A Community-Driven Approach to Landslide Hazard Mapping, Risk Assessment, and Management in Nepal

Achut Krishna PANDEY, Subash GHIMIRE and Suresh CHAUDHARY, Nepal

Keywords: community driven, landslide hazard mapping, mitigation strategies

Summary

This study presents an in-depth exploration of a collaborative strategy aimed at mitigating landslide risks in the Amilee region of Pyuthan District, Nepal. The study underscores the significance of integrating local community knowledge with advanced scientific methodologies to develop accurate landslide hazard maps, conduct thorough risk assessments, and devise effective mitigation strategies. By engaging local residents, the research identifies both natural and anthropogenic causes of landslides, assesses the vulnerability of the population and infrastructure, and proposes tailored solutions such as drainage management, slope stabilization, reforestation, and infrastructure retrofitting. The paper emphasizes that community involvement not only enhances the precision and cultural relevance of the risk assessments but also empowers the community, fostering a sense of ownership and resilience. This approach is presented as a scalable and sustainable model for disaster risk reduction that can be applied to other landslide-prone areas in Nepal, thereby contributing to long-term community safety and disaster preparedness.

A Community-Driven Approach to Landslide Hazard Mapping, Risk Assessment, and Management in Nepal

Achut Krishna PANDEY, Subash GHIMIRE and Suresh CHAUDHARY, Nepal

1. INTRODUCTION

Nepal’s rugged terrain, characterized by steep slopes and fragile geological formations, makes it highly susceptible to landslides, particularly during the monsoon season. Landslides in Nepal are often triggered by heavy rainfall, seismic activity, and human interventions such as deforestation and unplanned infrastructure development. The increasing frequency and severity of landslides pose a significant threat to the country’s socio-economic stability, necessitating a comprehensive approach to landslide risk management.

1.1 Background and Significance Landslides are among the top natural disasters in Nepal, accounting for considerable fatalities, injuries, and economic losses annually. According to the Ministry of Home Affairs (MoHA), from 1971 to 2016, landslides were the third most frequent hazard in Nepal after fires and floods. The economic impact of landslides is profound, with losses in agriculture, infrastructure, and property running into millions of dollars each year. The Amilee landslide in Pyuthan District represents a microcosm of the broader landslide issues facing Nepal. This study focuses on the Amilee landslide to explore how a community-driven approach can enhance the effectiveness of landslide risk management.

1.2 Study Area: Amilee Landslide The Amilee landslide is located in Ayirabati Rural Municipality, Pyuthan District, within Lumbini Province. This area is characterized by steep slopes, complex geological structures, and a monsoonal climate, making it highly prone to landslides. The landslide was triggered by a combination of natural factors, such as heavy rainfall, and anthropogenic factors, including haphazard road construction and improper waste management practices. The affected area includes agricultural lands, residential areas, and public infrastructure, highlighting the need for a comprehensive risk assessment and mitigation plan.

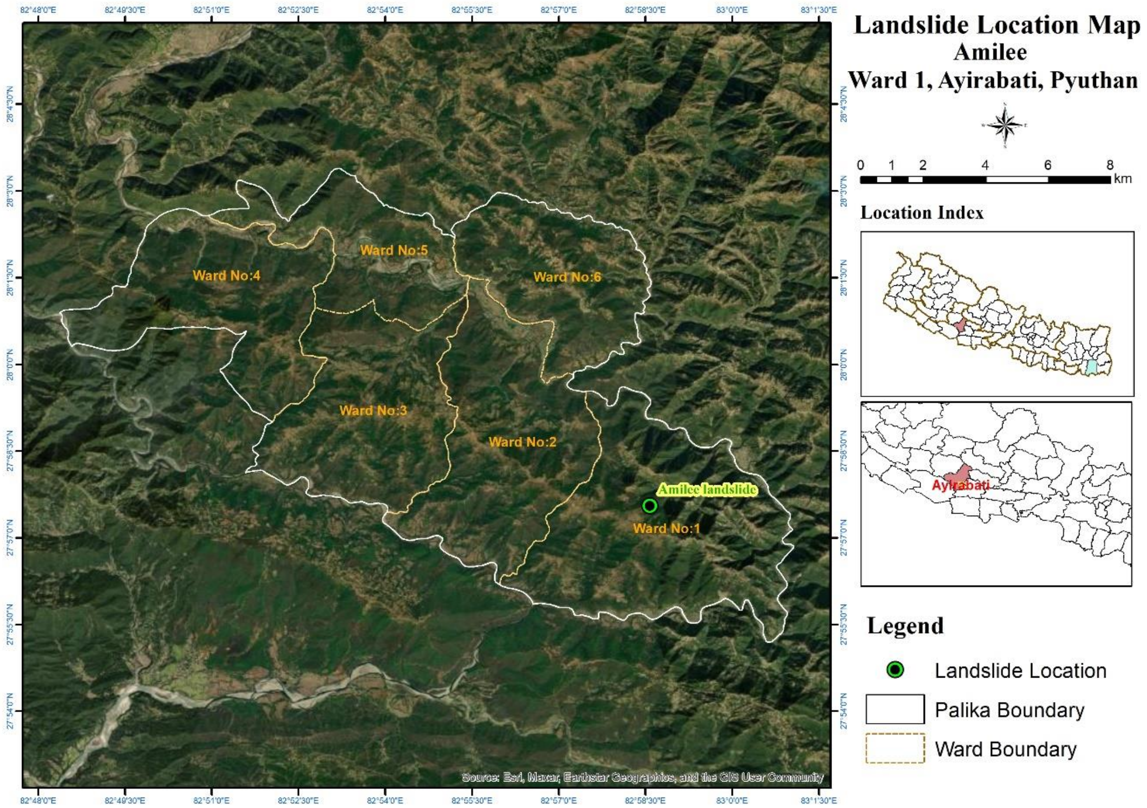


Figure: Location map of Amilee Landslide.

1.3 Objectives The main objectives of this study are:

- To develop a detailed landslide hazard map for the Amilee area that incorporates both scientific data and local knowledge.
- To assess the risk posed by potential future landslides to the local community, infrastructure, and environment.
- To propose mitigation strategies that are informed by both technical analyses and community input, ensuring they are practical and sustainable.
- To engage the local community in the process of landslide risk assessment and management, fostering a sense of ownership and resilience.

2. METHODOLOGY

The methodology employed in this study integrates scientific data collection with community engagement to ensure a comprehensive understanding of the landslide risk in Amilee. The approach is multidisciplinary, drawing on geology, engineering, social sciences, and local knowledge.

2.1 Data Collection Data collection was conducted in two phases: primary data collection through field surveys and secondary data collection from existing databases and literature.

2.1.1 Primary Data Primary data were collected through extensive field surveys in the Amilee landslide area. The tools and techniques used include:

- **Global Positioning System (GPS):** To precisely locate landslide features and collect coordinate data for mapping.
- **Brunton Compass:** For measuring the orientation of geological structures, which is critical for understanding the landslide dynamics.
- **Digital Elevation Models (DEMs):** SRTM 30m DEM was used to analyze the topography of the study area and identify slopes at risk.
- **Field Observations:** Detailed observations of the landslide area, including soil and rock types, vegetation cover, and signs of slope instability, were recorded.

2.1.2 Secondary Data Secondary data were obtained from various sources, including:

- **Geological Maps:** Provided by the Government of Nepal, Department of Mines and Geology, these maps were used to understand the lithological characteristics of the study area.
- **Landslide Inventories:** Previous records of landslides in the region were reviewed to identify patterns and high-risk areas.

2.2 Data Processing and Analysis Data processing involved the use of Geographic Information Systems (GIS) and specialized software to analyze the collected data and create hazard maps.

2.2.1 Geographic Information Systems (GIS) GIS software, specifically ArcMap, was used to create detailed maps of the landslide-prone areas. Layers were created to represent various factors influencing landslide risk, including slope, aspect, lithology, and land use. The GIS analysis facilitated the identification of high-risk zones and the creation of hazard zonation maps.

2.2.2 Google Earth Analysis Google Earth was used to analyze historical satellite imagery, allowing for the observation of changes in land use, vegetation cover, and the progression of the landslide over time. This visual analysis helped identify areas where human activities might have exacerbated the landslide risk.

2.2.3 Kinematic Analysis with DIPS Software (Discontinuity Analysis and Rock Slope Stability) DIPS software was used for kinematic analysis to assess the stability of slopes in the study area. This analysis involved evaluating the potential for various types of slope failures, such as planar sliding, wedge sliding, and toppling. The kinematic analysis provided critical insights into the likelihood of slope failure and helped inform the selection of appropriate mitigation measures.

(Jang et al., 2018; Norwegian Geotechnical Institute, 2015) In DIPS, kinematic analysis is typically performed by creating a 3D model of the rock mass and identifying the discontinuities within it. The software then analyzes the orientation, spacing, persistence, and roughness of these discontinuities to determine the potential failure modes and the overall stability of the slope.

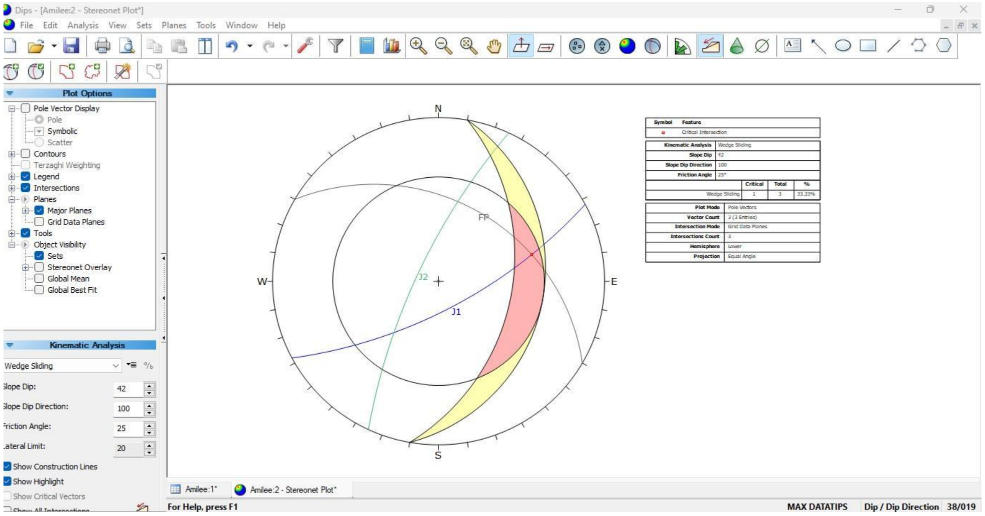
The wedge sliding kinematic analysis failure mode is a test for the sliding of wedges formed by the intersection of two planes. The key elements of wedge sliding kinematic analysis are Slope Plane, Intersection plotting, and Plane friction cone (angle measured from the perimeter of the stereo net).

The planar sliding (no limits) kinematic analysis option in the sidebar is simply a shortcut to the planar sliding option, with no lateral limits. When the lateral limits are turned off, the entire daylight region is considered kinematically valid, as shown below for pole vectors and dip vectors. The dip vector sliding analysis (with no lateral limits) is sometimes also used for wedge sliding analysis.

The planar sliding kinematic analysis failure mode is a test for sliding on a single plane. The key elements of the planar sliding kinematic analysis are daylighting conditions for planes, Pole Friction cone (angle measured from the center of the stereo net), and lateral limits (optional).

The flexural toppling kinematic analysis failure mode is a test for flexural toppling. The key elements of flexural toppling kinematic analysis are: slope plane, slip limit plane (based on slope angle and friction angle) and lateral limits.

The direct toppling kinematic analysis failure mode is a test for direct toppling. The key elements of direct toppling kinematic analysis are: two joint sets intersect such that the intersection lines dip into the slope and can form discrete toppling blocks, a third joint set exists which act as release planes or sliding planes allowing the blocks to topple. (Jang et al., 2018; Norwegian Geotechnical Institute, 2015)



Kinematic Analysis

Wedge Sliding

Slope Dip: 42

Slope Dip Direction: 100

Friction Angle: 25

Lateral Limit: 20

☑ Show Construction Lines

☑ Show Highlight

☐ Show Critical Vectors

Symbol	Feature
■	Critical Intersection

Kinematic Analysis	Wedge Sliding
Slope Dip	42
Slope Dip Direction	100
Friction Angle	25°

	Critical	Total	%
Wedge Sliding	1	3	33.33%

Plot Mode	Pole Vectors
Vector Count	3 (3 Entries)
Intersection Mode	Grid Data Planes
Intersections Count	3
Hemisphere	Lower
Projection	Equal Angle

Figure: Application interface window of DIPS program.

2.3 Community Engagement Community engagement was a central component of the study, ensuring that local knowledge and concerns were incorporated into the hazard assessment and risk management process.

2.3.1 Participatory Rural Appraisal (PRA) PRA techniques were employed to gather insights from the local community. These included:

- **Focus Group Discussions (FGDs):** These discussions were held with different segments of the community, including farmers, local leaders, and women's groups, to gather diverse perspectives on landslide risks and mitigation strategies.
- **Workshops and Training Sessions:** Workshops were organized to educate the community about landslide risks, early warning systems, and disaster preparedness. These sessions also served as platforms for the community to provide input on the proposed mitigation measures.
- **Stakeholder Meetings:** Meetings with local government officials, NGOs, and community leaders were held to ensure that the proposed mitigation strategies were aligned with local development plans and priorities.

2.3.2 Incorporation of Local Knowledge The study placed a strong emphasis on integrating local knowledge into the scientific analysis. Community members provided valuable information on historical landslide events, local soil and vegetation types, and traditional practices for slope stabilization. This information was crucial for validating the scientific data and ensuring that the hazard maps were accurate and relevant.

3. RESULTS

The results of the study include detailed hazard maps, a comprehensive Slope stability analysis, and a set of recommended mitigation measures. These results highlight the areas most at risk from landslides and provide a roadmap for reducing those risks.

3.1 Hazard Scenario

Since there are no casualties on lives or properties, they are not migrating from their place. The 10% of barren land is increasing yearly due to foreign employment and outmigration. Landslides impacted 7–8 Ropani crop fields below the landslide and in the spring source. It can also impact the communities with 6 households living downhill of the landslide in case of lack of treatment The summary of the Amilee landslide is tabulated (Table 1).

Table 1: Summary table of type, cause and impact of Amilee landslide.

Landslide	Type of movement	Rock type	Land cover	Triggering cause	Impact
Amilee Landslide	Debris flow	Limestone, Shale	Sparse forest and agricultural land	Rainfall and haphazard road construction	Ward office and settlement

3.2 Hazard Mapping The hazard mapping process identified several zones within the Amilee area with landslide risk. The hazard maps was created using a combination of field data, GIS analysis, and community input.

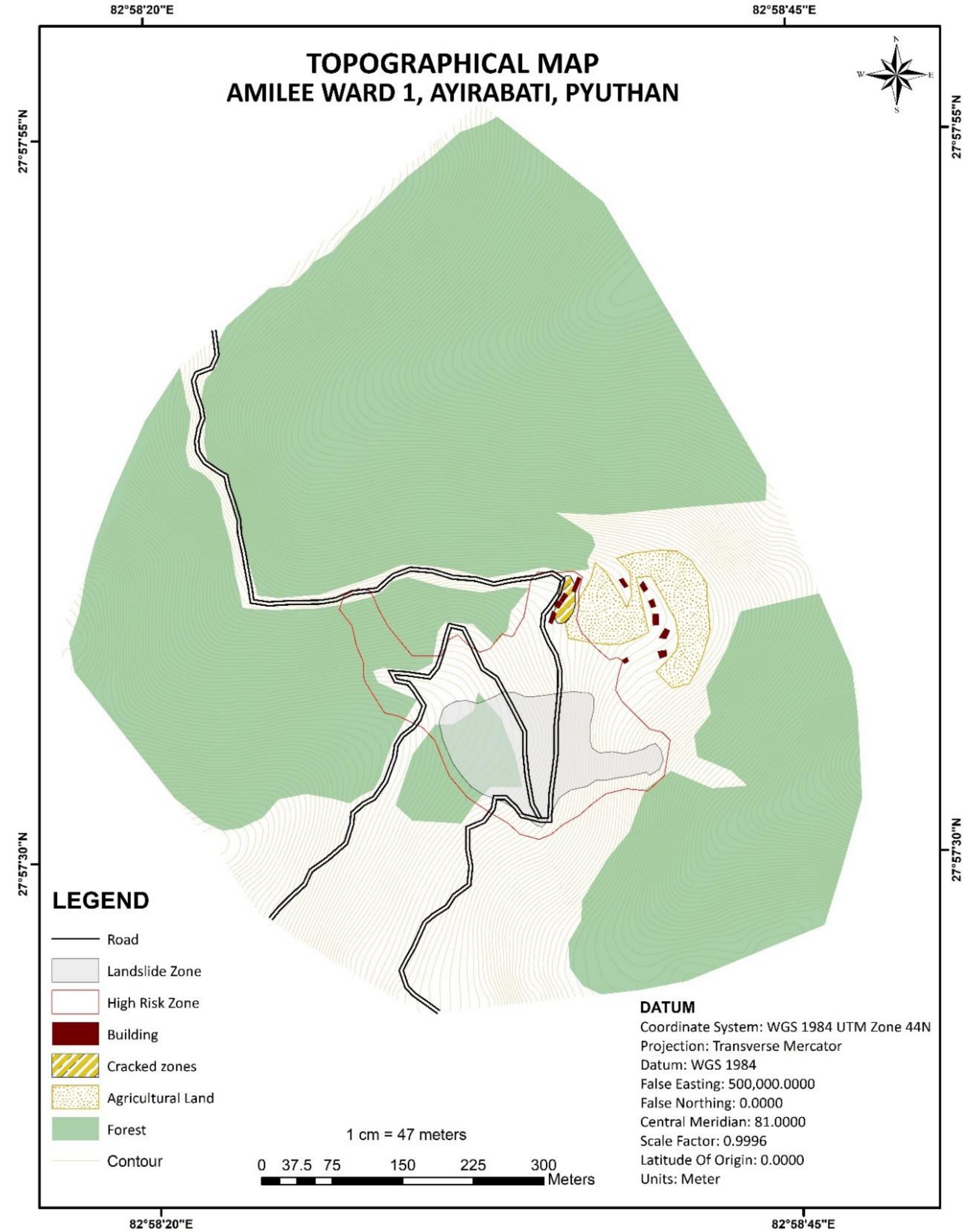
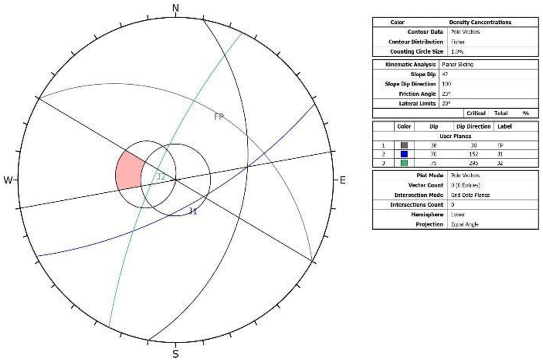


Figure: Hazard Map of Amilee landslide

3.2 Slope stability analysis The fieldwork involved measuring various parameters such as the orientation and number of discontinuities, slope type, slope angle, and friction angles of sediments. These parameters were analyzed to assess the stability of the slope. The DIPS software was used to input all the parameters and generate different diagrams to determine the likelihood of slope failure (Figure 7). The identified slope failure types included planar sliding, direct toppling, flexural toppling, and wedge sliding. (Cotecchia et al., 2020) The natural hillslope of the landslide was determined to be at a 42-degree angle with a southeast aspect. After analyzing the plotted diagrams, it was concluded that there was a probability of flexural toppling and wedge sliding occurring as summarized in Table 2.

Table 2: Summary table of kinematic analysis

Landslide	Slope (°)	Planar sliding	Planar sliding (no limits)	Direct toppling	Flexural toppling	Wedge sliding
Amilee Landslide	42	0	0	0	33.33%	33.33%

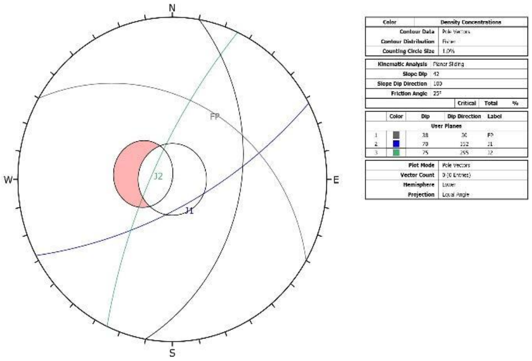


Color	Density Concentrations
Contour Data	Pole Vectors
Contour Distribution	Fisher
Counting Circle Size	1.0%
Kinematic Analysis	Planar Sliding
Slope Dip	42
Slope Dip Direction	100
Friction Angle	25°
Lateral Limits	20°

	Critical	Total	%

	Color	Dip	Dip Direction	Label
User Planes				
1	■	38	30	FP
2	🟦	70	152	J1
3	🟩	75	295	J2

Plot Mode	Pole Vectors
Vector Count	0 (0 Entries)
Intersection Mode	Grid Data Planes
Intersections Count	0
Hemisphere	Lower
Projection	Equal Angle

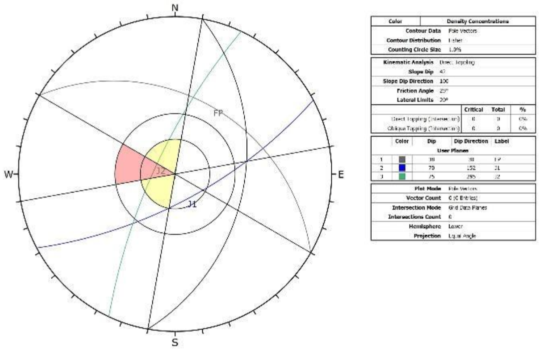


Color	Density Concentrations
Contour Data	Pole Vectors
Contour Distribution	Fisher
Counting Circle Size	1.0%
Kinematic Analysis	Planar Sliding
Slope Dip	42
Slope Dip Direction	100
Friction Angle	25°

	Critical	Total	%

	Color	Dip	Dip Direction	Label
User Planes				
1	■	38	30	FP
2	🟦	70	152	J1
3	🟩	75	295	J2

Plot Mode	Pole Vectors
Vector Count	0 (0 Entries)
Hemisphere	Lower
Projection	Equal Angle

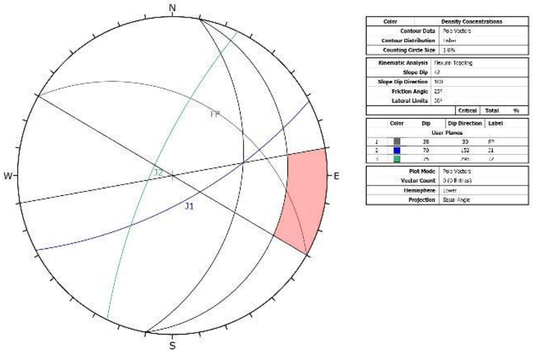


Color	Density Concentrations
Contour Data	Pole Vectors
Contour Distribution	Fisher
Counting Circle Size	1.0%
Kinematic Analysis	Direct Toppling
Slope Dip	42
Slope Dip Direction	100
Friction Angle	25°
Lateral Limits	20°

	Critical	Total	%
Direct Toppling (Intersection)	0	0	0%
Oblique Toppling (Intersection)	0	0	0%

	Color	Dip	Dip Direction	Label
User Planes				
1	■	38	30	FP
2	🟦	70	152	J1
3	🟩	75	295	J2

Plot Mode	Pole Vectors
Vector Count	0 (0 Entries)
Intersection Mode	Grid Data Planes
Intersections Count	0
Hemisphere	Lower
Projection	Equal Angle



Color	Density Concentrations
Contour Data	Pole Vectors
Contour Distribution	Fisher
Counting Circle Size	1.0%
Kinematic Analysis	Flexural Toppling
Slope Dip	42
Slope Dip Direction	100
Friction Angle	25°
Lateral Limits	20°

	Critical	Total	%

	Color	Dip	Dip Direction	Label
User Planes				
1	■	38	30	FP
2	🟦	70	152	J1
3	🟩	75	295	J2

Plot Mode	Pole Vectors
Vector Count	0 (0 Entries)
Hemisphere	Lower
Projection	Equal Angle

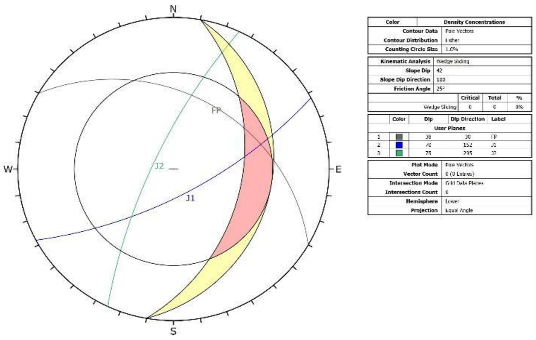


Figure: Stereographic projections of discontinuities present nearby the Amilee landslide.

Flexural toppling occur in landslides in steep slopes and weak geological formations. It involves the rotation and detachment of a block of rock or soil due to the force of gravity acting on it.

The weak layer or plane within the slope undergoes bending or flexure, leading to the detachment of a rock/soil block of material from the rest of the slope. Once the block is detached, it starts to rotate and topple downslope. The weight of the detached block is transferred to the lower portions of the slope, potentially increasing stress and instability in the areas. It can trigger additional landslides or slope failures. The movement and impact of the toppling block can disturb and destabilize the surrounding material.

It can pose significant risks to human lives, infrastructure, and the environment. The rapid movement of large blocks can cause destructive forces upon impact, leading to the destruction of settlements, roads, and vegetation. It can also result in the formation of debris flows or damming of rivers, further exacerbating the hazards.

Wedge sliding refers to the movement of a mass of rock or soil that is wedge-shaped and detaches from the surrounding slope and lead to an acceleration of the landslide movement. As the wedge slides downward, it will remove additional material and increase the overall volume and velocity of the landslide.

The movement of the wedge potentially trigger secondary landslides in the surrounding area. The sliding wedge can disturb the stability of the slope, creating additional weak points and reducing the overall resistance to movement. It can reshape the slope, displace soil and rock, and leave behind a scarred terrain characterized by debris, exposed bedrock, and altered drainage patterns.

Planar sliding refers to the movement of a mass of soil or rock along a distinct plane. Compared to other types of landslides, planar sliding tends to have a higher velocity due to the concentrated movement along the defined surface. This increased velocity can result in faster and more destructive landslides.

As the mass of soil or rock slides, it can accumulate more debris and gain momentum, leading to the potential for more extensive damage and destruction as it travels downhill. The sliding mass displace or remove existing vegetation, alter water drainage patterns, and reshape the landscape as it moves. This can result in changes to the natural topography and the destruction of ecosystems in the affected area.

Direct toppling refers to the rotational movement of large blocks or masses of rock or soil. increase the speed and distance of the landslide. As the blocks or masses rotate and fall, they can generate additional momentum, causing the landslide to travel farther and faster. This will intensify the destructive power of the landslide and increase the area affected by the event.

The toppling of large blocks will trigger secondary hazards such as rockfall, debris flow, or further landslides. The falling blocks will remove other loose materials. The movement and displacement of large blocks can create new landforms, modify the slope angles, and change the drainage patterns. These alterations can have long-term effects on the stability of the area and potentially increase the susceptibility to future landslides.

3.2.1 Population at Risk Approximately 200 people live in the vicinity of the Amilee landslide. The demographic profile of the community reveals that a significant portion of the population consists of children, elderly individuals, and women, who are particularly vulnerable to landslide hazards.

- **Vulnerable Groups:** 40% of the population are children and elderly individuals, making evacuation and emergency response more challenging.

3.2.2 Infrastructure at Risk The risk assessment identified several critical infrastructure elements that are at risk from future landslides.

- **Ward Office:** The local ward office is situated on a slope above the landslide-prone area, making it vulnerable to damage or collapse.
- **Roads and Transportation:** The main road connecting the village to other parts of the district is at risk of being blocked or destroyed by landslides, which would isolate the community and hinder emergency response efforts.
- **Agricultural Land:** Approximately 7–8 Ropani (about 0.36 hectares) of agricultural land are directly affected by the landslide, leading to reduced crop yields and economic losses.

3.2.3 Environmental Impact The landslide poses a significant risk to the local environment, including the potential for river damming and forest loss.

- **River Damming:** Continuous sediment deposition in the Jhimruk River, caused by the landslide, could lead to river damming, resulting in upstream flooding and damage to aquatic ecosystems.
- **Forest Loss:** The landslide has already led to the loss of several mature trees, and continued instability could result in further deforestation, affecting local biodiversity and contributing to soil erosion.

3.2.4 Economic Impact The economic impact of the landslide on the local community is significant, with losses in agriculture, infrastructure, and property.

- **Agricultural Losses:** The landslide has affected the productivity of agricultural lands, which are the primary source of income for many families in the area.
- **Property Damage:** The risk assessment identified several houses that are at risk of collapse due to the ongoing landslide activity. This could result in significant economic losses for affected families.

3.3 Causes of Landslides The study identified both natural and anthropogenic causes of the Amilee landslide, which are critical for understanding the factors contributing to slope instability.

3.3.1 Natural Causes Natural factors contributing to the landslide include the region's steep slopes, heavy monsoonal rainfall, and the weak geological formations in the area.

- **Geology:** The Amilee landslide area is characterized by weak, highly weathered rock formations, including limestone, shale, and quartzite. These rocks are prone to failure, particularly when subjected to the stresses of heavy rainfall and slope modification.
- **Rainfall:** The region experiences intense monsoonal rainfall, which saturates the soil and increases pore water pressure, leading to slope instability.

3.3.2 Anthropogenic Causes Human activities have exacerbated the natural susceptibility of the area to landslides.

- **Unplanned Road Construction:** The construction of roads in the area has involved extensive excavation and the removal of vegetation, which has destabilized the slopes. The lack of proper engineering measures, such as retaining walls and drainage systems, has further increased the risk of landslides.
- **Improper Waste Management:** The disposal of construction debris and other waste materials on the slopes has added to the instability. The accumulation of these materials on steep slopes has increased the load and contributed to slope failure.

4. DISCUSSION

The discussion section explores the implications of the findings for landslide risk management in Nepal, with a particular focus on the role of community participation and the integration of local knowledge with scientific methodologies.

4.1 The Role of Community Knowledge Community knowledge has proven to be invaluable in the landslide risk assessment process. Local residents have a deep understanding of the terrain and the factors that contribute to slope instability. Their observations and historical knowledge of past landslides provided critical insights that were not captured by scientific data alone.

- **Historical Knowledge:** Community members were able to provide detailed accounts of previous landslides, including their causes, impacts, and the effectiveness of past mitigation measures. This information was crucial for validating the hazard maps and ensuring that they reflected the real risks faced by the community.
- **Local Practices:** The community's traditional practices for managing slope stability, such as terracing and the use of specific vegetation types, were incorporated into the proposed mitigation strategies. These practices have been honed over generations and are well-suited to the local environment.

4.2 Integrating Scientific and Local Knowledge The integration of scientific methodologies with local knowledge resulted in more accurate hazard mapping and risk assessment. This approach also facilitated the identification of practical and culturally appropriate mitigation measures.

- **GIS and Local Input:** The use of GIS allowed for the creation of detailed hazard maps, while the incorporation of local knowledge ensured that these maps were accurate and relevant to the community's needs.
- **Validation of Data:** Community feedback was used to validate the scientific data, ensuring that the hazard maps accurately reflected the risks identified by the local population. This collaborative approach helped to build trust between the community and the researchers, leading to greater acceptance of the proposed mitigation measures.

4.3 Challenges and Limitations The study faced several challenges, including limited access to remote areas, the availability of high-resolution satellite imagery, and the variability of local knowledge. Additionally, the dynamic nature of landslides makes it difficult to predict future occurrences with absolute certainty.

- **Access to Remote Areas:** The steep and rugged terrain of the Amilee landslide area made it difficult to conduct field surveys and install monitoring equipment. This limited the amount of data that could be collected, particularly in the most hazardous areas.
- **Variability of Local Knowledge:** While local knowledge was invaluable, it was also variable, with different community members providing conflicting accounts of past events.

This variability had to be carefully managed to ensure that the hazard maps were accurate and reliable.

- **Dynamic Nature of Landslides:** Landslides are inherently unpredictable, with factors such as climate change potentially altering the frequency and severity of future events. This makes it challenging to develop long-term mitigation strategies that remain effective under changing conditions.

5. MITIGATION MEASURES

Based on the risk assessment and community input, the study proposes a set of mitigation measures tailored to the specific conditions of the Amilee landslide. These measures are categorized into short-term, mid-term, and long-term strategies to ensure a comprehensive approach to landslide risk management.

5.1 Short-Term Measures Short-term measures are designed to address the immediate risks posed by the landslide and prevent further damage. The recommended mitigative measures (Shrestha et al., 2012) are highlighted in the map and table 3 below for the Amilee landslide.

Table 3: recommended mitigation measures

Prevention measures	**Dimension**	**Zones:**
Roadside drainage	115m	Slope stabilization Zone 2
Retaining wall/roadside drainage	120m/5m	Slope stabilization Zone 3
Roadside drainage	65m	Slope stabilization Zone 4
Retaining wall/roadside drainage	50m/4m	Slope stabilization Zone 5
Retaining wall/roadside drainage	150m/4m	Slope stabilization Zone 1
Runoff managing drainage	130m	Drainage line 1
Runoff managing drainage	200m	Drainage line 2
Proper deposition of waste to safe place	2000 sq. m.	Waste management zone
Riparian planting	500 sq. m	Bio engineering zone 2
Terracing	1500 sq. m.	Bio engineering zone 1
Check dams/plantation	2 dams -1m height	Gully treatment zone 2
Check dams/plantation	6 dams -1m height	Gully treatment zone 1
Riparian planting	1000 Sq.m.	Bio engineering zone 3
Debris flow barrier/ gully treatment	40m/2m	Gully treatment zone 3

Figure: The recommended mitigation measures for the Amilee landslide

5.1.1 Drainage Management Proper drainage is crucial for preventing soil saturation and reducing the likelihood of landslides. The study recommends the installation of roadside drainage channels to divert water away from unstable slopes.

- **Drainage Channels:** These channels will be designed to capture and redirect surface runoff, preventing it from accumulating on the slopes and increasing pore water pressure.

5.1.2 Slope Stabilization Slope stabilization measures are essential for reinforcing the stability of the slopes and preventing further landslide activity.

- **Retaining Walls:** The construction of retaining walls is recommended in high-risk areas to support the slopes and prevent soil movement. The walls will be constructed using locally available materials and designed to withstand the pressures exerted by the slope.

- **Bioengineering Techniques:** Bioengineering techniques, such as terracing and the planting of deep-rooted vegetation, will be used to stabilize the soil and reduce erosion. These techniques are eco-friendly and cost-effective, making them suitable for use in rural areas.

5.1.3 Gully Treatment The treatment of gullies is necessary to prevent the further deepening and widening of these erosion features, which could exacerbate the landslide risk.

- **Check Dams:** The construction of check dams in gullies is recommended to slow down water flow and trap sediment. These structures will help to stabilize the gully floors and reduce the risk of further erosion.
- **Plantation:** The planting of vegetation in and around the gullies will help to reinforce the soil and prevent further erosion. Species with strong root systems will be selected to provide maximum stability.

5.2 Mid-Term Measures Mid-term measures focus on reducing the immediate risks associated with landslide-prone areas and improving the community’s preparedness for future events.

5.2.1 Early Warning Systems The establishment of early warning systems is a key mid-term measure that can significantly enhance landslide preparedness and response.

- **Monitoring Systems:** Inclinometers and piezometers can be installed in high-risk areas to monitor slope movements and changes in soil moisture levels. These sensors will provide real-time data that can be used to issue early warnings to the community.
- **Community Alert Systems:** The development of community-based alert systems, such as sirens and SMS notifications, will ensure that residents are quickly informed of impending landslides and can evacuate to safe areas.

5.2.2 Capacity Building Capacity building is essential for ensuring that the community is equipped to respond effectively to landslide hazards.

- **Training Programs:** Training programs can be conducted to educate residents on disaster preparedness and response, including evacuation procedures and the use of early warning systems.
- **Community Drills:** Regular community drills shall be organized to practice evacuation plans and ensure that all residents are familiar with the procedures.

5.2.3 Stakeholder Engagement Continued engagement with local stakeholders is crucial for ensuring the success of the mitigation measures.

- **Collaboration with Government Agencies:** The study recommends the establishment of formal partnerships with local government agencies to ensure that the mitigation measures are supported by policy and funding.
- **NGO Involvement:** Non-governmental organizations (NGOs) with expertise in disaster risk reduction should be engaged to provide technical assistance and support the implementation of the mitigation measures.

5.3 Long-Term Measures Long-term measures are aimed at addressing the root causes of landslide hazards and providing sustainable solutions for risk reduction.

5.3.1 Reforestation Reforestation is a critical long-term measure for stabilizing slopes and reducing the risk of landslides.

- **Large-Scale Planting:** The study recommends the large-scale planting of deep-rooted vegetation in high-risk areas. Species that are native to the region and well-adapted to the local climate should be selected to ensure their long-term survival and effectiveness.
- **Community Involvement:** The community must be actively involved in the reforestation efforts, including the planting and maintenance of the trees. This will not only enhance the effectiveness of the reforestation program but also foster a sense of ownership and responsibility among residents.

5.3.2 Land Use Planning Proper land use planning is essential for preventing future development in high-risk areas and promoting sustainable practices.

- **Zoning Regulations:** The implementation of zoning regulations will restrict construction and development in areas identified as high-risk by the hazard maps. These regulations will help to prevent the exacerbation of landslide risks and ensure that new developments are safe and sustainable.
- **Sustainable Practices:** The promotion of sustainable land use practices, such as agroforestry and contour farming, will help to reduce the impact of human activities on slope stability and enhance the resilience of the landscape.

5.3.3 Infrastructure Retrofitting The retrofitting of existing infrastructure is necessary to ensure that it can withstand the impacts of landslides.

- **Strengthening Roads and Buildings:** Roads and buildings in high-risk areas must be retrofitted with additional structural supports to prevent collapse during landslides. This will include the reinforcement of foundations, the installation of retaining walls, and the improvement of drainage systems.

- **Resilient Design:** New infrastructure projects in the region should be designed with resilience in mind, incorporating features such as flexible materials, elevated structures, and redundant systems to enhance their ability to withstand landslide impacts.

6. CONCLUSION

The study demonstrates the effectiveness of a community-driven approach to landslide hazard mapping, risk assessment, and management in Nepal. By integrating local knowledge with scientific methods, it is possible to develop more accurate hazard maps, conduct comprehensive risk assessments, and implement effective mitigation measures. The involvement of local communities in the process not only enhances the relevance and acceptance of the mitigation strategies but also empowers the community to take an active role in disaster risk reduction. The lessons learned from the Amilee landslide can be applied to other landslide-prone areas in Nepal, contributing to a more resilient and disaster-prepared society.

6.1 Future Research Directions Future research should focus on refining early warning systems, exploring the long-term impacts of reforestation on slope stability, and developing more robust models for predicting landslide occurrences in the context of climate change. Additionally, further studies should investigate the socio-economic benefits of involving communities in disaster risk management and explore ways to scale up these approaches to other regions in Nepal.

REFERENCES

- Cotecchia, F., Santaloia, F., & Tagarelli, V. (2020). Towards A Geo-Hydro-Mechanical Characterization of Landslide Classes: Preliminary Results. *Applied Sciences, 10*(22), 7960. https://doi.org/10.3390/app10227960
- Jang, H.-S., Zhang, Q.-Z., Kang, S.-S., & Jang, B.-A. (2018). Determination of the Basic Friction Angle of Rock Surfaces by Tilt Tests. *Rock Mechanics and Rock Engineering, 51*(4), 989–1004. https://doi.org/10.1007/s00603-017-1388-7
- Norwegian Geotechnical Institute. (2015). Using the Q-system. Norwegian Geotechnical Institute. Retrieved from http://www.ngi.no
- Shrestha, A. B., Ezee, G. C., Adhikary, R. P., & Rai, S. K. (2012). Resource Manual on Flash Flood Risk Management; Module 3 - Structural Measures. International Centre for Integrated Mountain Development (ICIMOD). https://doi.org/10.53055/icimod.570

CONTACTS

Achut Krishna Pandey
Department of geomatics engineering Kathmandu University
Kathmandu
Nepal

Tel. +9779857046310
Email: geomat.achut@gmail.com

Subash Ghimire
Department of geomatics engineering Kathmandu University
Kathmandu
Nepal
Tel. +9779841797156
Email: subash_ghimire@ku.edu.np

Suresh Chaudhary
National Society for earthquake technologies (NSET)
Kathmandu
Nepal
Email: schaudhary@nset.org.np