide areas had some previous landslides while 15% of the areas had frequent landslides. The landslide areas visited showed 35% slight and 65% moderate weathering. The slide areas also had 65% fossil solifluction while 35% landslide had no such legacies. The current condition of the landslide points showed that 55% of the slides had evidences of active soil erosion, 15% had some presence, slight presence in 15% and absent in 15% of the landslide areas.

3.1.3 Role of Relief

The 65% of the landslides had moderate valley depth and 35% had large valley depth. The steepness of slope the slide areas were moderate 35% and steep 65%, moreover the 50% of the landslide had presence of cliff and absent in 50%. The valley side slope hade 35% spur, 15% straight and 50% shallow cover, while the height difference between different valleys were observed which is as, 15% had small and large height each respectively and 70% had moderate height.

3.1.4 Role of Drainage

The present landslide inventory had very high drainage density. 65% of the landslide areas had gentle river gradient and 35% had moderate river gradient, slope undercutting was moderate in 80% landslide areas and severe in 20% areas, concreted seepage was present in 50% landslide areas and absent in rest 50% areas, standing water was absent in 81% areas and low in 19% areas, 40% of the landslide showed small and moderate recent incision each respectively while 20% had high recent incision and pour water pressure was low in 35% areas, moderate in 50% areas and high in 15% areas.

3.1.5 Role of Soil

Along the landslide sights the soil was present in 15% of the landslide valley floors, 35% of the site areas soil was present along the moderate slope and 50% of the landslide site had soil over the steep slope. The soil accumulation angle was moderate for 50% of the landslides, steep for 35% and 15% for very steep landslides. Depth of the soil for the slide areas were 60% moderate, low 20% and deep 20%. The sheet strength for the soil foe the landslide areas are high 20%, moderate 40% and low 40%. The liquidity index was low for all the landslide areas observed. The volume of expansion for the landslide areas were 85% moderate and 15% had high volume of expansion. The organic matter content of the soil was low in 85% of the slide areas and high in 15% of the areas. There was presence of coherent over incoherent beds over 80% of the slide points and absent in 20% of the areas.

3.1.6 Role of Man-made Features.

Excavation depth of the landslide areas was 35% small, 50% moderate and 15% has large depth. The man-made excavation position was 65% at high valley areas, 18% at low areas and 17% at valley areas. There was absence of reservoirs in the landslide points observed. 65% of the landslides had presence of drainage diversion across hillside and absent in 35% of the slide points. It was also observed 85% of the landslide areas had presence of cutting of basalt support and absent in 15% of the areas. 50% of the landslide had some loading of upper valley and the rest 50% had moderate loading. Deforestation was absent in 15% of the slide points, slight deforestation in 50% of the landslide areas and large deforestation in 35% of the areas. Roof-crop cultivation was absent in 50% of the areas, 32% had slight presence and 18% moderate presence in landslide areas. The unscientific construction was absent in 16% of the landslide areas, slight unscientific construction in 34% areas, moderate in 16% areas and high in 34% areas. Unscientific terracing was absent in 35% areas, slight in 50% areas and moderate in 15% areas.

Table 6: Identification of Rock types in Study Area

Description	Strength class (Selby, 1980)	Rock type (Selby, 1980)	Rock type (Identified from Checklist survey)	Photographic Evidence
Very weak rock	**5**	Chalk, Rock salt, Lignite, Phyllite	Phyllite	
Weak rock	**4**	Coal, Silkstone, Schist	Schist	

Table 6 (cont): Identification of Rock types in Study Area

Moderately strong rock	**3**	Slate, Shale, Sandstone, Mudstone	Sandstone	
Strong rock	**2**	Marble, Limestone, Dolomite, Andesite, Granite, Gneiss	Gneiss	
Very strong rock	**1**	Quartzite, Dolerite, Gabbro	Quartzite	

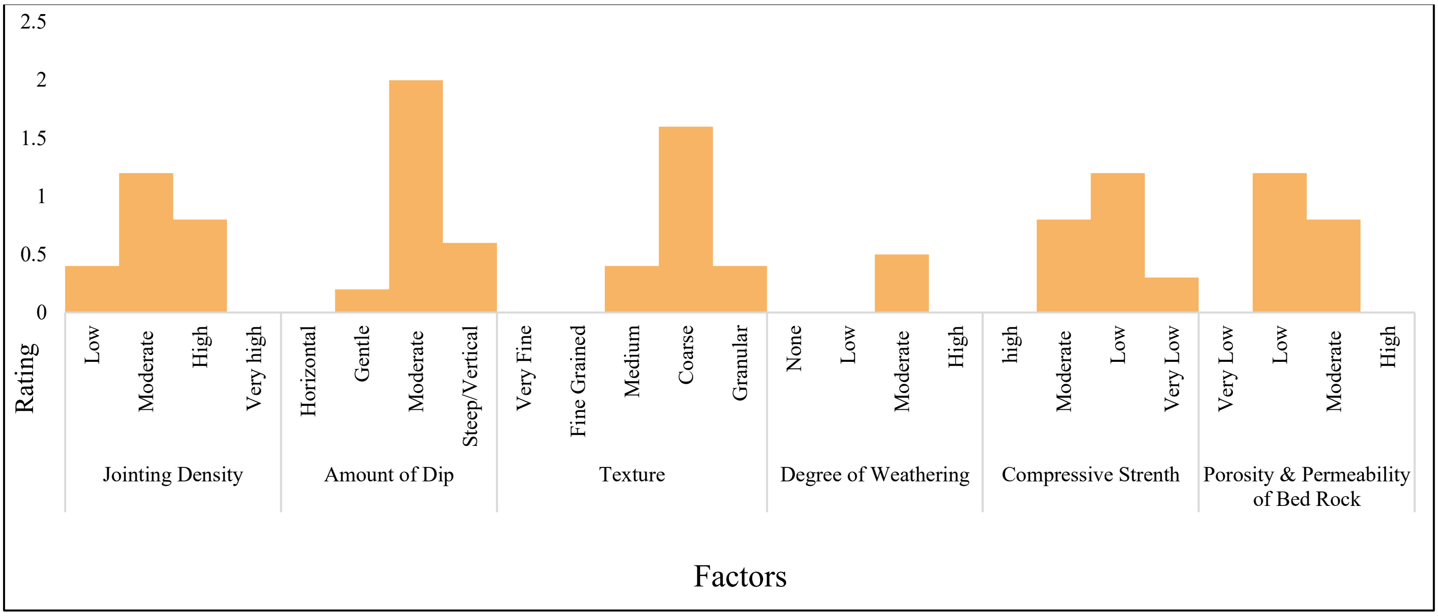

Figure 2: State of Weathering.

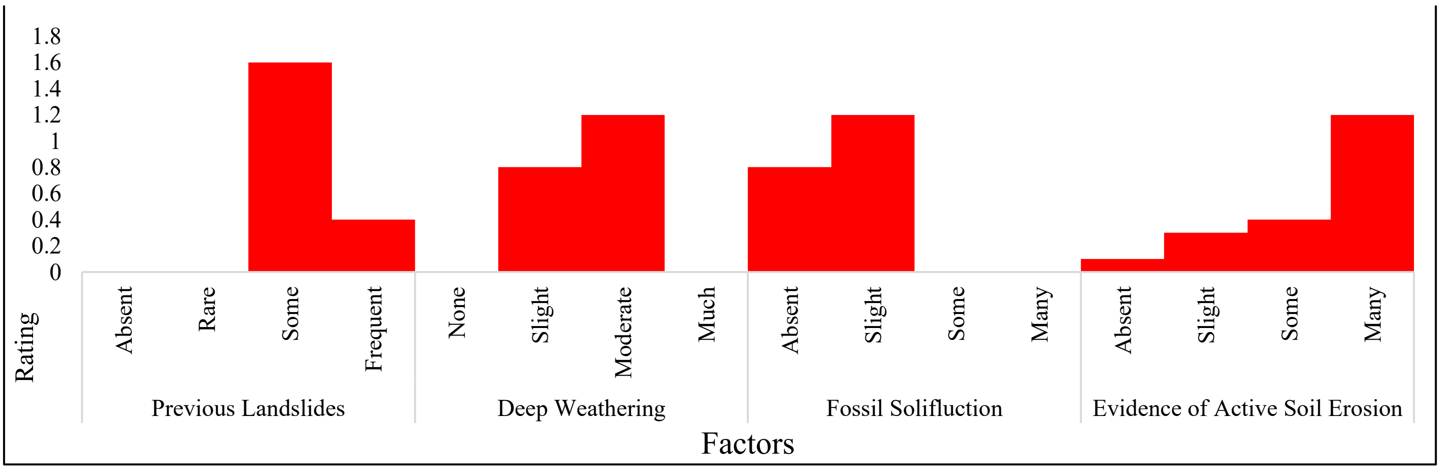

Figure 3: Legacies from the past.

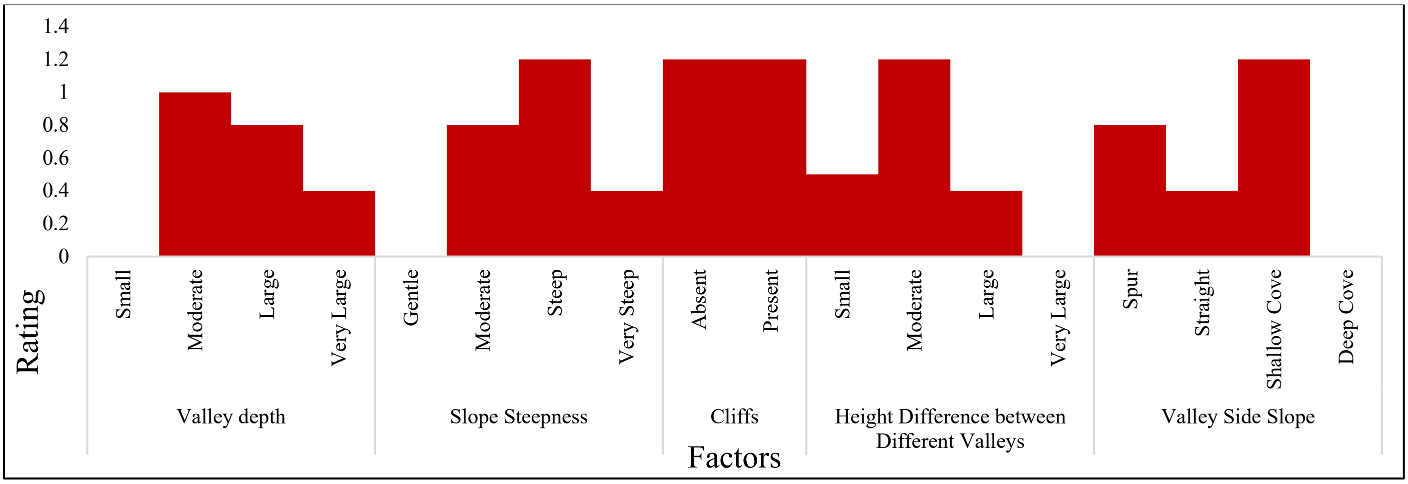

Figure 4: Role of Relief

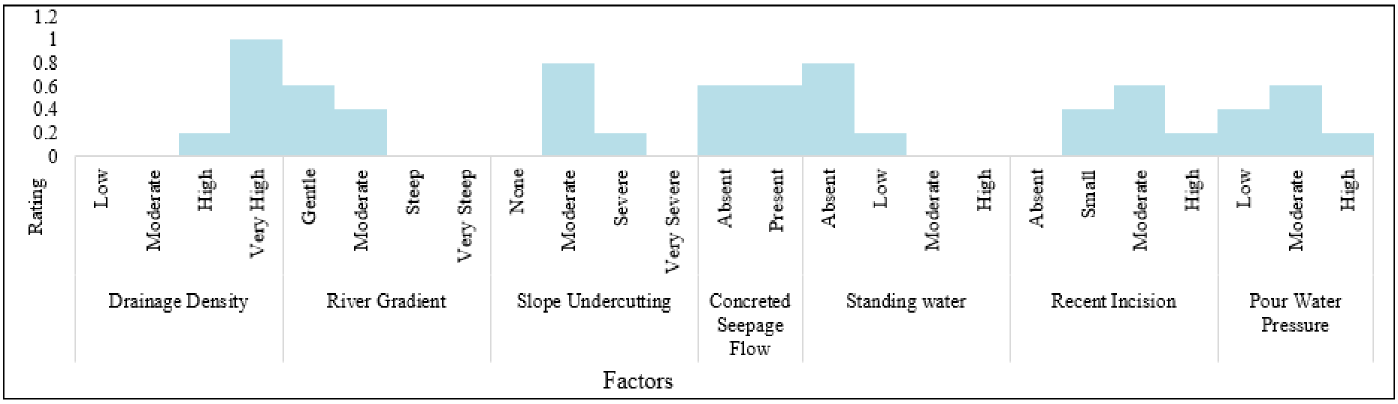

Figure 5: Role of Drainage

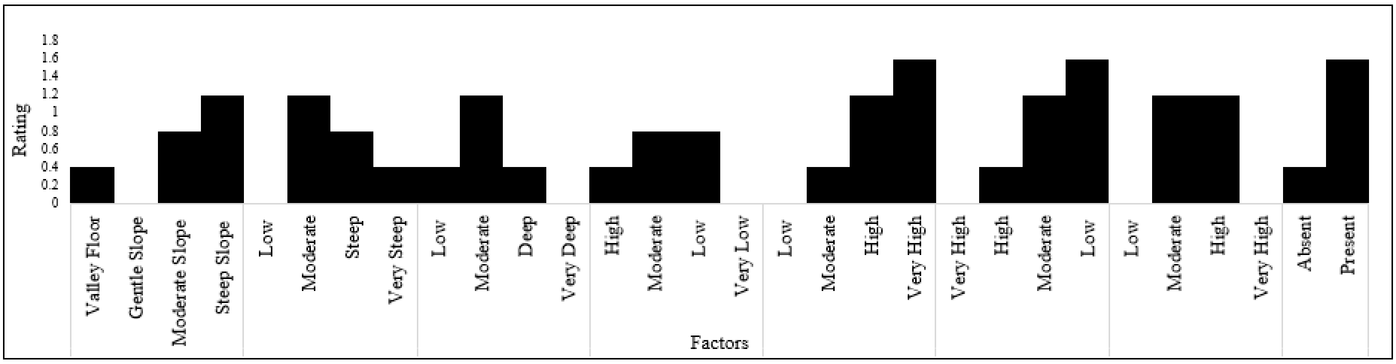

Figure 6: Role of Soil.

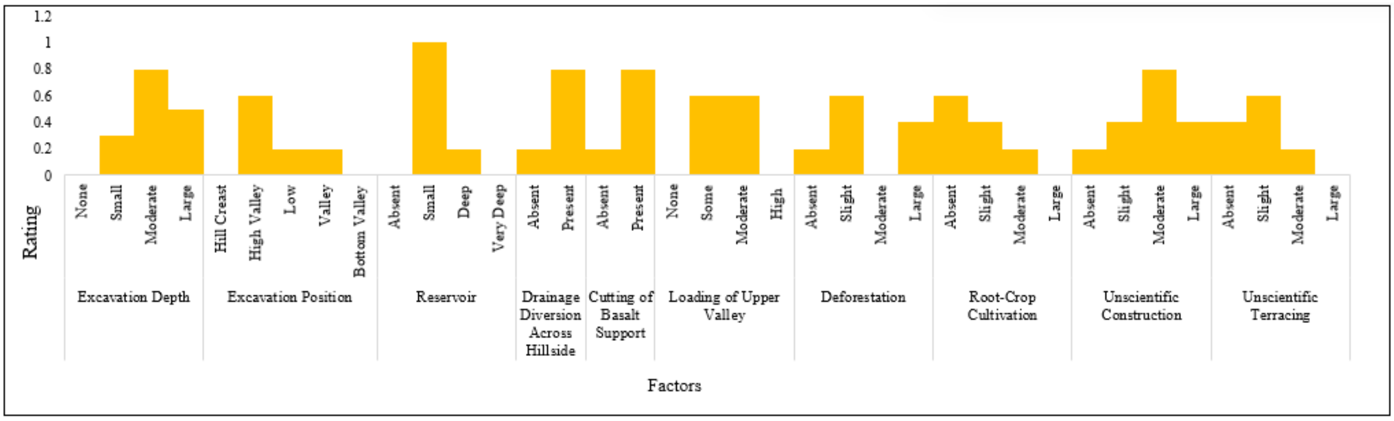

Figure 7: Role of Man-made Features

3.2 Relation between Natural Hazards and Local human system

3.2.1 Indicators of Climate Change

Approximately 2.57% of the respondent said that there has been increasing the amount of water available for livestock, while 7.89% of the people mentioned that there is increase in the amount of water available for household consumption. However, water availability for household use has decreased for 48.86% of the people, and for framing and cattle, it has decreased by around 51.22%. 43.25% and 46.21% of people, respectively, believe that the amount of water available for residential use and for farming and animals has not changed. About 60.28% of respondents saw a drop in crop productivity, and 54.66% of respondents saw an increase in the drying up of fresh water sources. Of those surveyed, 43.63% concur that the fresh water has not changed and 28.07% of the population saw no change in crop productivity.

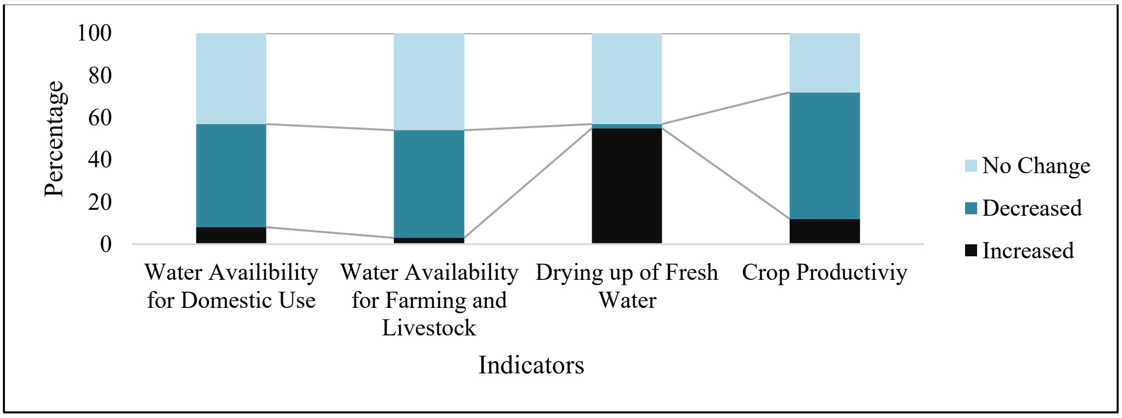

Figure 8: Indicators of Climate Change

3.2.2 Indicator of Socio-economic Development

Altercations in social and economic development metrics also cause landslides in mountainous areas. Road accessibility has improved over time, according to 67.89% of the population, while the household size has grown according to the 82.29% of the respondents. 59.36% of people have reported that their income has increased which has resulted in owning of more landownership as mentioned by 58% of the respondent.

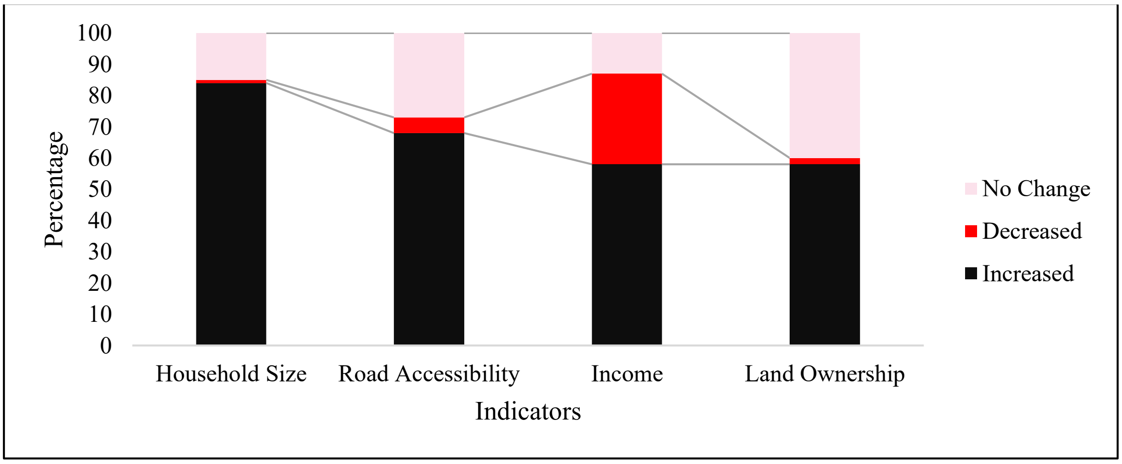

Figure 9: Indicators of Socio-Economic development.

3.2.3 Indicators of Resource Governance

According to 67.25% of the population, landholding sizes have grown larger. Traditional agriculture has slightly declined as stated by 48.09% of respondents, while many are now adopting modern agricultural methods, which has a support of 51.66%. However, the ratio of Gross Irrigated Area (GIA) to Gross Cropped Area (GCA) remains unchanged across different locations, noted by approximately 48.01% of the population. Additionally, 52.75% of the population reports no changes in the assessment of hazard information.

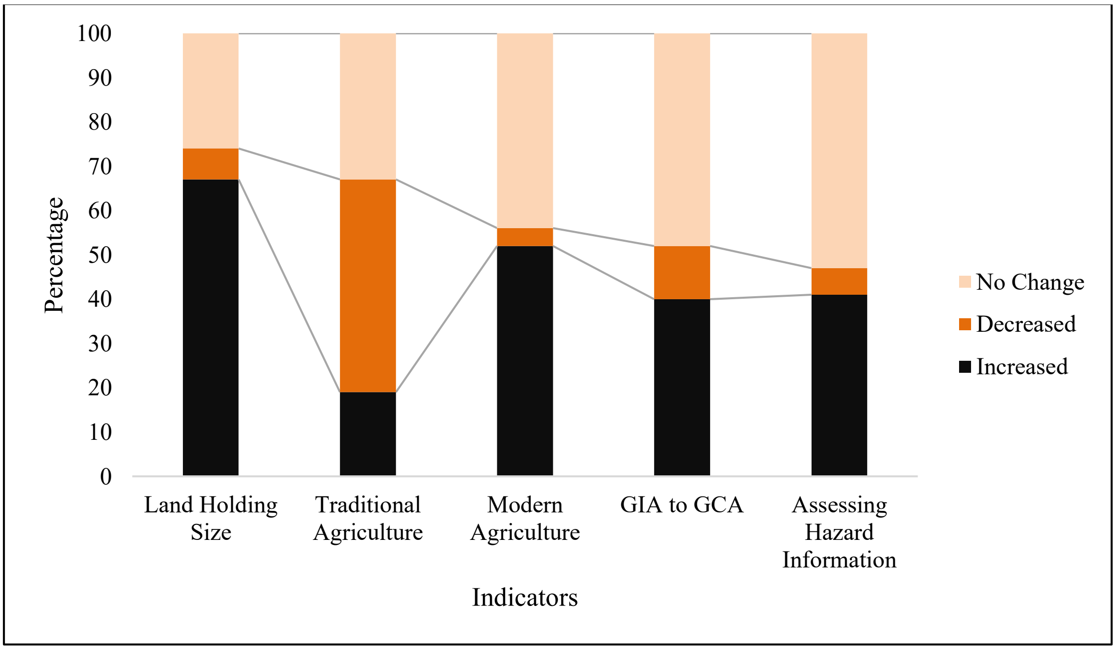

Figure 10: Indicators of Land Resource Governance

3.2.4 Bio-physical Drivers

According to 74.62% of the respondents, the intensity of rainfall has increased but the 84.21% of the people mentioned that the rainfall variability has also increased. 77.79% of the people believe that there has been no change in erratic events of rainfall while 18.77% of the people said that there is increase in rainfall erratic events. Thus, we can observe that the increase of landslides in these locations has been a result of a combination of rainfall intensity, rainfall variability and erratic events. According to 64.56% of the population, landslides are occurring more frequently. 33.43% of people believe that the frequency has remained unchanged. 51.68% of people have seen that landslides have become more intense, and 40.68% of people have mentioned that there has been no change in the intensity of landslide.

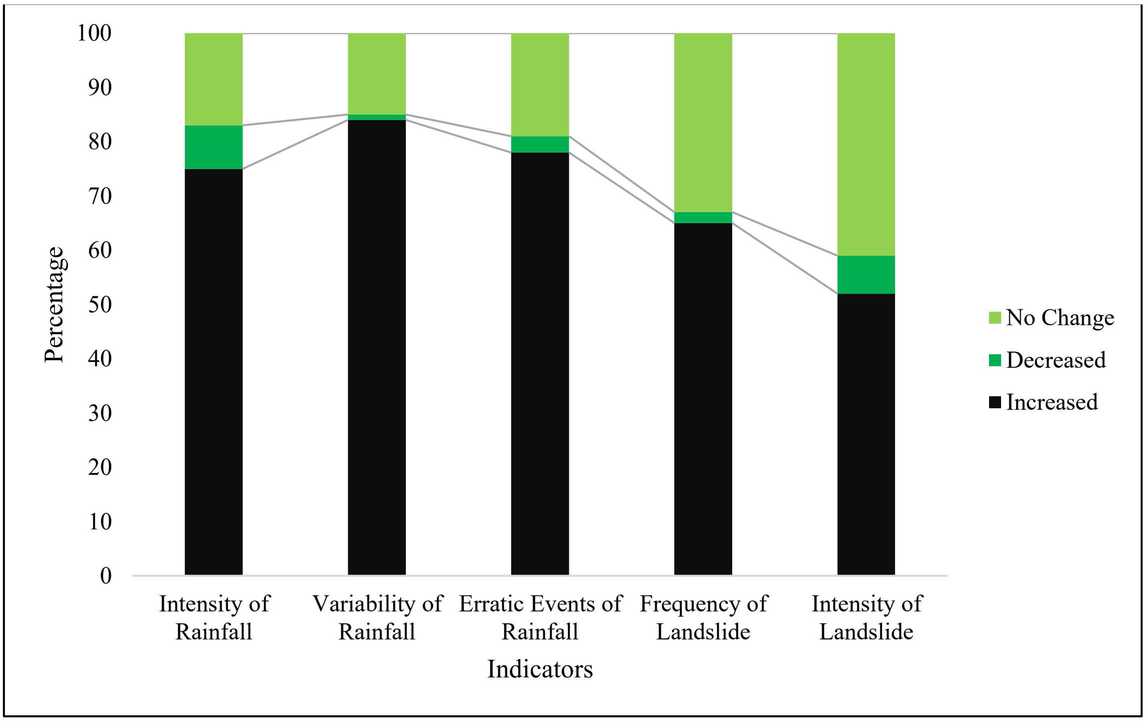

Figure 11: Indicators of Bio-physical Drivers.

3.2.5 Socio-economic Drivers

24.91% of the surveyed population voted for a drop in landslide awareness, while 64.55% of them supported raising knowledge of landslides in their community. While 77.47% of the population believes that population growth is on the rise, 8.26% believe that it has slowed, and 14.27% believe that nothing has changed. While 19.99% of the population believes that nothing has changed, 67.79% of the population believes that the vulnerability of the local population has risen. 59.99% of people say that social marginalization has risen. According to 9.58% and 30.43% of the population, social marginalization has decreased while remaining unchanged. The number of people changing their livelihoods has grown recently. While 24.4% of people believe that nothing has changed, 71% of people have observed an increase in the shifting of livelihoods. Since 57.77% of people agreed, there has been an increase in institutional backing. While 36.99% of the population saw a drop, 46.55% of the people voted for an increase in resources development. While 24.89% of people believe that poverty and marginalization have increased, 65.12% of people believe that poverty and marginalization have decreased.

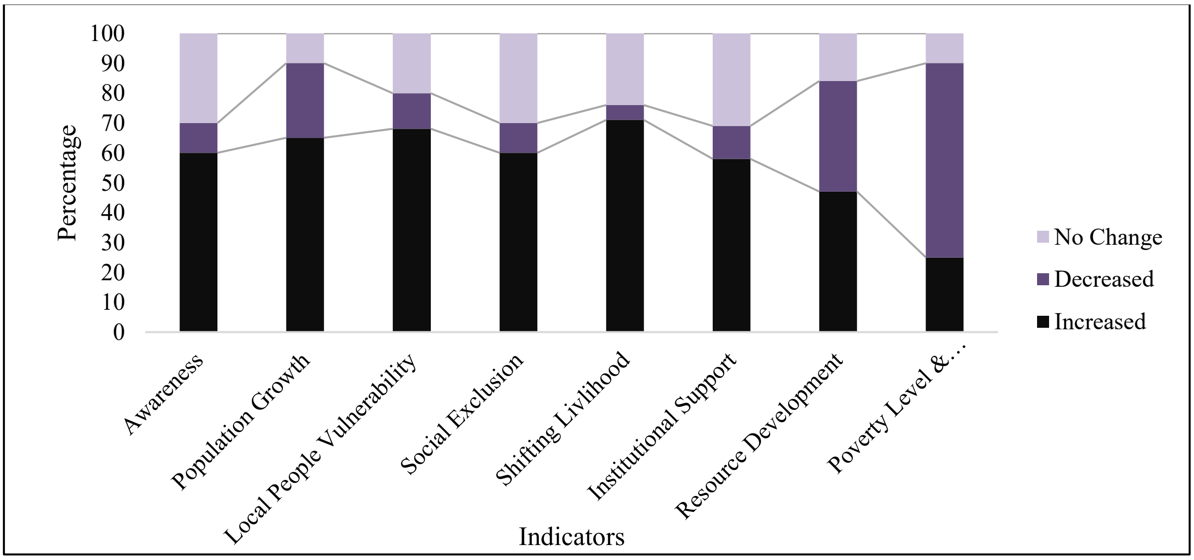

Figure 12: Indicators of Socio-Economic Drivers.

3.3 Community based Adaptation Practices

3.3.1 Sensitivity

With a weight of 0.202, the subfactor of fragile geology under the sensitivity factor has the greatest influence on the likelihood of a landslip because it contains rocks with low comprehensive strength and hardness, such as gneiss, schist, and phyllite. Due to active soil erosion and the presence of strong beds over weak beds, the slope undercutting has a weighted score of 0.142, making it the second dominant component. Although steep slope had a weighted value of 0.131 and heavy rainfall had a weighted score of 0.141, it has been noted that the "instability" of the slope increases as the slope's gradient increases. Additionally, the checklist survey indicates that 35% of landslides had moderate slope, whereas 65% of landslides had a steep slope.The least weighted score was 0.018 for inadequate road network. The sensitivity factor has a consistency Ratio of 0.093.

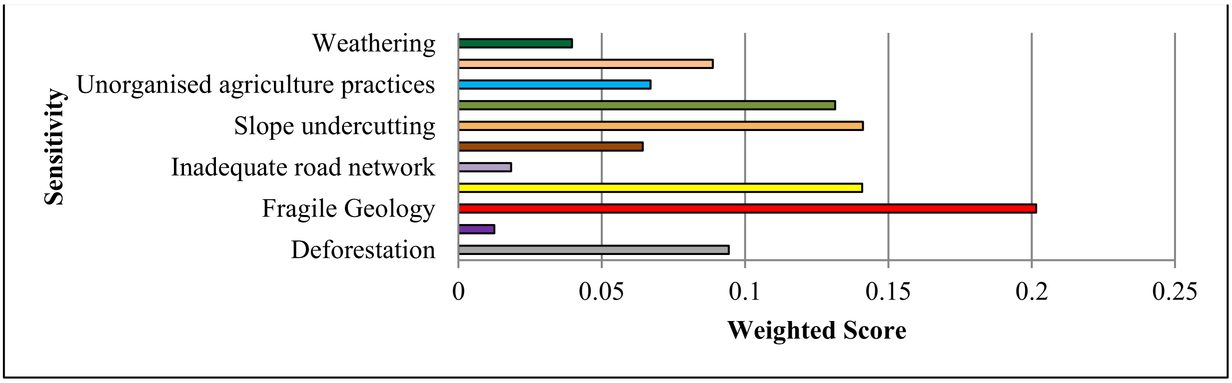

Figure 13: Sensitive factors of landslide along the SH 12, Kalimpong.

3.3.2 Critical stress moment

Within the critical stress moments factors, the slope failure parameter takes the most prominent role, achieving a score of 0.196, as the threshold capacity of the landslide site was surpassed, causing the slope failure. The second most significant factor is the disruption of road connectivity, which has a weighted score of 0.179 and results in a stoppage of vehicular traffic on the roads. The third stress factor is the decline in vegetation, assigned a weighted score of 0.177, and the reduction in vegetation, which aids in soil stabilization, contributes to soil degradation and erosion with a weighted score of 0.112. The critical stress moments have consistency ratio of 0.094.

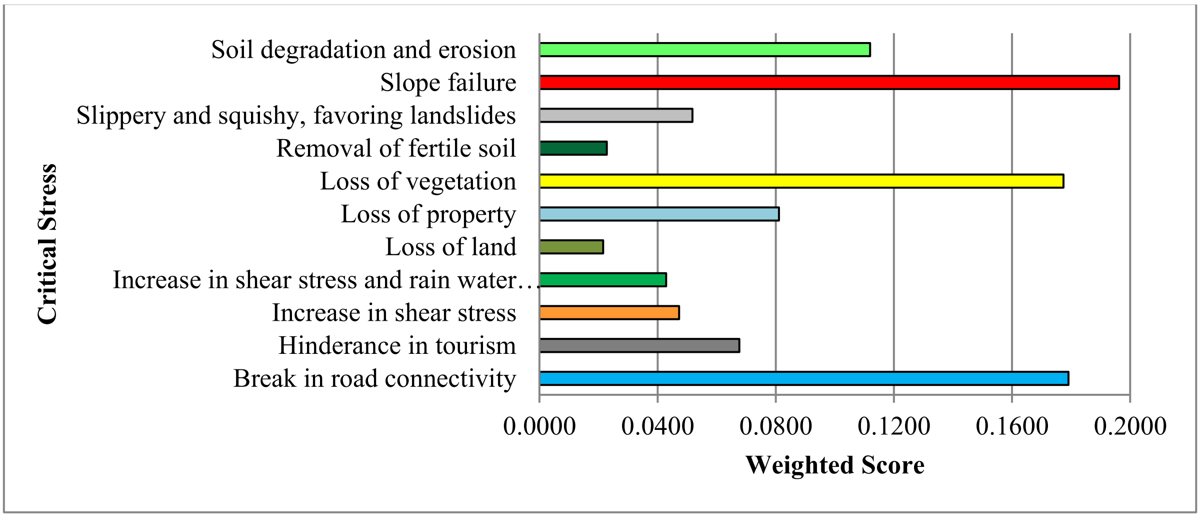

Figure 14: Local people perceptions on CSMs along the SH 12, Kalimpong.

3.3.3 Adaptation Practices

Adaptation strategies are crucial in addressing and averting landslides. Retaining walls, assigned a significant score of 0.238, are crucial in adaptation efforts as they help stabilize slopes, offer structural support to the land, and prevent soil erosion. The second most significant factors are terrace farming, scoring 0.188. This method utilizes significantly stepped sloping terrains, which decreases the velocity of water runoff and stabilizes slopes, thereby minimizing the possibility of landslides on farmers' agricultural lands. Thirdly, constructing check dams with a weighted score of 0.154 along minor waterways aids in diminishing landslide risks, while the community-based weighted score of 0.112 facilitates land resource management and averts actions that result in soil instability, with the least significant factor being relocation and rehabilitation, which has a weighted score of 0.021. The Adaption practices have a consistency ratio of 0.098.

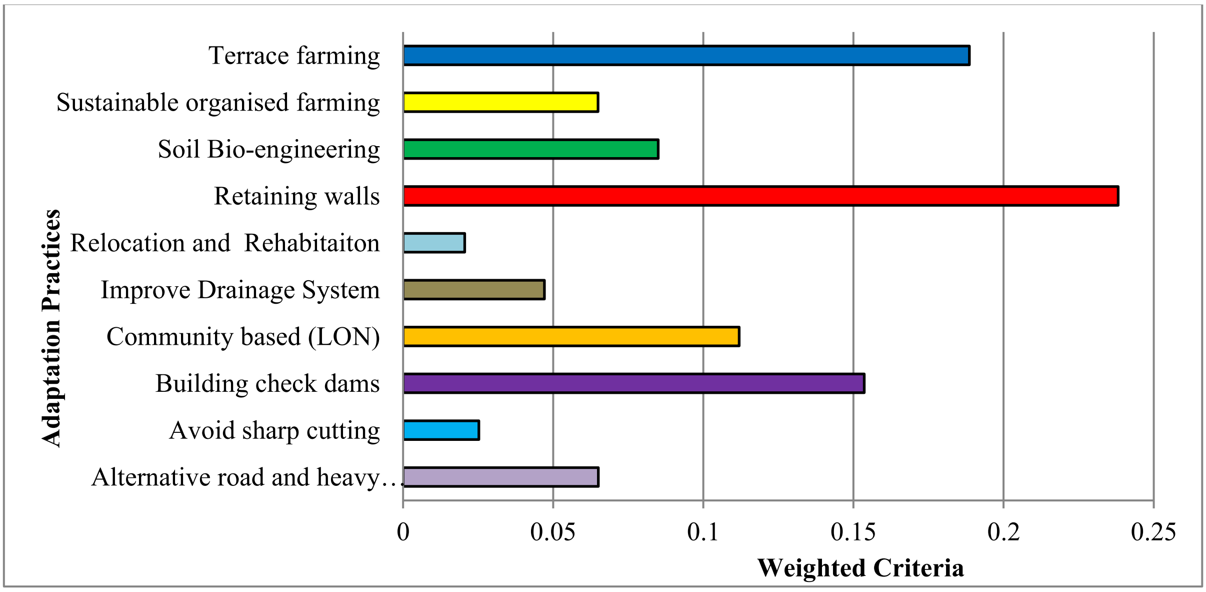

Figure 15: Local people perception on Adaptation Practices to prevent landslides along the SH 12, Kalimpong

4. Conclusion

The study shows that the state highway-12 is prone to landslides due to its geological setting and the domineering factors responsible for it are weathering, past legacies of landslide, relief, drainage, and intervention of man-made features. The interventions by humans have increased due to increase in population and household size of the families which has created pressure on availability of water for domestic use, farming, livestock and crop productivity. The perception of the people on landslides frequency and intensity is that it has increased due to increase in intensity, variability and erratic events of rainfall. Due to such vulnerabilities, there has been shift in the people socioeconomic driving factors like the socioeconomic development of the people is due to the increased road connectivity, rise in income due to shift in economic livelihood practices and increase in ownership of land. The people have also taken up modern agricultural practices. The people have become more aware about landslides, social exclusion have risen and also decrease in poverty and marginalization. The sensitivity factors fragile geology, slope under cutting and heavy rainfall are the prominent factors initiating landslide. The critical stress leading to slope failures, loss of vegetation and break in road connectivity. The retaining walls, terrace farming and building check dams are playing a significant role in adaptation practices. So, it should be necessary for the local authorities to take up active role in getting people more aware on landslides and its sensitive factors. Close monitoring should be done in construction activities. Community based adaptation practice should be promoted and quick action and measures should be taken by the government authorities during the aftermath of landslides. Providing the locals with necessary requirements like financial support, fooding and shelter. Hence it is a continuous support is necessary to adapt to the landslides.

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