Final Report

On

Geo-Hazard Assessment of Different Vulnerable Areas of Gurbhakot Municipality

Surkhet District

Karnali Province

Submitted to

Local Initiatives for Biodiversity, Research and Development (LI-BIRD)

Submitted by

Himalayan Earth Science Research Center and Solutions Pvt. Ltd

2026

TABLE OF CONTENTS

List of Tables

List of Figures

Chapter-1

Introduction

1.1 Background

Landslides are among the most significant natural hazards worldwide, particularly in regions underlain by weak lithological units and characterized by steep terrain. Their occurrence is especially frequent in mountainous environments, where complex interactions between geological conditions and geomorphic processes contribute to slope instability (Gerrard, 1994). Nepal, located in the central Himalayan region, is highly susceptible to such hazards due to its fragile geological setting and rugged topography (Dangol, 2006). The steep relief and narrow north–south physiographic extent of the country further aggravate slope instability, resulting in frequent landslides and intensified erosion processes (Hasegawa et al., 2009).

The primary causes of slope failure in the Nepalese Himalayas are closely linked to weak and highly deformed geological formations, often associated with major structural features such as thrusts, faults, and folds (Upreti, 2001). Numerous studies have emphasized the dominant role of geological and geomorphological factors in landslide initiation and development (Delmonaco et al., 2005; Chigira and Yagi, 2006; Nakano et al., 2016; Kumar et al., 2019; Sigdel and Adhikari, 2020a). In addition to these natural controls, anthropogenic activities—including deforestation, improper land-use practices, and slope modification for infrastructure development—have significantly increased landslide susceptibility (Cui et al., 2023). External triggering factors such as intense rainfall and seismic events further exacerbate slope instability, frequently leading to catastrophic failures (Upreti and Dhital, 1996; Dahal and Hasegawa, 2008).

Slope stability in the Himalayan region is influenced by a range of interrelated factors, including elevation, slope gradient, lithology, geotechnical properties of soils and rocks, degree of weathering, soil thickness, slope aspect, and groundwater conditions (Bhandari and Dhakal, 2018). Historical events, such as the 1985 Trishuli River landslide disaster and the 2015 Gorkha earthquake, highlight the high vulnerability of the region to mass wasting processes and their far-reaching impacts (Galay, 1987).

The hilly and mountainous regions of Nepal are particularly prone to such hazards, posing significant challenges for the development of resilient infrastructure, safe settlements, and sustainable communities. The severity of landslide impacts is further intensified by unplanned urban expansion, poorly engineered infrastructure, unsustainable resource extraction, and inadequate drainage management. Coupled with intense monsoonal precipitation and frequent seismic activity, these factors make landslides an almost recurrent phenomenon in many parts of the country. Without the implementation of scientifically informed planning and long-term risk reduction strategies, both the frequency and consequences of such disasters are likely to increase.

In response to the growing landslide risk, LI-BIRD is implementing the PRARAMBHA project in Gurbhakot Municipality, with the objective of strengthening multi-hazard early warning systems and promoting anticipatory action for vulnerable communities. As part of this initiative, the present study focuses on conducting a rapid geo-hazard assessment of nine pre-identified landslide and landslide-prone sites, considering both rainfall-induced and human-induced triggering mechanisms.

In response to a formal request from LI-BIRD, Himalayan Earth Science Research Center and Solutions Pvt. Ltd., drawing on its expertise in geo-hazard assessment and risk analysis, has undertaken a comprehensive evaluation of the project area. The assessment has been carried out in accordance with the Terms of Reference (ToR), integrating field investigations, geological analysis, and hazard evaluation to provide a scientific basis for risk mitigation and informed decision-making.

1.2 Study Area

The study area concentrates on the most at-risk settlements within Gurbhakot Municipality, as identified by municipal authorities. Nine sites have been selected across Wards 1, 2, 3, 5, 6, and 14, representing locations highly prone to landslides, slope instability, and related geo-hazards. These sites were prioritized based on historical disaster records, local community inputs, and preliminary assessments conducted by the municipality.

Focusing on these areas enables a targeted evaluation of the factors influencing risk to both settlements and infrastructure. The study is designed to deliver site-specific geo-hazard assessments, delineate high-risk zones, and propose evidence-based measures for reconstruction, mitigation, and potential relocation. This targeted approach supports efficient resource allocation while enhancing safety and resilience in the municipality's most vulnerable regions. The study area is illustrated in Figure 1.

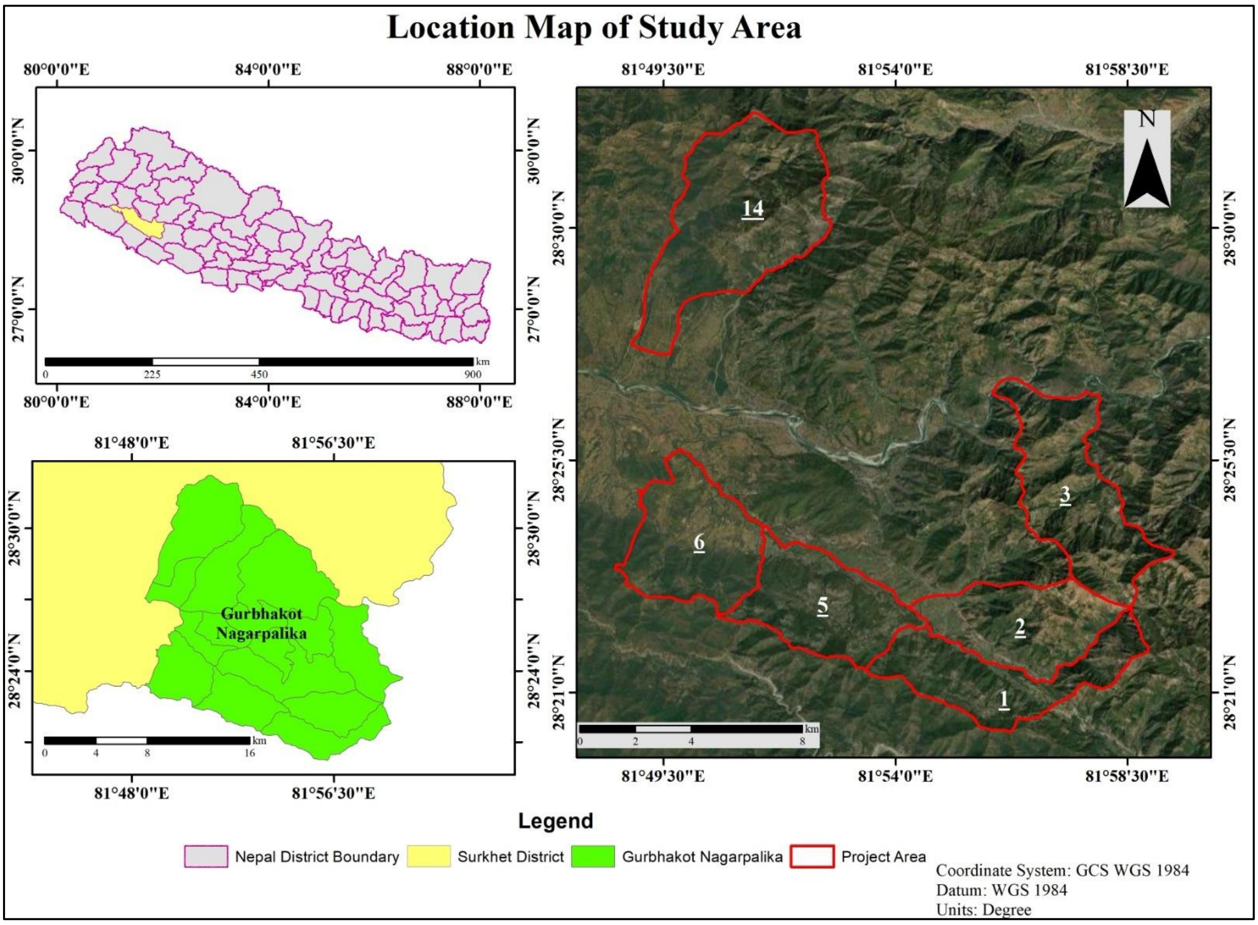


Figure 1: Location Map of the Study area

1.3 Objectives

The main objective of the study is to conduct a preliminary landslide risk assessment of 9 pre-identified landslide-prone sites across different area of Gurbhakot Municipality. In achieving the main objectives, the specific objectives of the study are as follows:

- ✓ Conduct a rapid geo hazard assessment of nine pre-identified landslide and landslide-prone areas.
- ✓ Carry out geological, engineering geological, and geomorphological studies of the identified landslides.
- ✓ Prepare maps of elements at risk, incorporating socio-economic and engineering aspects.

- ✓ Provide recommendations on the urgency of required interventions, the type of further studies needed, and options for partial or complete relocation or other mitigation measures.

1.4 Scope of Work

The scope of the preliminary geo hazard assessment will include:

- ✓ Analyze available free satellite imagery to identify traces of landslides, subsidence, or surface cracks from relevant imagery sources.
- ✓ Conduct consultations with local authorities and communities and other concerned stakeholders to gather social and other necessary information.
- ✓ Collect available records and reports related to previous landslides from relevant institutions or sources.
- ✓ Undertake field visits to nine pre-identified landslides affected
- ✓ communities and sites to carry out a rapid geo hazard assessment
- ✓ Assess the need for resettlement of affected households, if applicable.
- ✓ Identify and map affected infrastructure such as roads, settlements, and other structures.
- ✓ Recommend whether further detailed studies are required.
- ✓ Provide recommendations for short-term/immediate and long-term mitigation measures.

1.5 Limitations of the assessment

This study presents a rapid geo-hazard assessment of pre-identified landslides in Gurbhakot Municipality and does not include detailed landslide mapping, geotechnical or geophysical investigations, or slope stabilization design. Due to the limited duration of fieldwork, comprehensive geological and geotechnical analyses were beyond the scope of this assessment. Therefore, the recommendations are based solely on observations from the walkover survey and should not be considered a replacement for detailed, instrument-based investigations.

Chapter – 2

Methodology

The study mainly targets zones surrounding landslides that threaten settlements and essential community infrastructure. It involves a focused assessment of areas already impacted by landslides, along with locations that are potentially vulnerable to future failures, taking into account both the physical characteristics of slope instability and associated human factors. The overall methodology is organized into four sequential phases, as illustrated in the flow chart (Figure 2).

2.1 Desk Study

A comprehensive desk review forms the foundation of systematic geo hazard assessment by compiling and analyzing existing information relevant to slope instability and landslide risk. This process begins with the collection and review of secondary data from government agencies, academic studies, project reports, and institutional databases to understand the historical and environmental context of the study area. Topographic maps and satellite imagery are carefully examined to identify terrain characteristics such as slope gradient, drainage patterns, land use, and surface changes over time. These spatial datasets help detect potential landslide-prone zones and human-induced modifications to the landscape. In addition, geological and geomorphological information is studied to understand rock types, structural features, soil conditions, weathering processes, and landform evolution, all of which influence slope stability. Reviewing previous disaster records provides insight into the frequency, location, and impact of past landslides and related hazards. Rainfall data and patterns are also analyzed to determine triggering thresholds and seasonal risk trends. Together, this desk-based assessment supports evidence-based planning by identifying high-risk areas, guiding field investigations, and informing reconstruction and relocation decisions with a strong scientific foundation.

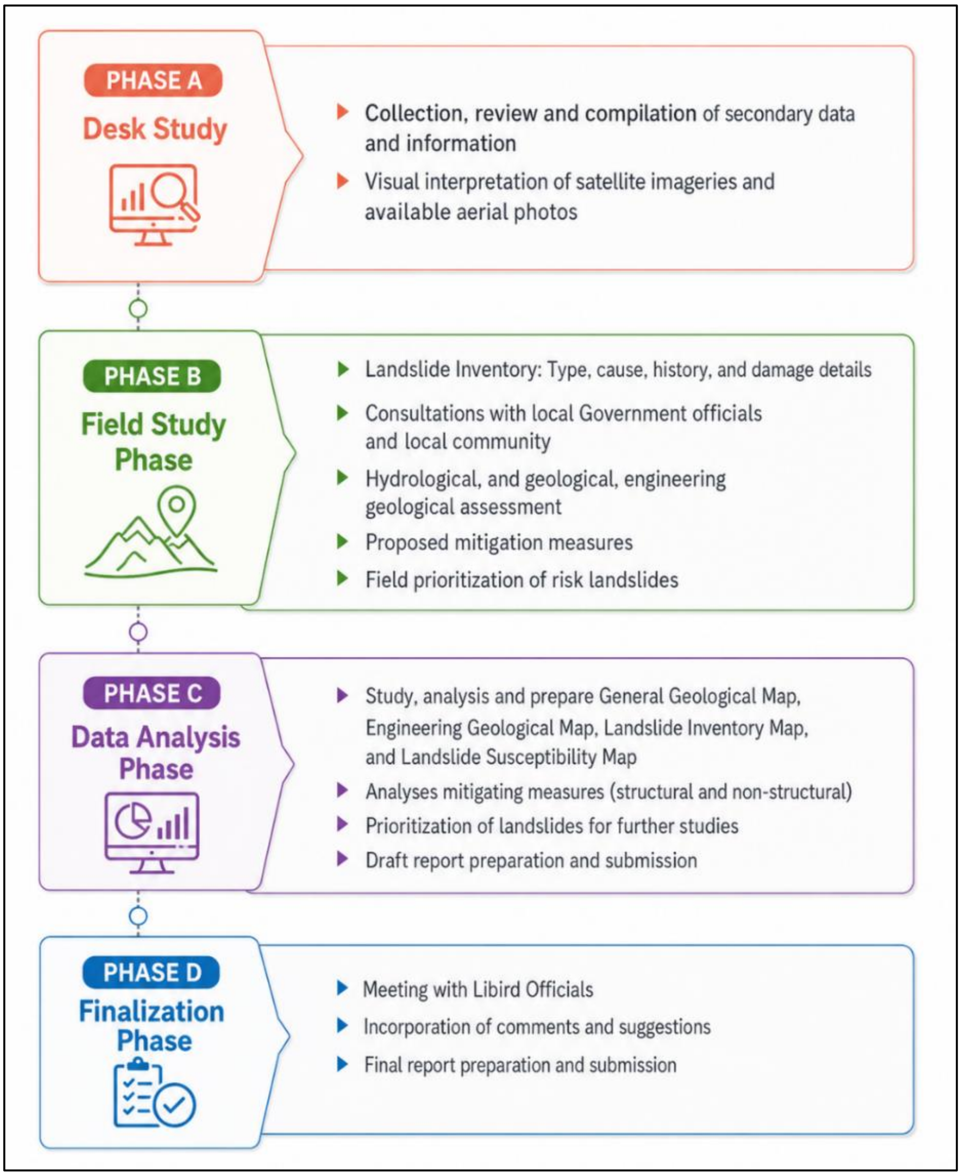


Figure 2: General Methodological chart adopted in this study

2.1.1. Stakeholder Consultation and Data Collection

A participatory approach was adopted through the organization of interaction programs, workshops, and consultative meetings within the project area, involving a wide range of stakeholders. Participants comprised representatives from local government institutions, community leaders, affected residents, and relevant authorities (Figure 3 & Figure 4). The discussions centered on the historical progression of landslides, current hazard situations, and local experiences with past disaster events. Preliminary hazard mapping exercises were also introduced, enabling stakeholders to better visualize risk-prone areas and contribute their observations on affected locations. These sessions further provided an effective platform for identifying key informants with in-depth knowledge of the socio-economic and environmental impacts of landslides in the region.

Figure 3 Interaction programme and pre-discussion presentation at Gurbhakot Municipality office, Surkhet

Figure 4: Discussion with different wards members of the Gurbhakot Municipality office.

2.1.2 Focused Group Discussion (FGD)

Building on the information obtained through key informant interviews, Focus Group Discussions (FGDs) were organized at the community level to encourage shared learning and explore the socio-economic dimensions of landslides in greater depth. These sessions were facilitated by trained field enumerators assigned by the consultant, ensuring that discussions remained systematic and inclusive. The FGDs were conducted in small, focused groups to promote open interaction and active engagement among participants. Attendees included members of vulnerable households, women's associations, youth groups, local entrepreneurs, and other affected community members (Figure 5). The discussions addressed issues such as economic losses induced by landslides, access to emergency response systems, and the presence of livelihood recovery initiatives and local perceptions of disaster risk.

Figure 5: Focal group discussion at the landslide affected community level

2.2. General Geological and Engineering Geological Assessment

The geological investigation commenced with an extensive review of available geological maps, reports, and other relevant published and unpublished literature pertaining to the study area. These sources offered a preliminary understanding of the regional geological framework, which was later validated and refined through systematic fieldwork. Subsequent analysis focused on geological and engineering geological conditions to determine potential hazards and site-specific vulnerabilities. This included the examination of rock types, soil characteristics, and structural elements that influence slope stability. The assessment further delineated zones susceptible to slope instability, such as landslides, ground subsidence, and erosion processes, all of which contribute to an increased likelihood of landslide occurrence in the area.

2.2.1. Landslide Inventory and Susceptibility Map

A comprehensive landslide inventory was developed through the collection and analysis of both historical records and recent landslide occurrences. This process involved the integration of remote sensing data, detailed field investigations, and information obtained from local authorities and community sources. Each identified landslide was systematically documented, including key attributes such as its geographic location, dimensions, classification, time of occurrence, underlying causes and triggering mechanisms, as well as associated impacts and damages. This data was collected from Li-Bird previous study and susceptibility map was adopted in this study as shown in Figure 6.

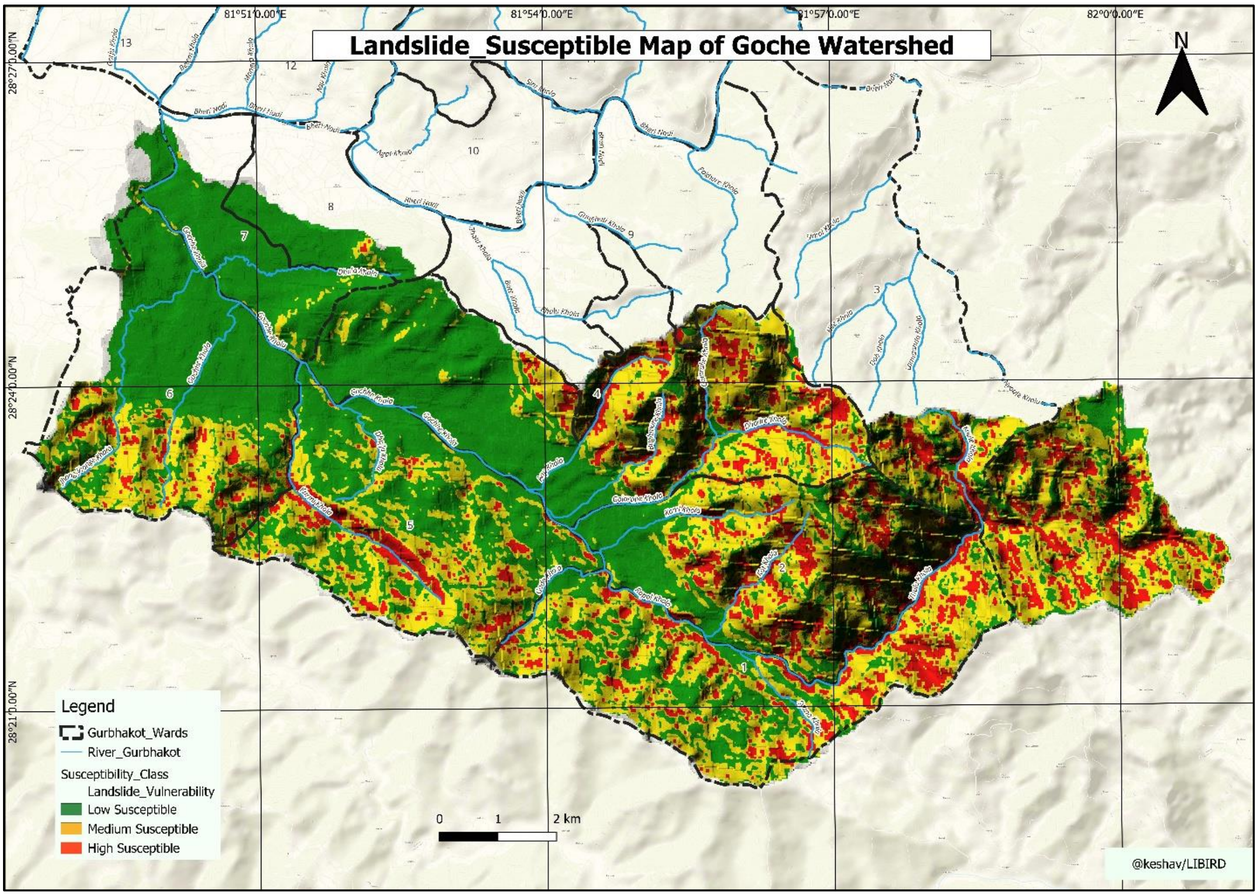


Figure 6: Landslide Inventory and susceptibility Map of the study area (adopted from Li-bird unpublished data)

2.3 Data Interpretation and Analysis

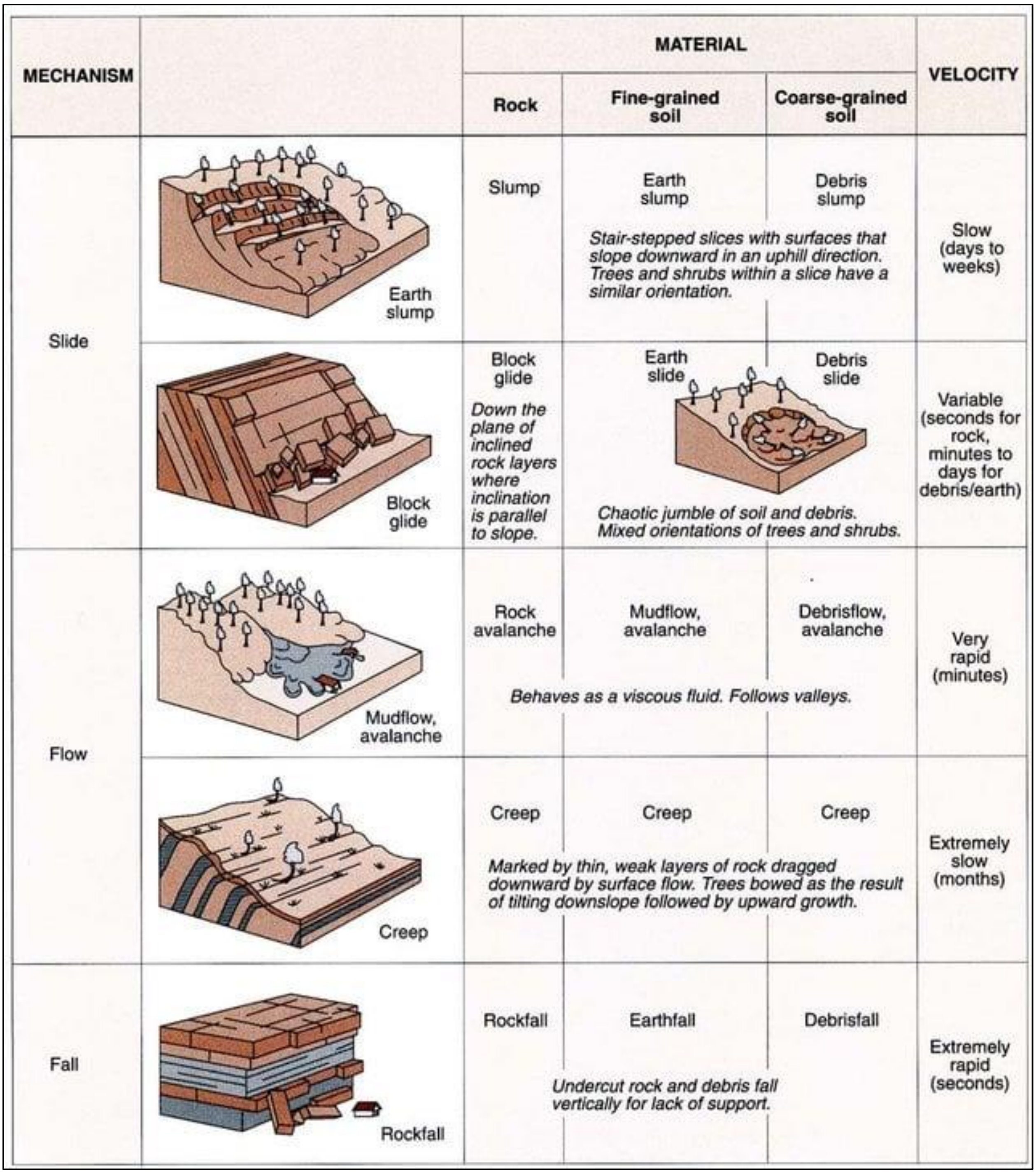
The data collected during the desk and field studies were analyzed to identify the key contributing factors to landslides. The analysis includes:

2.3.1 Geospatial Analysis and GIS Mapping

Photographic documentation is carried out systematically to record existing conditions, hazard features, and vulnerable structures for analysis and reporting. In addition, GPS-based location mapping is used to accurately record the coordinates of observed features and hazard points, ensuring precise spatial referencing. GIS modeling techniques were applied to develop boundaries of risk zone by incorporating geological, hydrological, and topographic factors.

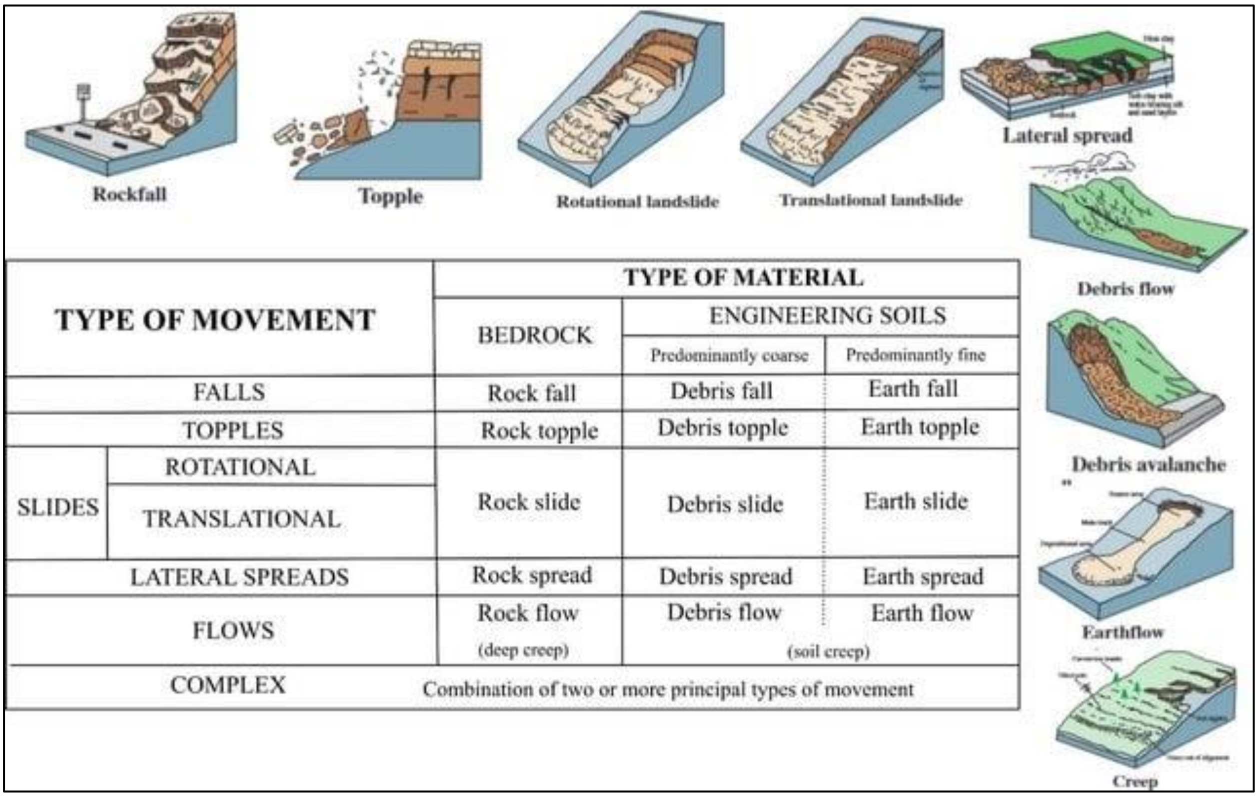
2.3.2 Preliminary Assessment of Landslides

A thorough preliminary evaluation of landslide conditions in the study area was carried out to identify and categorize the various forms of slope failure, such as debris flows, rock falls, and both rotational and translational slides as classified by Varnes (Figure 7 and Figure 8). The assessment examined the key contributing factors, including inherent geological conditions, the role of surface and subsurface water, and the influence of human activities. In addition, the study recorded the scale and nature of damage associated with both past and recent landslide events, with particular attention to their effects on infrastructure, farmland, and residential areas. The investigation further reviewed the present condition of landslide-affected zones, distinguishing between active, inactive (dormant), and reactivated sites.



MECHANISM		MATERIAL			VELOCITY
		Rock	Fine-grained soil	Coarse-grained soil	
Slide	Earth slump	Slump	Earth slump Stair-stepped slices with surfaces that slope downward in an uphill direction. Trees and shrubs within a slice have a similar orientation.	Debris slump	Slow (days to weeks)
	Block glide	Block glide Down the plane of inclined rock layers where inclination is parallel to slope.	Earth slide Chaotic jumble of soil and debris. Mixed orientations of trees and shrubs.	Debris slide	Variable (seconds for rock, minutes to days for debris/earth)
Flow	Mudflow, avalanche	Rock avalanche	Mudflow, avalanche Behaves as a viscous fluid. Follows valleys.	Debrisflow, avalanche	Very rapid (minutes)
	Creep	Creep Marked by thin, weak layers of rock dragged downward by surface flow. Trees bowed as the result of tilting downslope followed by upward growth.	Creep	Creep	Extremely slow (months)
Fall	Rockfall	Rockfall	Earthfall Undercut rock and debris fall vertically for lack of support.	Debrisfall	Extremely rapid (seconds)

Figure 7: A classification of landslides, in accordance with Varnes (1978



TYPE OF MOVEMENT		TYPE OF MATERIAL		
		BEDROCK	ENGINEERING SOILS	
			Predominantly coarse	Predominantly fine
FALLS		Rock fall	Debris fall	Earth fall
TOPPLES		Rock topple	Debris topple	Earth topple
SLIDES	ROTATIONAL	Rock slide	Debris slide	Earth slide
	TRANSLATIONAL			
LATERAL SPREADS		Rock spread	Debris spread	Earth spread
FLOWS		Rock flow (deep creep)	Debris flow (soil creep)	Earth flow
COMPLEX		Combination of two or more principal types of movement		

Figure 8: Abbreviated version of Varnes' classification of slope movements (Varnes 1978) along with major types of landslides (USGS, 2004).

2.3.3 Recommendation of Mitigation Plans and Relocation Sites

A wide range of recommendations was formulated to address landslide mitigation and reduce associated risks. These measures encompassed structural interventions, non-structural approaches, as well as bioengineering and nature-based techniques. In addition, suitable relocation options were identified for communities residing in high-risk areas, with careful consideration given to the geological stability and habitability of alternative sites. The proposed strategies were designed in accordance with disaster risk management principles, aiming to ensure sustainable and long-term solutions for areas vulnerable to landslides.

2.4 Report Writing

In the final stage, the results obtained from the desk study, field investigations, data processing, and interpretation were systematically integrated into a comprehensive report. The report provides a detailed overview of the geological and geomorphological conditions of the study area, along with a preliminary assessment of landslide occurrences, types, and controlling factors. It further presents the prioritization of identified landslides based on their relative risk and significance, highlighting sites that require more detailed investigation.

In addition, the report incorporates field-based recommendations aimed at mitigating landslide hazards, including both engineering and non-engineering measures. Where necessary, it also identifies and evaluates potential relocation sites for communities exposed to high levels of risk, ensuring that these alternatives are safe, stable, and suitable for long-term settlement. Overall, the report serves as a practical framework to support informed decision-making and sustainable management of landslide-prone areas.

Chapter – 3:

General Setting and Attributes of the Study Area

3.1 Location and Accessibility

Gurbhakot Municipality is situated in the mid-western region of Nepal within Surkhet District, which lies in Karnali Province. The municipality is located in the Inner Terai zone, characterized by a combination of low-lying valleys and adjoining hill slopes. The risk settlements are distributed across different wards of Gurbhakot Municipality, reflecting the spatial coverage of the study area. These settlements include Kalche (Tallo Gaun) in Ward No. 1; Khola Dhab and Lekha Malarani in Ward No. 2; Bithrikhola, Hile, and Lekha Kuriley in Ward No. 3; Pokharpata in Ward No. 5; Sindure Khola Gaun in Ward No. 6; and Beteni/Belgaira in Ward No. 14. It lies to the east of Birendranagar, the district headquarters, and is well connected by the Madan Bhandari Lokmarg, a major east–west highway traversing the Inner Terai region of the country. This strategic roadway provides essential connectivity to other parts of the district and neighboring regions, facilitating the movement of people, goods, and services. The accessibility of the municipality is further supported by a network of feeder roads like Kohalpur Jajarkot Road section linking other rural settlements to the main highway, although road conditions may vary seasonally, particularly during the monsoon period. The geographical coordinate of the area lies within the Latitude: 28°33′ N to 28°53′ N Longitude: 81°08′ E to 81°59′ E.

3.2 Physiography

Gurbhakot Municipality lies within the Inner Terai (Bhabar–Dun) physiographic zone of Nepal, representing a transitional landscape between the Siwalik Hills to the south and the Middle Mountain region to the north. This setting gives the area a mixed physiographic character, comprising river valleys, gently undulating plains, and surrounding hill slopes.

The elevation of the municipality generally ranges from approximately 300 m to 1,200 m above mean sea level, reflecting significant vertical variation within a relatively short horizontal distance. The lower elevations are dominated by flat to gently sloping valley floors formed by alluvial deposits, which are suitable for agriculture and settlement. In contrast, the higher elevations consist of moderately steep to steep slopes with rugged terrain, often dissected by seasonal streams and gullies.

Topographically, the area shows strong relief variation, with slopes becoming steeper toward the northern and southern hill margins. These slopes are commonly composed of weathered and fractured materials, making them prone to erosion and landslide activity, particularly during intense monsoon rainfall. The drainage network, controlled by local tributaries connected to the Bheri River system, plays a key role in shaping the terrain through continuous erosion and sediment transport.

3.3 Climate

Gurbhakot Municipality experiences a subtropical to warm temperate climate, influenced by its location in the Inner Terai region and its range of elevations. The climate is characterized by distinct seasonal variations in temperature and precipitation, largely controlled by the South Asian monsoon system.

The climatic data indicate moderate thermal conditions and pronounced seasonal variability in rainfall across Surkhet District (Bhandari, 2013, DHM). The mean annual temperature is approximately 21.47°C in Surkhet reflecting generally warm conditions throughout the year. In terms of precipitation, Surkhet receives a higher annual rainfall (1609 mm) compared indicating a relatively wetter climatic regime in Surkhet. Seasonal rainfall distribution shows that the majority of precipitation occurs during the monsoon and post-monsoon period (July–November), with averages of 1109 mm in Surkhet. During the winter season (November–March), rainfall significantly decreases to 135 mm in Surkhet. The pre-monsoon period (March–June) contributes moderate rainfall, with 389 mm in Surkhet. Seasonal temperature variation further highlights climatic differences. During the monsoon and post-monsoon period (July–November), the mean temperature is around 23.7°C in Surkhet. In winter (November–March), temperatures drop to 15.48°C in Surkhet. The pre-monsoon season (March–June) is relatively warmer, with average temperatures of 24.69°C in Surkhet

3.4 Geological Setting

3.4.1 Regional Geology

Based on geological map (DMG, 1987), the regional geology of the Surkhet area is characterized by a diverse stratigraphic sequence ranging from the Upper Pre-Cambrian to the Pleistocene. The uppermost sequence is the Siwalik Group (Mid-Miocene to Pleistocene), a fluvial succession divided into the Upper Siwalik, which contains coarse boulders and conglomerates; the Middle Siwalik, consisting of arkosic sandstones and pebbly beds with plant and animal fossils; and the Lower Siwalik, characterized by fine-grained sandstones interbedded with purple and chocolate-colored shales. Underneath lies the Surkhet Group (Cretaceous to Eocene), which includes the Suntar Formation's greenish-grey sandstones, the fossiliferous carbonaceous shales of the Swat Formation, and the ferruginous quartzites and limestones of the Melpani Formation.

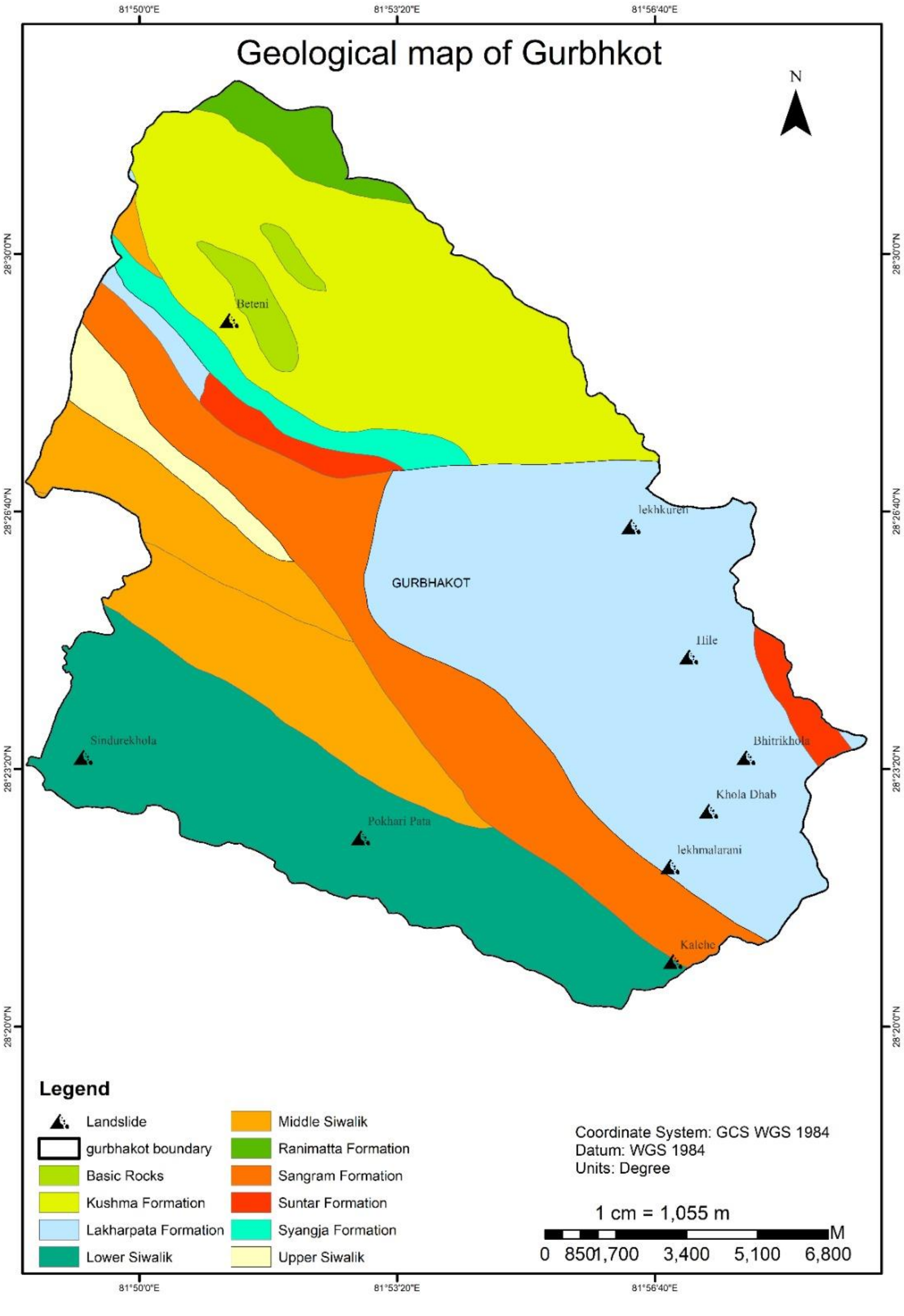


Figure 9: General Geological Map of the study area

The older basement and metasedimentary rocks are represented by the Mid-Land Group (Upper Pre-Cambrian to Late Paleozoic). This group encompasses the Gondwana Sub-group, featuring the black shales of the Takure Formation, and the extensive Lakharpata Sub-group, which includes various limestone and shale formations like the Lakharpata, Syangja, Sangram, and Galyang. Notably, the Lakharpata Formation contains significant algal structures and stromatolites. Finally, the Dailekh Sub-group forms the deepest stratigraphic units in this legend, consisting of the Ranimatta Formation with its chloritic phyllites and basic intrusions, the ripple-marked quartzites of the Kushma Formation, and the basal Augen gneisses and feldspathic schists of the Ulleri Formation.

Table 1: Regional Geological division of the Study area (DMG, 1987)

Group / Sub-group	Formation	Lithological Description
Siwalik Group	Upper Siwalik (Us)	Coarse boulders, conglomerates with irregular beds and lenses of sandstones and thin intercalations of yellow, brown, and grey sandy clays.
	Middle Siwalik (MS_1 & MS_2)	Fine to coarse-grained arkosic, pebbly sandstones; grey to dark grey clays/shales; pseudo conglomerates and mudstones; contains plant and animal fossils.
	Lower Siwalik (Ls)	Fine-grained hard grey sandstones interbedded with purple- and chocolate-colored shales, nodular maroon clays, and pseudo conglomerates.
Surkhet Group	Suntar Formation (Sn)	Fine to medium-grained greenish grey sandstones and purple shales with intercalations of green splintery shales.

Group / Sub-group	Formation	Lithological Description
	Swat Formation (Sw)	Grey to dark grey carbonaceous crumpled shales with fossiliferous limestones (*Nummulites sp, Assilina sp.*) and ferruginous quartzites at the base.
	Melpani Formation (Mp)	White, grey, ferruginous well-bedded massive quartzites interbedded with carbonaceous shales, conglomerates, and fossiliferous limestones.
Mid-Land Group (Gondwana Sub-group)	Takure Formation (Tk)	Black shales, psammitic schists, and conglomeratic phyllites.
Mid-Land Group (Lakharpata Sub-group)	Lakharpata Formation (Lk)	Fine-grained grey and dolomitic limestones with black to grey shales; contains algal structures and stromatolites.
	Syangja Formation (Sy)	White to milky white, pale orange, or purplish calcareous quartzites and dolomitic limestones with grey, purple, and green shales.
	Sangram Formation (Sg)	Black, dark grey to greenish grey splintery pencil-structured shales with thin white limestone intercalations and cross-bedded quartzites at base.
	Galyang Formation (Gl)	Dark grey shales finely intercalated with grey calcareous slates and sandstones; frequent dark grey to bluish grey limestones and dolomites.
Dailekh Sub-group	Ranimatta Formation (Rm)	Grey, greenish grey gritty chloritic phyllites, phyllitic quartzites, and metasandstones with frequent basic intrusions.

Group / Sub-group	Formation	Lithological Description
	Kushma Formation (Ks)	White to grey, fine to medium-grained massive ripple-marked quartzites intercalated with green chloritic phyllites.
	Ulleri Formation (Ul)	Augen gneisses and feldspathic schists.

3.4.2 Geology of the Study area

The geology of the Gurbhakot area (Figure 9) represents a structurally complex transition between the Sub-Himalayan (Siwalik) zone and the Lesser Himalaya. The area is dominated by sedimentary rocks of the Siwalik Group, which include mudstone intercalated with sandstone in the Lower Siwalik, medium- to coarse-grained sandstone with mudstone and occasional pebbles in the Middle Siwalik, and conglomerates in the Upper Siwalik. These rocks are generally weakly consolidated and highly susceptible to weathering and erosion, making them prone to slope instability.

The Lesser Himalayan sequence is represented by the Surkhet Group and the Lakharpata Formation. The Surkhet Group, including units such as the Suntar Formation, comprises interbedded sandstone and shale with occasional quartzite and ferruginous layers, indicating deposition in shallow marine to transitional environments. The Lakharpata Formation is the most extensively exposed unit and consists mainly of grey to bluish-grey limestone and dolomite interbedded with shale and calcareous quartzite. Although the carbonate rocks are relatively competent, the interlayering with shale and the presence of fractures and joints reduce overall rock mass strength.

These lithological units are arranged in an east–west trend and are strongly influenced by compressional tectonics, including thrusting, folding, and faulting. Older metamorphic rocks of the Midland Group, such as the Ranimata Formation and Ulleri Gneiss, occur in the southern part and consist of phyllite, schist, quartzite, and augen gneiss. The Bheri River flows through the central part of the area, following structurally weak zones, and has incised deeply into softer lithologies, forming steep, erosion-prone slopes

3.4.3 Engineering Geological Conditions

The engineering geological conditions of the Gurbhakot area are generally week and highly variable due to lithological and structural complexity. The Siwalik rocks, composed of weakly consolidated mudstone, sandstone, and conglomerate, are highly susceptible to weathering, erosion, and saturation, leading to frequent shallow landslides and debris flows, especially during the monsoon.

In the Lesser Himalayan units, the Surkhet Group shows interbedding of strong sandstone and weak shale, creating differential strength conditions that favor planar and wedge failures along bedding planes. The Lakharpata Formation, although consisting of relatively competent limestone and dolomite, is highly fractured and interlayered with shale, reducing overall stability and increasing the risk of rockfall and block sliding.

Metamorphic rocks of the Midland Group, such as phyllite and schist, contain well-developed foliation planes that act as weak zones, making slopes prone to planar failure, particularly when foliation dips toward the slope. Structurally, faults, folds, and thrust zones further weaken the rock mass and facilitate groundwater infiltration.

Additionally, deep river incision by the Bheri River has created steep and unstable slopes, often undercutting the toe of hillsides. Overall, the combination of weak lithology, structural discontinuities, and active erosion makes the area highly susceptible to landslides and slope instability.

Chapter -4

Preliminary Stability Assessment of Individual Landslide

4.1 Landslide Selection

A nine previously identified landslide sites were selected for the stability assessment. Each site was examined in the field and systematically recorded. The collected information covers precise geographic coordinates along with key landslide attributes, including type, current activity, size, probable causes, and triggering factors. The study also documents existing mitigation practices and evaluates the extent of damage, considering both human impacts and losses to property. In addition, information on nearby vulnerable houses, infrastructure, and other assets was gathered to understand potential risk exposure. All surveyed landslides were spatially delineated using drone-based observations. Each site has been organized into a standardized database and supported with field photographs for clear documentation and future reference.

Table 2 List of the studied sites

Name of the settlement	Municipality/Ward
Kalche	Gurbhakot-1
Khola Dhab	Gurbhakot-2
Lekh Malarani	Gurbhakot-2
Hile	Gurbhakot-3
Timure/Bhitri Khola	Gurbhakot-3
Lekh Kurile	Gurbhakot-3
Pokahari Pata	Gurbhakot-5
Tilkeni/Sindure Khola	Gurbhakot-6
Betine/Belgaura/Hileni	Gurbhakot-14

4.2 Kalche (GW1-01) Landslide

The Kalche landslide is situated in Ward No. 1 of Gurbhakot Municipality at coordinates 28°20'50.602" N latitude and 81°56'53.571" E longitude, with an elevation of approximately 1325 m above sea level. The landslide is located along the Madan Bhandari Highway, specifically within the Botechaur–Tulsipur road section.

4.2.1 Landslide Activity and History

The landslide was first activated in 2071 B.S. and has shown recurrent activity since then three times on 2076, 2080 and primarily triggered by intense monsoon rainfall. In addition to natural factors, anthropogenic activities have also contributed to its instability. In particular, slope cutting during road expansion has disturbed the natural equilibrium of the slope, leading to further reactivation of the landslide. Overall, the Kalche landslide can be categorized as a reactivated and rainfall-induced landslide, with both natural processes and human interventions playing important roles in its ongoing instability.

4.2.2. Geology of the assessment site

The study area is underlain by highly weathered, dark grey to purple shale and sandstone exposed along the upslope. The surface is predominantly covered by residual soil of approximately 1-3 m thickness, locally mixed with colluvial pebbles and boulders. These materials are relatively loose and susceptible to erosion. The slope faces southeast with an average inclination of about 55°, making it inherently unstable. The landslide extends from near the road cut and continues downslope, with an approximate length of 150 m and width of 50 m. It is characterized as a shallow slide.

Field observations indicate the presence of tension cracks at both the crown and within the main body of the landslide, suggesting past movement and potential for reactivation. Although no active movement is currently observed, the slope remains vulnerable.

The primary triggering factor appears to be gully erosion, which intensifies during the monsoon season. Significant soil loss occurs due to concentrated surface runoff. Additionally, the emergence of small springs, particularly during the monsoon, contributes to increased pore water pressure, further reducing slope stability. The downslope area is especially prone to instability due to continuous erosion. Nearby infrastructure, including a road and an existing school, lies within the potential impact zone and could be at risk during periods of intense rainfall.

At present, some stabilization measures have been implemented, including gabion walls along the road cut and downslope sections, which provide partial protection.

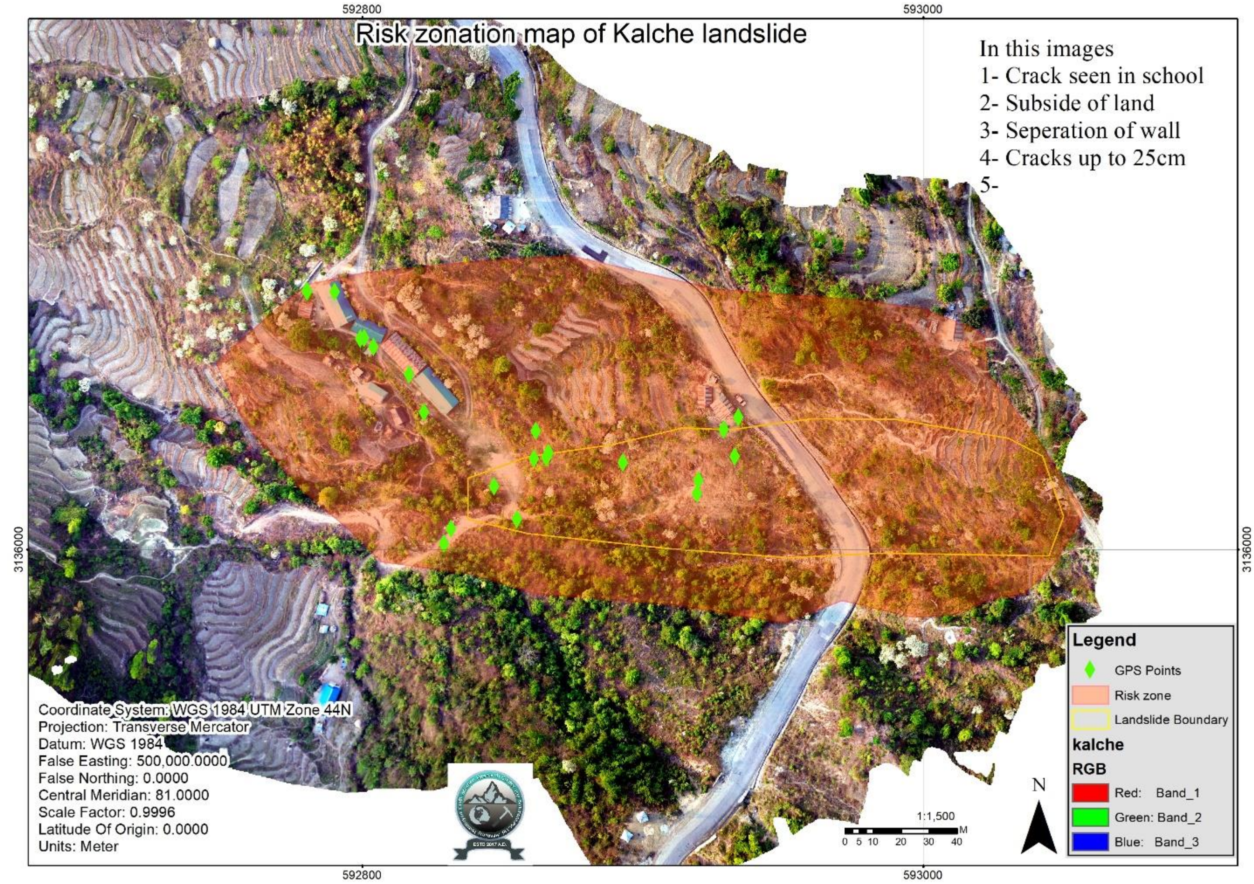


Figure 10: Photo Mosaic view with landslides boundaries from drone Images of Kalche Landslide, Gurbhakot-01.

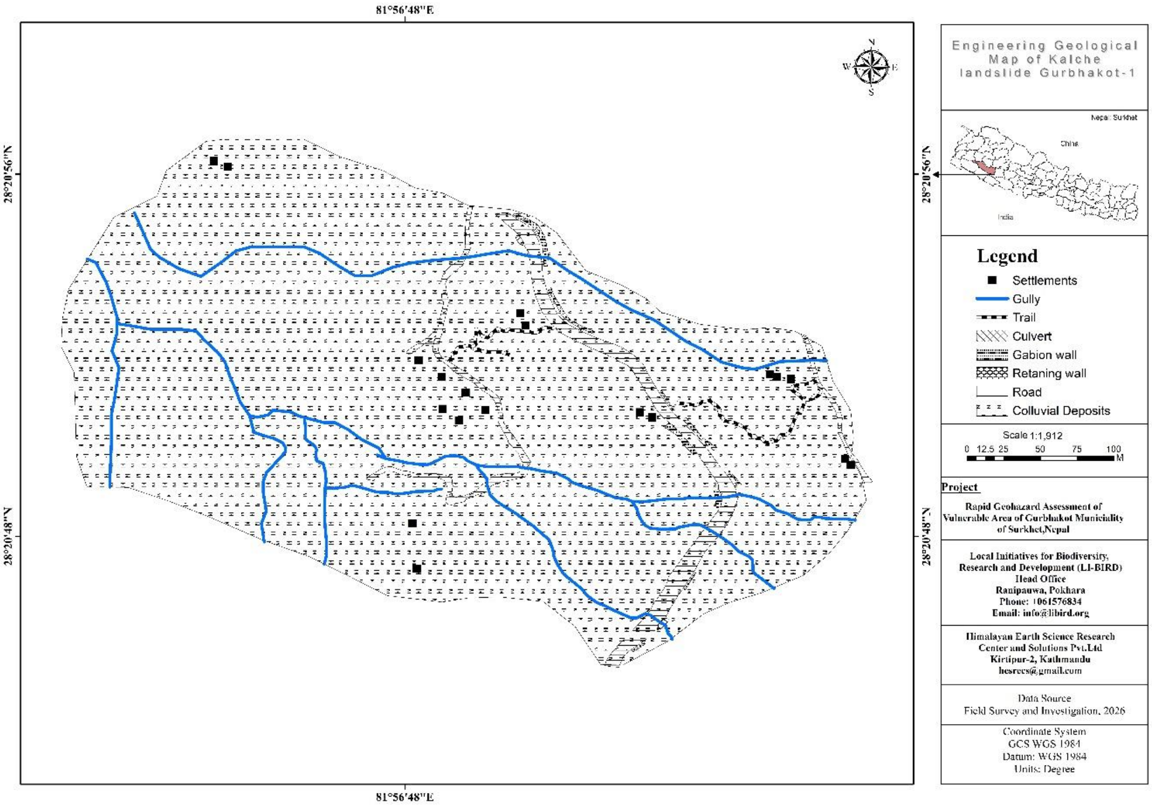


Figure 11: Engineering Geological map of Kalche landslide, Gurbhakot-1

4.2.3 Affected Houses and Infrastructure:

The settlement consists of 90 houses, of which 2–3 houses are identified as being at immediate risk from the present landslide condition. Key infrastructure potentially affected includes the road and a nearby school. Cracks have already been observed on land, indicating ground deformation and possible future impacts on additional structures if the slope becomes active again.

4.2.4 Mitigation and Control Measures

Effective mitigation of the landslide requires an integrated approach combining drainage control, bioengineering, and regular monitoring. Surface water should be properly managed by constructing catch drains and side drains along the upslope nearby road to safely divert runoff away from the affected area. These drainage channels should be lined to minimize infiltration and prevent further erosion, while gully development can be controlled through the installation of check dams or drop structures. In addition, subsurface drainage measures such as horizontal drains or perforated pipes are essential to reduce pore water pressure within the slope along the cut slope. Spring water emerging within the landslide zone should be properly collected and channelized to prevent saturation of slope materials. Bioengineering techniques should also be applied by establishing vegetation cover with deep-rooted grasses, shrubs, and trees to enhance soil binding and reduce erosion in the upslope of the road which is crown part of the landslide. Regular monitoring and maintenance are equally important, including periodic inspections during and after the monsoon season, along with timely repair of drainage systems and any damaged protective structures to ensure long-term slope stability.

4.2.5 Risk Level

Based on field observation, the probability of hazard occurrence in the Kalche landslide, landslide area is considered **Medium (Category 2).** Although the current condition does not indicate immediate large-scale failure, continued erosion during intense rainfall may gradually enlarge the affected area. Therefore, timely implementation of drainage improvement and gully control measures is recommended to maintain long-term slope stability and protect nearby houses Mandan Bhandari Highway.

Table 3: General characteristics of Kalche Landslide

ID	Kalche (GW1-01)
District	Surkhet
Municipality	Gurbhakot Municipality
Ward No.	1
Settlement	Kalche
Latitude	28°20'50.602" N
Longitude	81°56'53.571" E
Elevation	1325 m
Total Houses	90
Houses at Immediate Risk	2–3
Type	Shallow Landslide
Material	Residual soil with colluvial pebbles and boulders

Geology	Highly weathered red-purple shale and sandstone (fractured)
Initiation	2076 B.S. (reactivated multiple times, including 2081 B.S.)
Length	150 m
Width	50 m
Depth	2–3 m
Slope Angle	55°
Aspect	Southeast
Current Condition	Inactive
Activity Trend	Reactivates during monsoon and slope cutting
Major Causes	Pore water pressure, groundwater, weak geology, road cutting
Triggering Factors	Monsoon rainfall, poor drainage, gully erosion
Damage	Risk to houses, road, school
Risk Level	Medium (Category 2)
Mitigation	Drainage, gabion walls, bioengineering
Urgent Needs	Drainage control, slope stabilization

Figure 12 Glimpse of instability scenarios over the Kalche landslide.

4.3 Khola Dhab(GW2-01) Landslide

4.3.1 Location and General Information of Khola Dhab Landslide

The Khola Dhab landslide is located in Ward No. 1 of Gurbhakot, Surkhet. The landslide area lies at approximately 28°22'47.24" N latitude and 81°57'21.329" E longitude, with an elevation of about 1772 m above sea level. The affected settlement is locally known as Khola Dhab (GW2-01). The area is accessible through local rural roads connected to nearby settlements and agricultural land.

4.3.2 Landslide Activity and History

The landslide area became noticeably active after the intense rainfall event of 2081 B.S. The instability is mainly associated with monsoon-induced gully erosion and uncontrolled surface runoff. In addition to natural causes, human activities such as road cutting and slope disturbance have contributed to slope weakening and erosion processes. Tributary flow and concentrated runoff have progressively swept away soil mass materials and houses, enlarging the gully and increasing slope vulnerability during the rainy season. At present, the landslide can be categorized as a rainfall-induced erosional slope failure with relatively low activity.

4.3.3 Geology and engineering Geological condition of the assessment site

The affected area is mainly covered by residual soil deposits developed over weathered slope materials. The slope is generally mild in gradient and used for seasonal agricultural activities that largely depend on monsoon rainfall. Geologically, the area consists of red purple shale and phyllite is present throughout area. The dipping of the bedrock dip toward the north; however, no observed rock failure at the present condition.

The main geomorphological problem observed in the site is active gully erosion along the gully nearby cultivated land. During the monsoon season, several natural springs are originated throughout the village. Surface runoff during heavy rainfall erodes the loose residual soil and transports debris downslope through small tributary channels towards the houses. No major tension cracks or large scarps were identified during field observation, suggesting that the current instability is primarily erosional rather than deep-seated sliding.

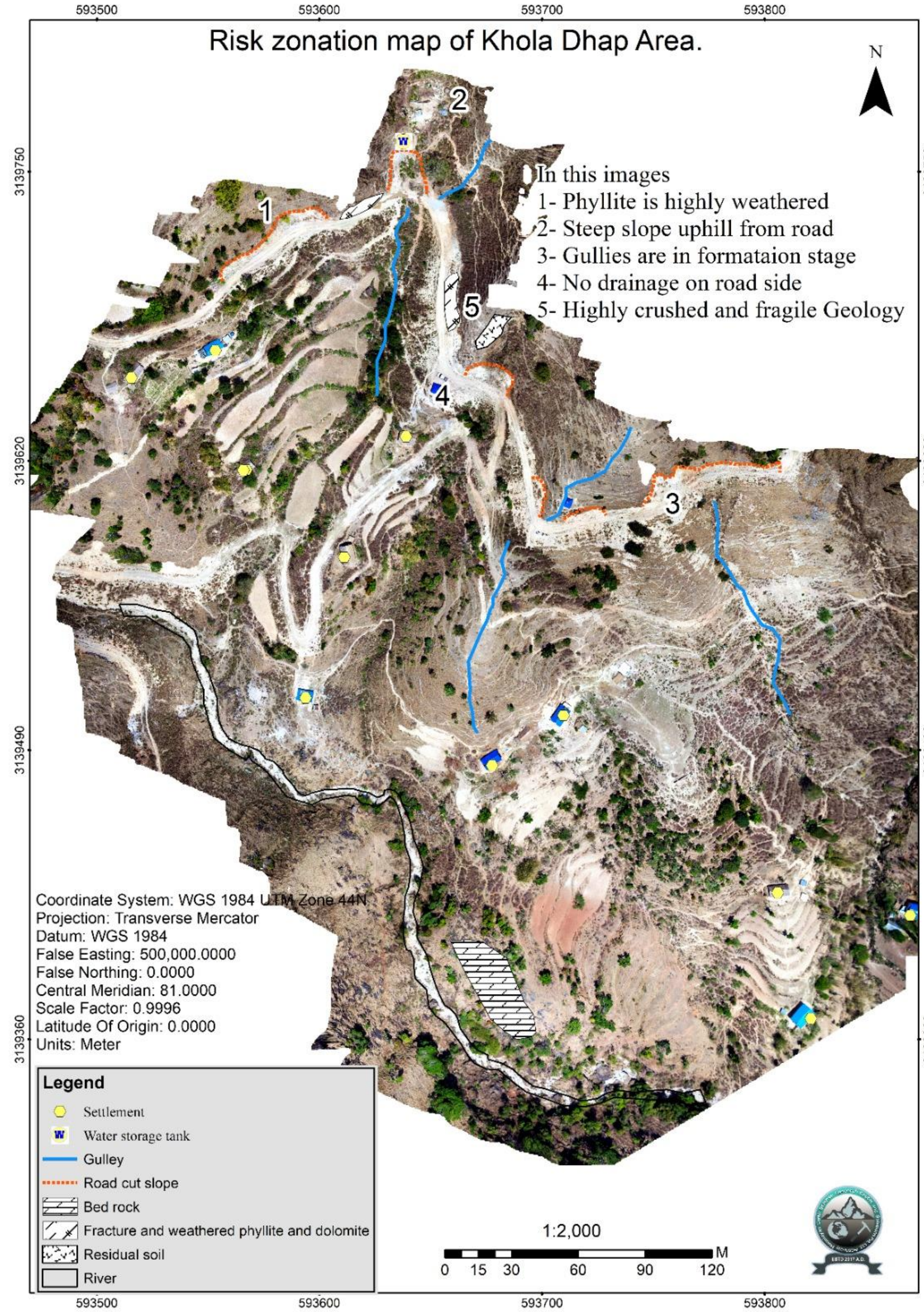


Figure 13: Photo Mosaic view with landslides boundaries from drone Images of Khola Dhab Landslide, Gurbhapot-02.

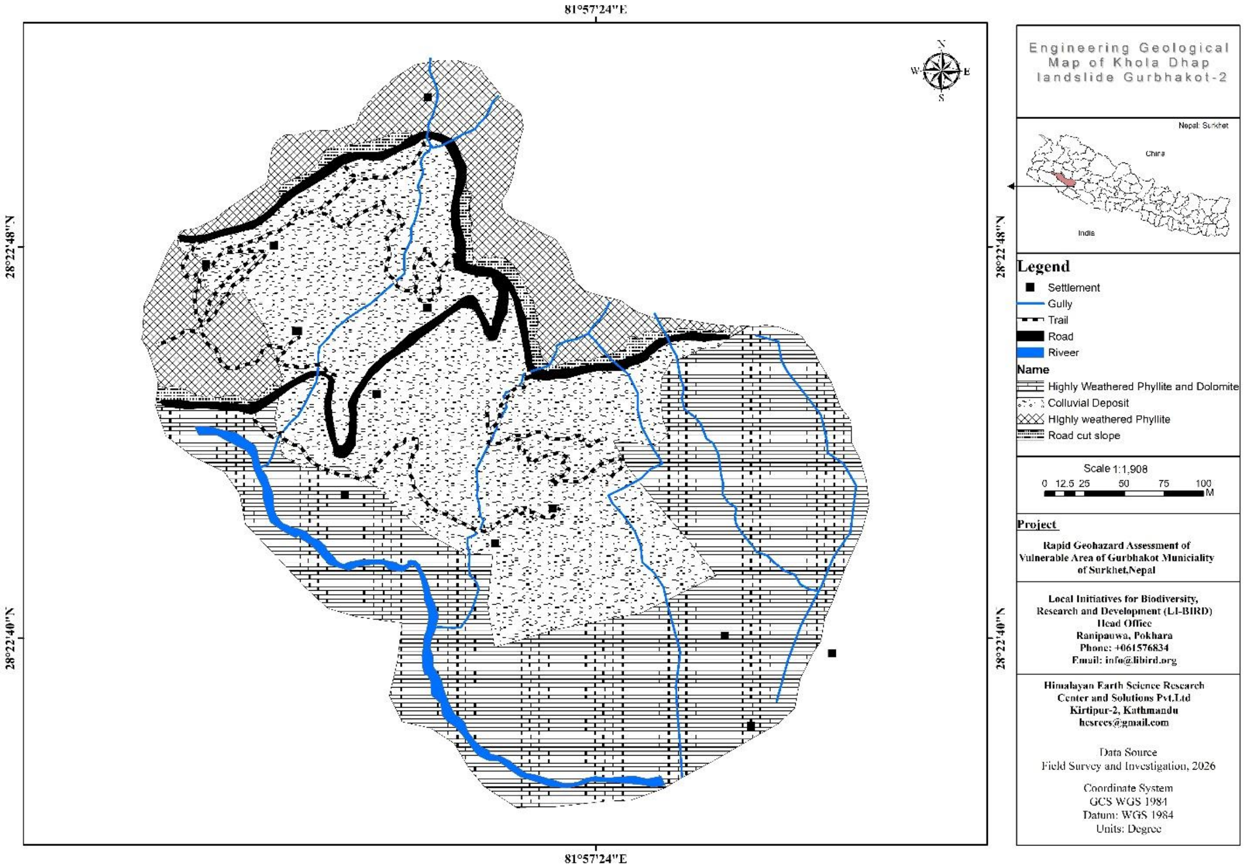


Figure 14: Engineering Geological Map of Khola Dhap landslide, Gurbhakot-02.

4.3.4 Affected Houses and Infrastructure:

The settlement consists of approximately 55 houses with a population of around 32 households. Among them, about 6 houses are considered to be at immediate risk from ongoing gully erosion and associated springs. Agricultural land surrounding the settlement is also vulnerable to soil loss during heavy rainfall events. The major infrastructure potentially affected includes local access roads, agricultural terraces, and nearby settlement areas.

4.3.5 Mitigation and Control Measures

Appropriate mitigation measures are required to control gully erosion and prevent further degradation of the land. Surface drainage management should be prioritized by constructing properly designed catch drains and side drains to safely divert runoff away from the vulnerable area. For the spring water, some channels are constructed to divert the water nearby the houses.

4.3.6 Risk Level

Based on field observation, the probability of hazard occurrence in the Khola Dhab landslide area is considered **low risk (category 1),** and the present community risk level is also categorized as low. The instability is mainly limited to seasonal gully erosion and localized soil loss rather than large-scale landslide movement.

Although the current condition does not indicate immediate large-scale failure, continued erosion during intense rainfall may gradually enlarge the affected area. Therefore, timely implementation of drainage improvement and gully control measures is recommended to maintain long-term slope stability and protect nearby houses and agricultural land.

Table 4: General characteristics of the Khola Dhab landslide area

Parameter	Description
ID	Khola Dhab (GW2-01)
District	Surkhet
Municipality	Gurbhakot Municipality
Ward No.	2
Settlement	Khola Dhab
Latitude	28°22'47.24" N
Longitude	81°57'21.329" E
Elevation	1772 m
Total Houses	55
Houses at Immediate Risk	6
Type	Gully erosion
Material	Phyllite and Residual soil
Geology	Shale and phyllite with Residual soil deposits rock are dipping toward north; no failure is observed
Initiation	Reactivated after intense rainfall event of 2081 B.S.
Length	
Width	
Depth	
Slope Angle	Mild slope
Aspect	South east slope
Current Condition	Less active

Activity Trend	Seasonal gully erosion increases during intense rainfall and springs originated
Major Causes	Monsoon rainfall, surface runoff, gully erosion,
Triggering Factors	Heavy rainfall, poor drainage condition, uncontrolled runoff
Damage	Risk to nearby houses, agricultural land, and local access road and seepage in the house during rainfall
Risk Level	Low (category 1)
Mitigation	Drainage improvement, diversion of water of springs
Urgent Needs	Gully management, surface drainage control, erosion protection

Figure 115: Photographs of instability area of Khola Dhab landslide zone

4.4 Lekh malarani(GW2-02)

The Lekh Malarani landslide is located in Ward No. 2 of Gurbhakot, Surkhet. The landslide area lies at approximately 28°22'16.07" N latitude and 81°57'06.27" E longitude, with an elevation of about 1398 m above sea level. The settlement is identified as Lekh Malarani (GW2-02). The area is accessible through local rural roads connected with nearby agricultural land and settlements.

4.4.1 Landslide Activity and History

The landslide was first activated in 2076 B.S. following intense monsoon rainfall. The failure is mainly associated with small-scale soil sliding and gully erosion processes triggered by prolonged rainfall and surface runoff. Field information indicates that the area experienced damage to houses and rural infrastructure during previous rainfall events, and some houses were reportedly swept away approximately eight years ago due to slope instability and erosion. The landslide activity is generally localized and seasonal in nature. During the monsoon season, runoff concentration within gullies increases erosion and weakens the slope materials. Although the present activity level is relatively low, continued rainfall and improper drainage may reactivate the slope in the future.

4.4.2 Geology and Engineering Geological Condition of the Assessment Site

The study area is underlain by highly weathered red-purple shale, slate, sandstone, and dolomite belonging to the Surkhet Group. The surface is predominantly covered by residual soil deposits distributed throughout the cultivated land. These soils are relatively loose and vulnerable to erosion during periods of heavy rainfall.

Topographically, the area consists of mild to gentle slopes with some saddle-shaped spur features. Two to three gullies are present within the settlement area, contributing to localized erosion and instability. The observed landslide is characterized as a very small-scale soil slide associated with weathered residual soil. The primary causes of instability include weathering of rocks, formation of weak residual soil, seasonal monsoon rainfall, and uncontrolled surface runoff. Rill and gully erosion are actively occurring within cultivated land, particularly during intense rainfall events. Although no major active scarp or deep-seated movement was observed during the field investigation, the slope remains sensitive to continued erosion and saturation.

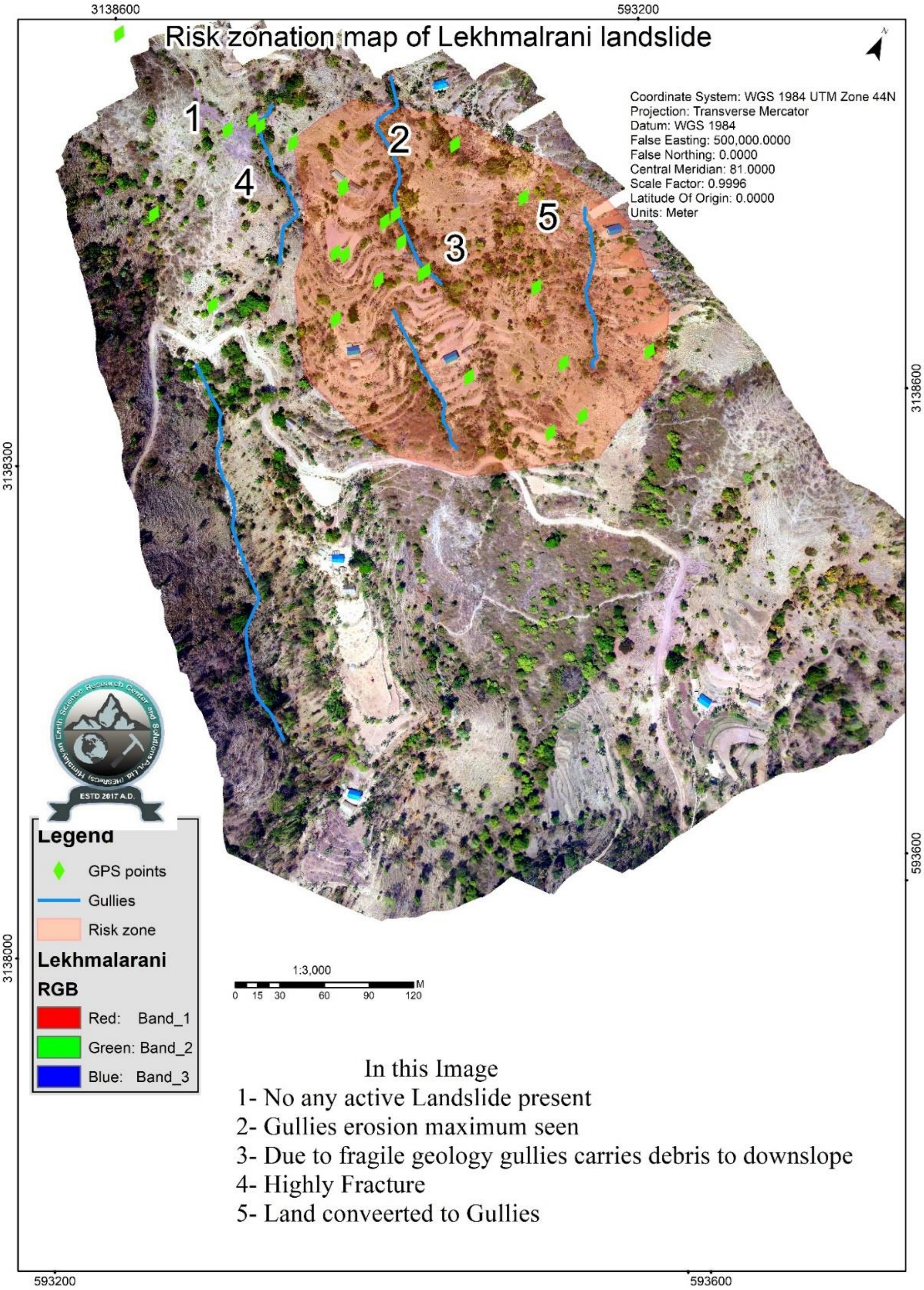


Figure 16: Photo Mosaic view with landslides boundaries from drone Images of Lekh Malarani Landslide, Gurbhakot-02.

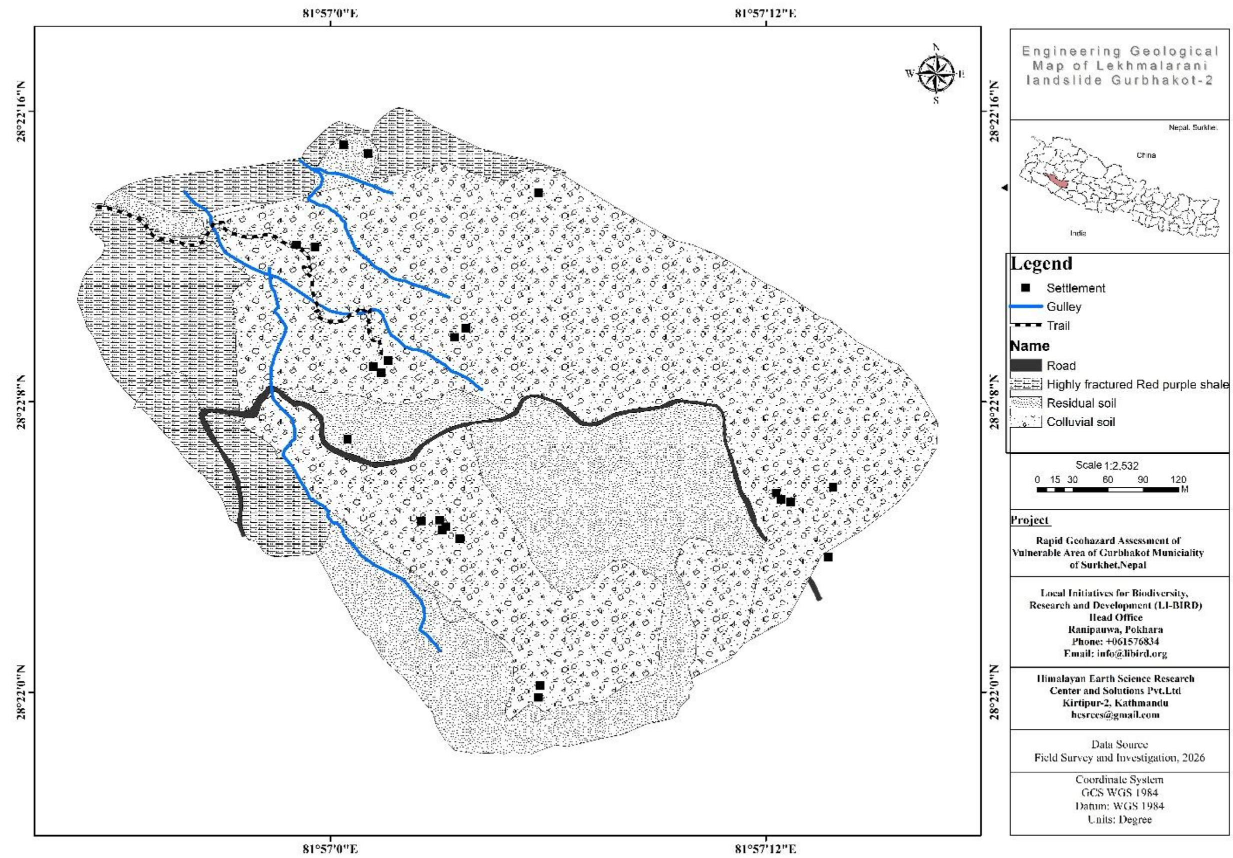


Figure 17: Engineering Geological Map of Lekh Malarani landslide, Gurbhakot-02.

4.4.3 Affected Houses and Infrastructure

The settlement consists of approximately 25 houses. At present, no houses are identified as being under immediate high risk; however, localized erosion and small soil slides may gradually threaten agricultural land and nearby structures if left unmanaged. The major infrastructure potentially affected includes rural roads, cultivated terraces, and local settlement areas. Past incidents indicate that road construction activities and improper slope modification may have contributed to slope weakening. Seasonal erosion also affects agricultural productivity and local accessibility during the monsoon period.

4.4.4 Mitigation and Control Measures

Appropriate mitigation measures are necessary to reduce ongoing erosion and improve slope stability in the area. Surface drainage management should be improved by constructing side drains and diversion channels to safely discharge runoff away from vulnerable slopes and gullies. Proper drainage maintenance during the monsoon season is essential to minimize water concentration and soil saturation.

4.4.5 Risk Level

Based on field observations, the Lekh Malarani landslide is categorized as a small-scale rainfall-induced soil slide with **low risk (Category 1).** The instability is primarily associated with surface erosion, weathered residual soil, and seasonal monsoon activity.

Table 5: General characteristics of the Lekh Malarani landslide area

Parameter	Description
ID	Lekh Malarani (GW2-02)
District	Surkhet
Municipality	Gurbhakot Municipality
Ward No.	2
Settlement	Lekh Malarani
Latitude	28°22'16.07" N
Longitude	81°57'06.27" E
Elevation	1398 m
Total Houses	25
Houses at Immediate Risk	Not identified
Type	Very small-scale soil slide
Material	Residual soil
Geology	Highly weathered red-purple shale, slate, sandstone and dolomite (Surkhet Group)
Initiation	2076 B.S. after intense rainfall
Slope Angle	Mild to gentle slope
Aspect	Saddle spur terrain
Current Condition	Localized erosion and inactive shallow slide
Activity Trend	Reactivates during monsoon season
Major Causes	Weathering of rocks, residual soil formation, monsoon rainfall
Triggering Factors	Heavy rainfall, poor drainage, gully erosion
Damage	Risk to rural roads, cultivated land and nearby settlement
Risk Level	Low (Category 1)
Mitigation	Drainage management, surface and subsurface water management,
Urgent Needs	Proper surface and subsurface drainage management

Figure 18 Measurement of rock orientation in the periphery of the settlement

4.5 Hile Landslide (GW-03 – 01)

The Hile landslide is located in Ward No. 3 of Gurbhakot, Surkhet District within the Karnali Province. The assessment site is located at Hile village (GW3-01), is situated at an elevation of approximately 1501 m above sea level. The geographic coordinates for the center of the settlement are recorded at latitude 28°24'46.993" N and longitude 81°56'48.235" E. The settlement consists of a total of 30 houses distributed across the hillside.

4.5.1 Landslide Activity and History

The geo hazard history of this site dates back to 2071 B.S., when the area was significantly affected by intense rainfall. The landslide is described as a potential failure, with a colluvial mass subsiding toward to the downslope of the road. Unlike purely surface-level erosion, this movement suggests a structural weakness within the slope material. Current observations indicate associated geo hazard conditions such as road narrowing, which hampers local accessibility and suggests ongoing slow movement or debris accumulation.

4.5.2 Geology and Engineering Geological Condition of the Assessment Site

Geologically, the study area is characterized by the presence of phyllite, shale which is intercalated with grey dolomite and some quartzite beds. The topographical conditions of the Hile settlement are characterized by moderate to steep slopes, which inherently increases the risk of gravitational failure. The root cause of the stability problem is identified as fragile geology. The engineering geological assessment notes that the downslope consists of a colluvial mass colluvial debris making it highly susceptible to subsidence.

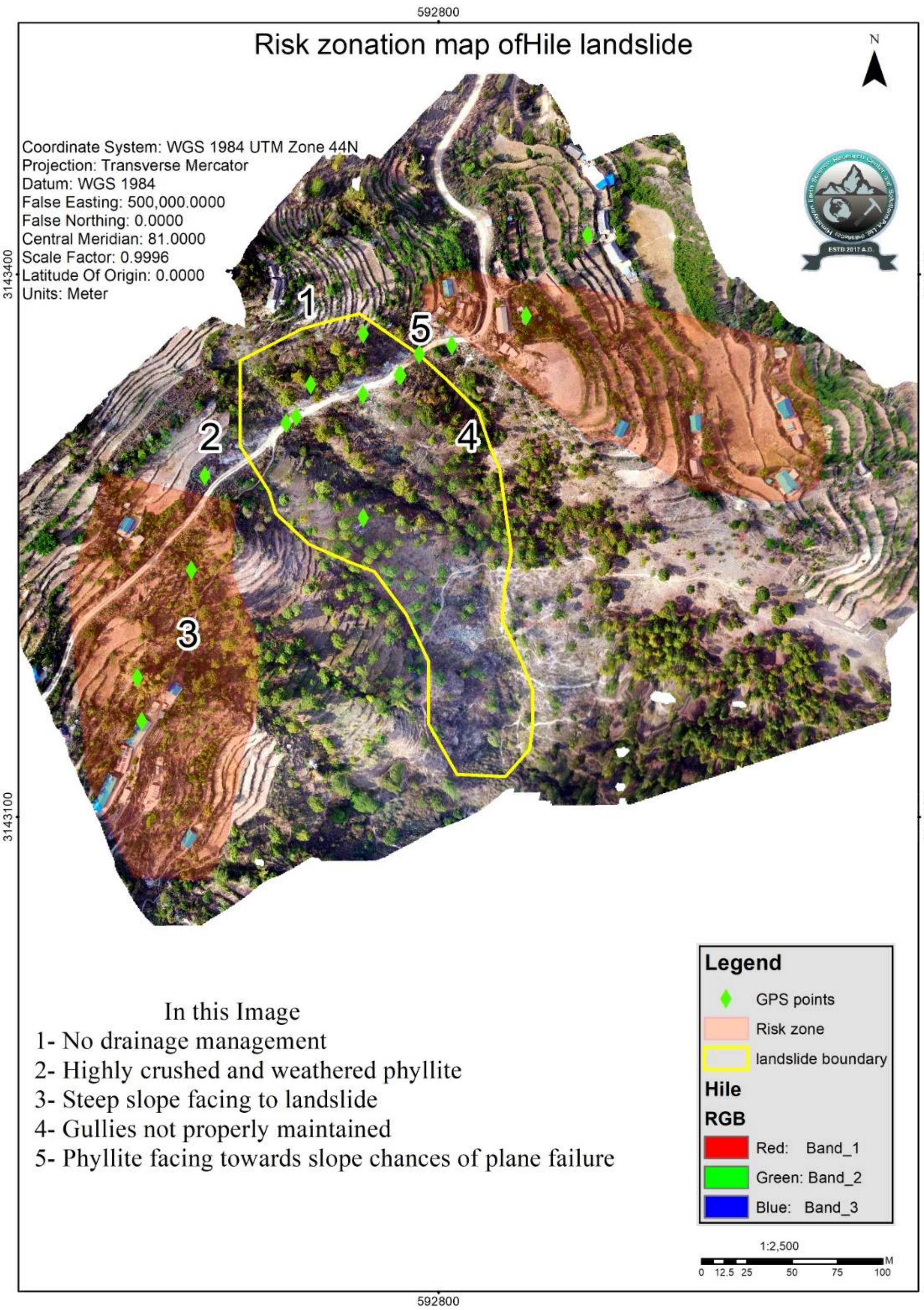


Figure 19: Photo Mosaic view with landslides boundaries from drone Images of Hile Landslide, Gurbhakot-03.

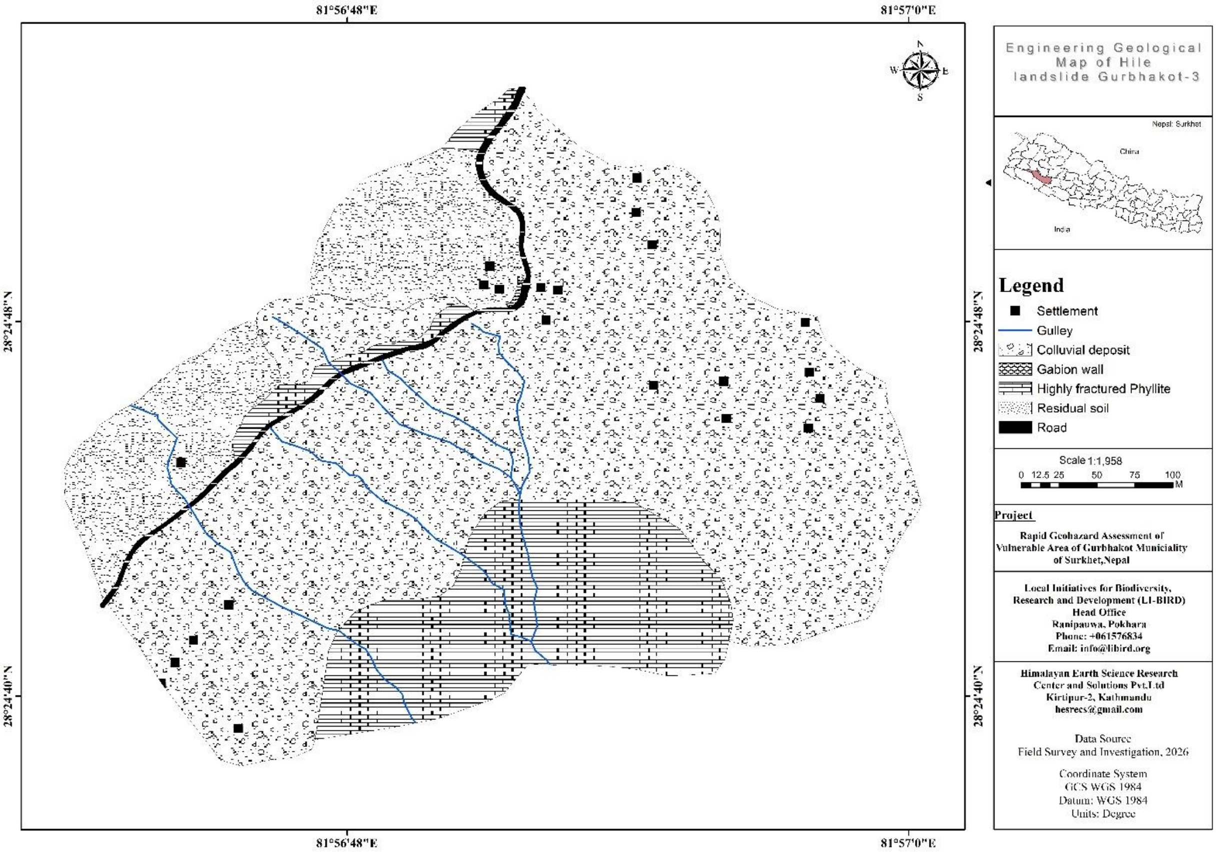


Figure 20: Engineering Geological Map of Hile Landslide, Gurbhakot-03.

4.5.3 Affected Houses and Infrastructure

Out of the 30 houses in the settlement, 3 houses and the local school building and cultivated land located in the downslope area are identified as being at immediate risk. These structures are particularly vulnerable when intense rainfall triggers further landslide activity. Field investigations revealed visible cracks in the school building, indicating that the downslope movement is already impacting critical community infrastructure. A large gabion is already constructed to protect school building. The narrowing of the rural road further highlights the impact of the landslide on local transportation.

4.5.4 Mitigation and Control Measures

To address the stability issues at Hile, a combination of structural and drainage-based mitigation is required. The primary recommendation is the identification of the slip surface to better understand the depth of failure. Immediate control measures include surface drain management to prevent water infiltration and the construction of a gabion wall on the uphill side of the road to provide toe support and catch debris. Additionally, the treatability status suggests benching of the slope in the downslope area to reduce the overall gradient and improve the factor of safety for the settlement and the school.

4.5.5 Risk Level

The Hile landslide is categorized as having a **medium risk level (Category 2)** for the community. Although the probability of a massive, sudden hazard occurrence is currently rated as "medium, the threat to the 3 houses and the school remains significant during the monsoon season.

Table 6: General characteristics of the Hile landslide area

Parameter	Details
Settlement Name	Hile (GW3-01)
Mun/District/Province	Gurbhakot-3, Surkhet, Karnali Province
Location: GPS coordinates	Northing: Latitude: 28°24'46.993" Easting: Longitude: 81°56'48.235" Elevation: 1501 m
Total number of houses	30
Description of landslide cracks, estimated volume of debris, etc.	May be plane failure also colluvial mass subsite at downslope
Topographical and Geomorphological Conditions within the settlement area	Moderate to steep slope
Geological/Engineering Geological Conditions of the settlement area	Possibility of plane failure, steep slope, bedrock of phyllite exposed on road section. Attitude of bedrock is 122/49
History of Geohazard problem	2071 (intense rainfall)
Geohazard condition and associated problems	Road narrowing
Root Causes of problems	Fragile geology
Engineering Aspects (Infrastructures and their impacts)	Cracks in school in the downslope
Socio-economic Conditions	-
Recommendation/Urgency of treatment	Identification of slip surface, Surface drain management
Control measures	Surface drain management and gabion wall in uphill from road

Conclusion	The slide is initiated by the intense rainfall, in the road cut section there is possibility of plane failure. Due to the lack of side drain all the surface runoff water flow through gully present in downslope increasing the possibility of debris flow.
Houses at immediate risk from the present geo hazard conditions	3 houses and school at downslope at risk when intense rainfall triggered landslide
Probability of hazard occurrence	No
Risk level at the community	Medium (category 2)
Treatability Status	Gabion wall on uphill from road and benching of slope in downslope

Figure 21 Representative photo of the geo hazard problem adjacent to the settlement slope

4.6 Timure/ Bhitri khola(GW3-02) Landslide

The Timure/ Bhitri khola landslide is located in Gurbhakot-3, Surkhet District, within the Karnali Province. The assessment site, identified as settlement Timure/ Bhitri khola (GW3-02), is situated at an elevation of approximately 1716 m above sea level. The geographic coordinates for the settlement are recorded at latitude 28°23'28.963" N and longitude 81°57'50.420" E. The settlement consists of a total of 15 houses.

4.6.1 Landslide Activity and History

The geo hazard history of this site is marked by a significant event in 2071 B.S., when intense rainfall triggered a flash flood that swept away 3 houses near a gulley. The landslide is described as a debris flow consisting of a colluvium mass with boulder-sized fragments of dolomite. Current observations indicate that the settlement and the road exist on a gulley road, where flash floods carrying debris continue to threaten the infrastructure in various parts.

4.6.2 Geology and Engineering Geological Condition

Geologically, the assessment site is characterized by a bedrock of dolomite and phyllite. The topographical conditions of the Timure/ Bhitri khola settlement are defined by steep slopes, which contribute to the debris flow hazard. The root cause of the stability problem is identified as intense rainfall acting upon the local geomorphology.

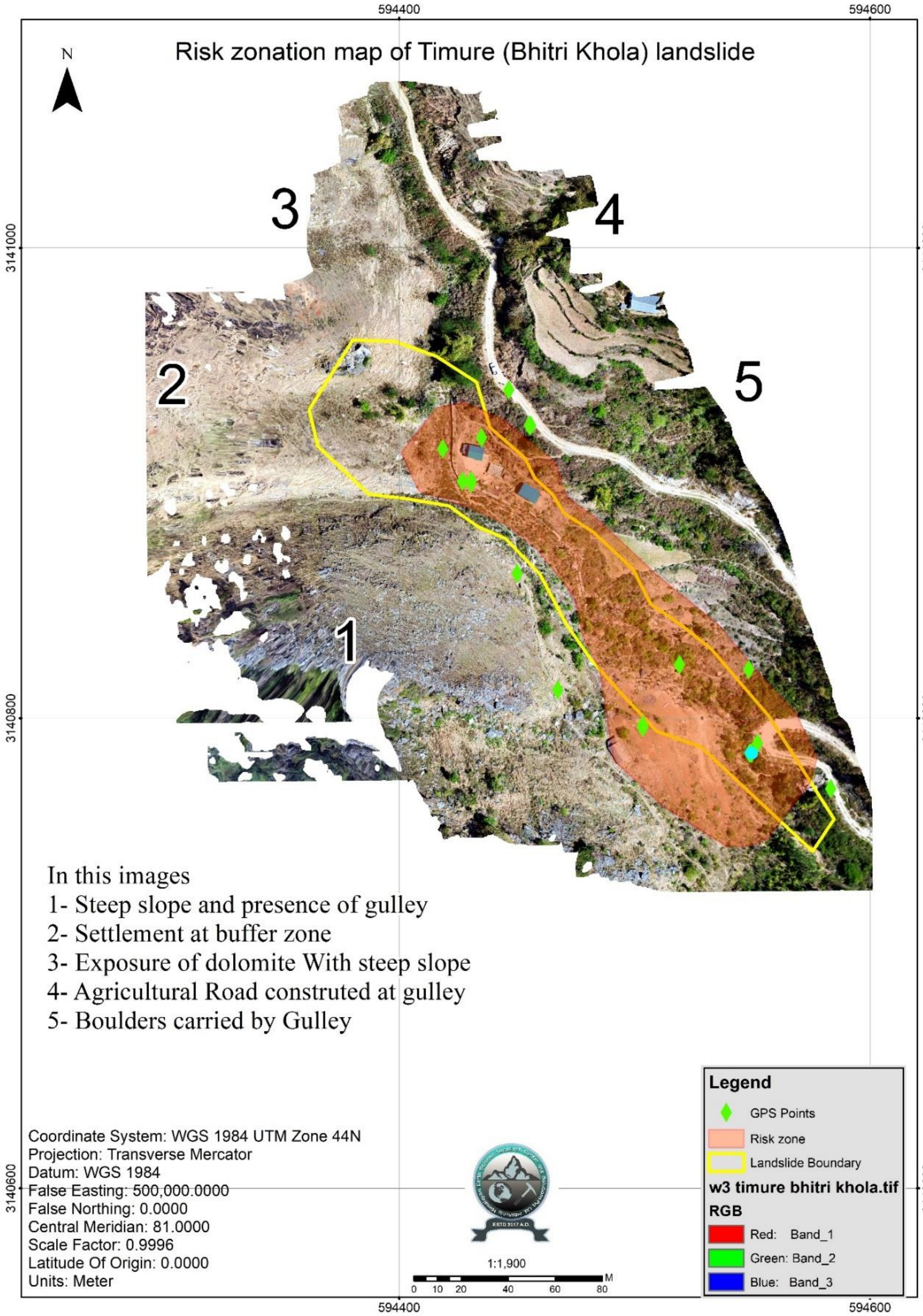


Figure 22: Photo Mosaic view with landslides boundaries from drone Images of Timure/ Bhitrikhola Landslide, Gurbhakot-03.

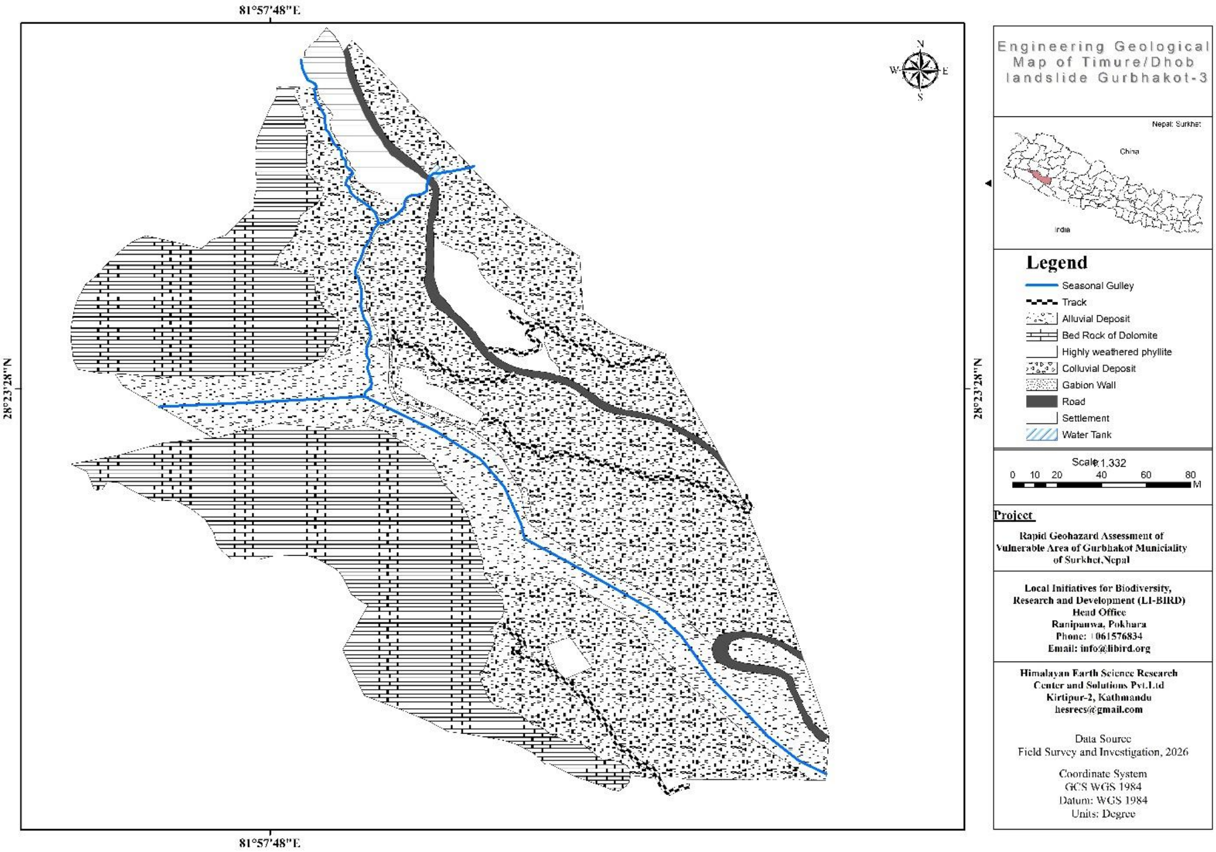


Figure 23: Engineering Geological Map of Timure Dhob/Bhitri khola landslide, Gurbhakot-03.

4.6.3 Affected Houses and Infrastructure

Out of the 15 houses in the settlement, 4 houses located near the gulley are identified as being at immediate risk. These structures are particularly vulnerable during the monsoon season and may need to be shifted to ensure safety. Historically, engineering impacts have already been recorded with the loss of 3 houses. The existing road infrastructure also remains in danger of being swept away by debris during flash flood events.

4.6.4 Mitigation and Control Measures

To address the geohazard conditions, a focus on hydraulic control and structural protection is required. The primary recommendation is to control the incision of the gulley and reduce the velocity of water flow, particularly during the monsoon. The final recommendation is to relocate the houses which lies just downstream part of upslope gullies.

4.6.5 Risk Level

The Timure/ Bhitri khola landslide is categorized as having a **high level (Category 3)** at the downslope villages especially rainfall season. In dry, no any risk is identified. However, the probability of hazard occurrence is high during the monsoon season, and the threat to the 4 houses at immediate risk remains a critical concern. So, it is recommended that the four houses near the gulley be shifted before or during the monsoon to ensure resident safety.

Table 7: General characteristics of the Timure /Bhitrikhola landslide area

Settlement Name	Timure/ Bhitri khola (GW3-02)
Mun/District/Province	Gurbhakot-1, Surkhet, Karnali
Location: GPS coordinates	Northing: Latitude:28°23'28.963" Easting: Longitude: 81°57'50.420" Elevation: 1716 m
Total number of houses	15
Description of landslide: dimensions of landslide, cracks, estimated volume of debris, etc.	Debris flow, colluvium mass, boulders size fragments of dolomite
Topographical and Geomorphological Conditions within the settlement area	Steep slope.
Geological/Engineering Geological Conditions of the settlement area	Bedrock of dolomite and phyllite
History of Geohazard problem	2071 intense rainfall swept 3 houses near by gulley
Geohazard condition and associated problems	As road and settlement exist on gulley road and 3-4 houses are in danger if flash flood carries debris may swept the houses and road in different parts
Root Causes of problems	Intense rainfall
Engineering Aspects: (Infrastructures and their impacts)	swept 3 houses nearby gulley
Socio-economic conditions	
Recommendation/Urgency of treatment	Control the incision of gulley and control the velocity of water in monsoon
Control measures	Proper drainage management, gabion wall to protect road
Houses at immediate risk from the present geohazard conditions	4 houses are near by the gulley they need to shift in monsoon
Probability of hazard occurrence	In monsoon
Risk level at the community	High (Category 3)
Treatability Status	Yes

Figure 24: Photographs indicates the view of debris flow gully and risk zone of the Bhitrikhola landslide

4.7 Lekh Kurile landslide (GW-03_03)

The Lekh Kurile landslide is located in Ward No. 3 of Gurbhakot Municipality in Surkhet District, Karnali Province. The landslide area lies at an elevation of approximately 962 m above mean sea level and is situated at coordinates 28.441001667° N latitude and 81.939705000° E longitude. The site is accessible through the local rural road network connecting nearby settlements and agricultural areas. The landslide has developed mainly along the road section and surrounding slope area.

4.7.1 Landslide Activity and History

The landslide is an old and repeatedly active slope failure zone that has been creating problems in road operation for several years. According to local information and field observation, the landslide was first initiated during the flood event of 2067 B.S. Later, the earthquake of 2072 B.S. further destabilized the slope condition. The landslide was reactivated again during the monsoon periods of 2081 and 2082 B.S. due to intense rainfall and slope saturation. Continuous road cut excavation and inadequate drainage management have further aggravated the instability condition. During monsoon periods, debris flow and surface erosion are commonly observed within the landslide body.

4.7.2 Geological and Engineering Geological Conditions

The topography of the landslide area is characterized by a steep slope near the crown portion, while the middle body part consists of a comparatively moderate slope. The downslope area has developed a gully due to continuous surface runoff and erosion processes.

Geologically, the area consists mainly of highly crushed, fractured, and weathered bedrock of phyllite shale which is intercalated with thinly bedded dolomite. The dolomite is highly fractured and sheared with some folded structures are also seen. The bedrock attitude is approximately 115/35. The rock mass is composed of thinly fractured materials with poor engineering properties and potential shear zones. Engineering geological investigation indicates that the slope is highly vulnerable to failure due to the combined effect of weak geological conditions, slope cutting, and poor drainage management.

4.7.3 Affected Houses and Infrastructure

The settlement surrounding the landslide area is sparsely distributed, and the majority of local people are dependent on agriculture for their livelihood. The houses in the area are generally old and constructed using stone and mud mortar, making them vulnerable to landslide impacts.

The rural road passing through the landslide area is the major infrastructure affected by slope instability. The road width has become narrow due to repeated slope failures and erosion during monsoon seasons. Existing retaining and drainage structures have been damaged in several locations. An electric pole located near the road section is also vulnerable to slope movement and possible collapse. Continued landslide activity may further threaten transportation access and nearby infrastructure.

4.7.4 Mitigation and Control Measures

Several mitigation measures are recommended to reduce landslide risk and stabilize the slope. Proper road cut slope protection measures should be implemented near the crown portion of the landslide. Surface and subsurface drainage systems should be constructed and maintained properly throughout the year to safely manage runoff water and reduce infiltration into the slope. The crushed and highly fractured rock materials continuously falling from the slope should be controlled by applying appropriate engineering protection measures such as wire mesh installation, rockfall protection systems, and shotcrete application along the upslope section. In the downslope area, proper cascade drainage management and erosion control measures should be implemented to minimize soil loss, surface erosion, and debris movement during monsoon periods.

4.7.5 Risk Level

Based on field observation, the Lekh Kurile landslide is considered a **high-risk (category 3)** landslide area. The landslide is old and active, with high possibility of reactivation during future monsoon periods. The road section passing through the landslide zone remains highly vulnerable to further collapse and debris flow events if proper stabilization and drainage management works are not carried out immediately. Nearby infrastructure including electric poles and road also at considerable risk due to ongoing slope instability. Although no houses are located nearby the landslide area, the possibility of human casualty is comparatively low. However, continued slope failure may seriously affect transportation access and public safety along the road corridor.

Table 8: General characteristics of the Lekh Kurule landslide area

Particulars	Description
Settlement Name	Lekh Kurule (GW3-03)
Municipality/District/Province	Gurbhakot Municipality, Surkhet District, Karnali Province
Location: GPS coordinates	Northing: 28.441001667° N Easting: 81.939705000° E Elevation: Approximately 962 m amsl
Total number of houses	No nearby houses within immediate landslide area
Description of landslide	An old and active landslide developed mainly along the rural road section. Cracks, debris flow, rockfall, and surface erosion were observed within the landslide body.
Topographical and Geomorphological Conditions	The slope is steep near the crown portion and comparatively moderate within the middle body part. Downslope gully erosion and surface runoff are prominent.
Geological/Engineering Geological Conditions	The area consists of highly crushed, fractured, and weathered bedrock with poor engineering properties. Weak rock mass and shear zones contribute to instability.
History of Geo hazard problem	The landslide was initiated during the flood event of 2067 B.S., further destabilized by the 2072 earthquake, and reactivated during monsoon periods of 2081 and 2082 B.S.
Geo hazard condition and associated problems	Continuous rockfall, debris movement, road instability, and surface erosion threaten transportation access and nearby infrastructure.
Root Causes of problems	Heavy rainfall, slope saturation, weak fractured rock mass, road cut excavation, inadequate drainage, and erosion processes.
Engineering Aspects	Road narrowing, damaged drainage structures, unstable cut slopes, and vulnerable electric poles were observed along the road corridor.

Socio-economic Conditions	The local population is mainly dependent on agriculture. Although no houses are located nearby the landslide area, transportation and local access are vulnerable.
Recommendation/Urgency of treatment	Immediate slope stabilization, drainage improvement, and rockfall protection measures are required.
Control measures	Surface and subsurface drainage, wire mesh installation, shotcrete application, gabion retaining structures, cascading drainage management, and bioengineering measures are recommended.
Conclusion	Lekh Kurule is considered a high-risk landslide area with high probability of reactivation during future monsoon seasons.
Houses at immediate risk	No houses are located within the immediate landslide zone, therefore the possibility of human casualty is comparatively low.
Probability of hazard occurrence:	Yes, during the monsoon
Risk level at the community:	High (Category 3) (but no relocation)
Treatability Status:	Treatable with detail study, proper engineering structure for road cut slope protection, drainage surface and subsurface management.

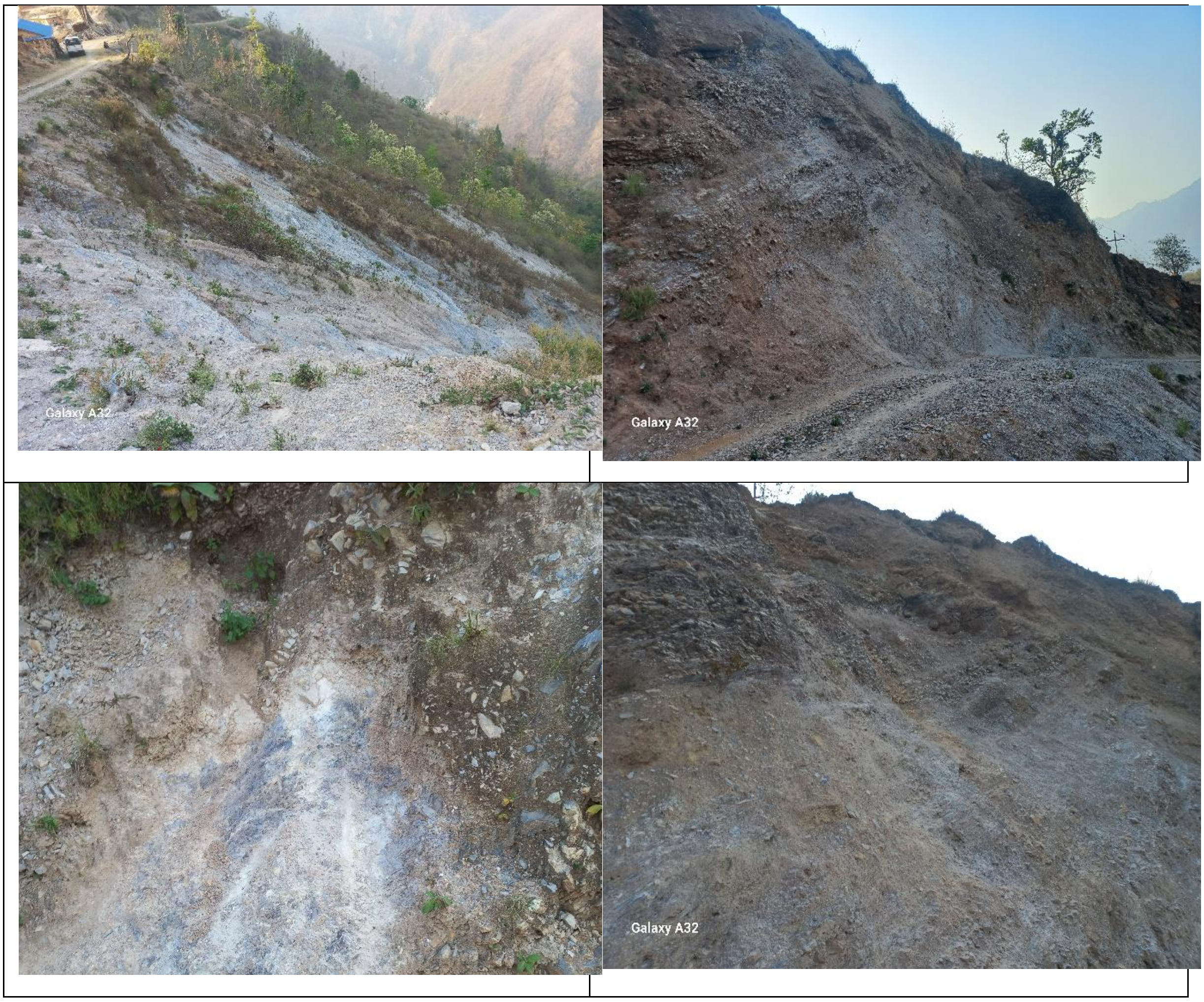


Figure 25: Photographs showing detail view of Lekh Kurule landslides with sheared zone

4.8 Pokhari Pata landslide (GW-05_01)

The Pokhari Pata landslide is located in Ward No. 5 of Gurbhakot Municpality in Surkhet District. The landslide area lies at an elevation of approximately 1190 m above mean sea level and is situated at coordinates 28°22'26.62" N latitude and 81°52'51.27" E longitude. The site is accessible through the rural road network connecting nearby settlements and local agricultural areas.

4.8.1 Landslide Activity and History

The landslide appears to have been triggered mainly by intense rainfall during 2082 B.S., which increased soil saturation and reduced slope stability. In addition, road construction activities such as cut-slope excavation, narrowing of the road section, and disturbance of colluvial deposits have further destabilized the slope. Poor drainage conditions and concentration of runoff water have also contributed to the development of the landslide.

4.8.2 Geological and Engineering Geological Conditions

The topography of the landslide area is characterized by a steep upper slope near the crown portion, whereas the middle and lower sections gradually become gentler toward the toe area. The geomorphological setting indicates an unstable hill slope affected by weathering, erosion, and human-induced disturbances. Accumulation of debris material and surface deformation were observed in different parts of the slope.

The geological condition of the area is dominated by sedimentary rock sequences composed mainly of interbedded sandstone and mudstone. The mudstone layers are highly weathered and comparatively weak, while sandstone beds are relatively stronger and more resistant. Differential weathering between these lithological units has created unfavorable slope conditions. Engineering geological investigation also identified cracks on the road surface and near the crown portion of the landslide, indicating active slope movement.

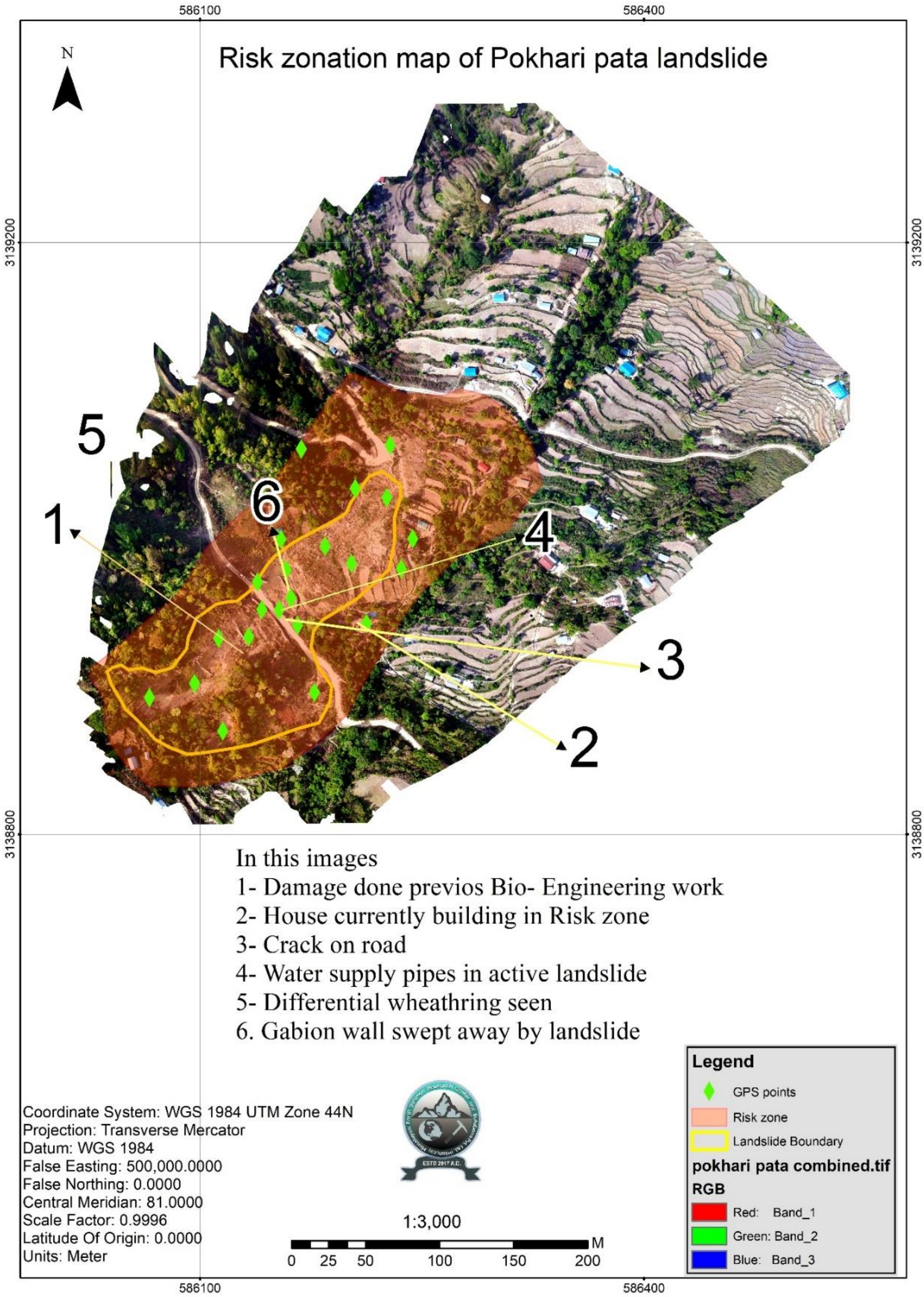


Figure 26: Photo Mosaic view with landslides boundaries from drone Images of Pokhari Pata Landslide, Gurbhakot-05.

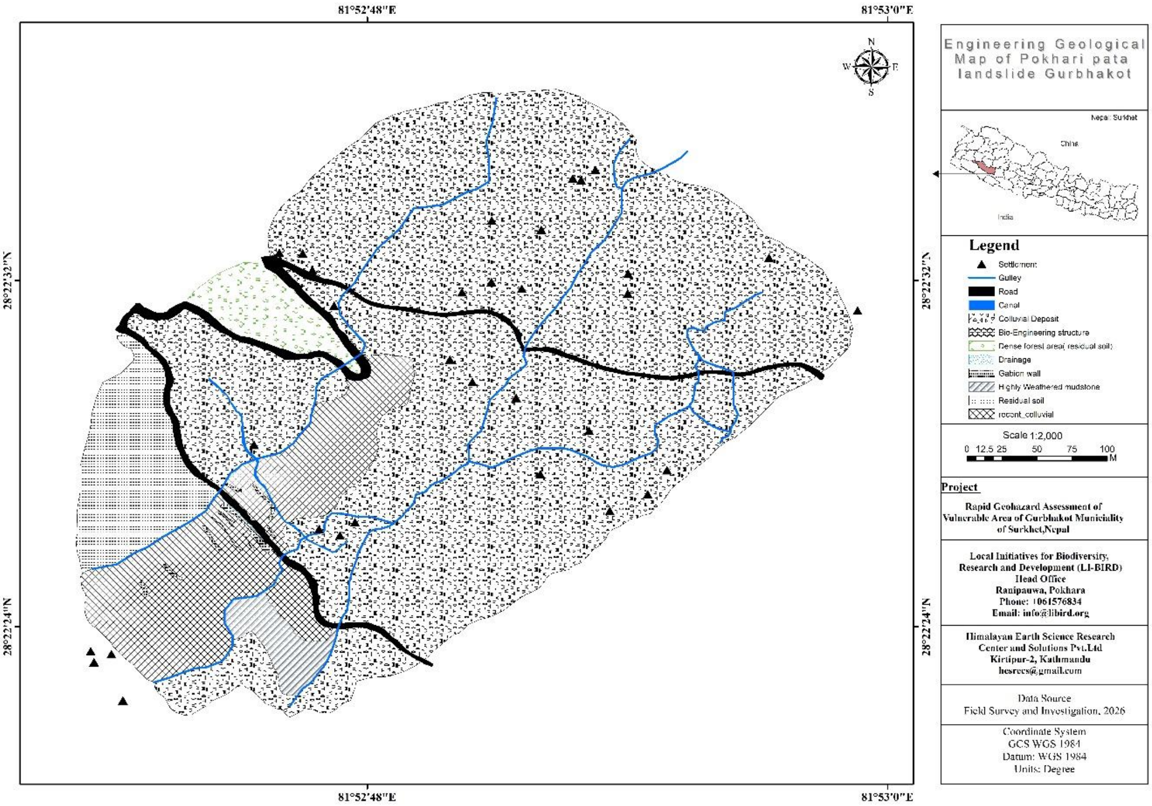


Figure 27: Engineering Geological Map of Pokharipata Landslide, Gurbhakot-05.

4.8.3 Affected Houses and Infrastructure

The settlement surrounding the landslide consists of approximately 108 households, among which around 93 households are considered vulnerable to landslide-related impacts. Field observation revealed that two houses located within the landslide body are presently under direct threat due to ongoing ground movement and slope instability.

The landslide has caused damage and instability along the rural road section passing through the area. Disturbance of colluvial deposits within the road alignment has increased the risk of further slope failure. Due to failure of slope, a long gabion wall is disrupted and uphill slope is also bending. In the body part, previously implemented bioengineering work also swept away and reaming structure still seen as overhanging materials. Water supply pipelines constructed within the landslide body are also vulnerable to deformation and damage. Continued movement of the slope may threaten additional houses and infrastructure located downslope.

4.8.4 Mitigation and Control Measures

Several mitigation measures are recommended to reduce landslide risk in the area. Proper surface and subsurface drainage systems should be constructed to safely manage runoff water.

Cascade drainage in downhill side and slope stabilization measures such as uphill benching, and gabion retaining structures along vulnerable road sections are necessary. Bioengineering techniques including plantation and vegetation cover should also be implemented in body part as well as near toe part to improve slope stability. Furthermore, detailed geotechnical (drilling) and geophysical survey (ERT) are recommended before undertaking permanent stabilization and road improvement works.

4.8.5 Risk Level

Based on field observation and preliminary engineering geological assessment, the Pokhari Pata landslide is considered as a **high-risk (Category 3)** landslide area. There is high chance of reactivation of the landslide in future, especially during upcoming monsoon season due to heavy rainfall condition. The settlements located at both crown and toe part of the landslide are still vulnerable to slope movement. One house constructed near the right flank portion of the landslide is highly vulnerable and may be seriously in risk if immediate protection and stabilization work is not carried out. The rural road will be collapsing if protection work is not carried out.

Table 9: General characteristics of the Pokhari Pata landslide area

Settlement Name	Pokhari Pata (GW5-01)
Municipality/District/Province	Gurbhakot Municipality–5, Surkhet District, Karnali Province
Location	The landslide is located at coordinates 28°22'26.62" N latitude and 81°52'51.27" E longitude with an elevation of approximately 1190 m above mean sea level.
Total Number of Houses	The settlement area consists of approximately 108 houses, among which nearly 93 houses are considered vulnerable to landslide impacts.
Description of Landslide	The landslide area shows evidence of differential weathering within sedimentary rock formations composed of interbedded sandstone and mudstone. Cracks were observed along the road section and near the crown portion of the landslide. Small debris accumulation was also noted during field investigation.

Topographical and Geomorphological Condition	The topography of the area is characterized by a steep slope near the crown portion, while the middle and toe sections become comparatively gentle.
Geological and Engineering Geological Condition	The geological condition of the area is dominated by interbedded sandstone and mudstone. The mudstone layers are highly weathered and weak, which has contributed to slope instability.
History of Geohazard Problem	The landslide was significantly influenced by intense rainfall during 2082 B.S., which increased slope instability and triggered ground movement.
Geo-hazard Condition and Associated Problems	Road narrowing, cut-slope excavation during road construction, and slope disturbance were observed in different sections of the landslide area.
Root Causes of Problems	The major causes of the landslide include intense rainfall, improper road construction practices, and disturbance of colluvial materials along the rural road section.
Engineering Aspects	Disturbance was observed along the road section due to instability of colluvial deposits. Two houses located within the landslide body remain at risk. Water supply pipelines constructed within the landslide body are also vulnerable to damage.
Socio-economic Condition	Several settlements are located both upslope and downslope of the landslide area, making local communities vulnerable to future slope movement and infrastructure damage.
Recommendation / Urgency of Treatment	Further detailed investigation is recommended. Slope benching from the road section toward the uphill side, downslope stabilization, and reduction of road load are necessary. Immediate treatment measures should be implemented because many settlements exist in the surrounding area.
Control Measures	Proper drainage management, toe protection work, gabion retaining structures, and bioengineering techniques are recommended to stabilize the slope.

Conclusion	The landslide area requires immediate attention because houses located near the crown, toe, and right flank portions remain highly susceptible to future slope failure.
Probability of Hazard Occurrence	Yes, there is high probability of future landslide occurrence, especially during the monsoon season.
Risk Level at Community	High risk (Category 3)
Treatability Status	The landslide is treatable with detailed engineering geological and geotechnical investigation followed by appropriate stabilization measures.

Figure 28: Details view of Pokari Pata landslide

4.9 Tilkeni / Sindure Khola Gau Landslide (GW6-01)

The Tilkeni / Sindure Khola Gau landslide is located in Ward No. 6 of Gurbhakot within Surkhet District. The landslide area lies at an elevation of approximately 888 m above mean sea level and is situated at coordinates 28°23'27.38" N latitude and 81°49'23.12" E longitude. The site is accessible through the rural road network connecting nearby settlements and agricultural land.

4.9.1 Landslide Activity and History

Although detailed historical records of previous landslide events are not available, local people reported repeated small-scale slope failures and road-related instability during monsoon seasons. The slope instability in the Tilkeni / Sindure Khola Gau area was further aggravated after the 2023 Jajarkot earthquake. Local people reported the development of new cracks and widening of existing tension cracks after the earthquake event. Continuous rainfall, and weak geological conditions, has gradually increased slope instability in the area over time.

4.9.2Geological and Engineering Geological Conditions

The topography of the area is characterized by moderate to steep slope conditions. The slope surface is comparatively unstable, and proper gully protection measures were not observed during the field investigation. Surface runoff and slope erosion are actively affecting different parts of the area.

The geological condition of the landslide area mainly consists of interbedded sandstone and mudstone formations. The mudstone layers are highly weathered and possess low shear strength, making the slope susceptible to failure during rainfall events. Cultivated land is present around the landslide area, which may further influence slope instability due to irrigation and surface water infiltration. Several cracks are also seen in some part of the cultivated land.

The major causes of the landslide include highly weathered mudstone, low-strength slope materials, haphazard road cutting practices, and inadequate drainage management. Road excavation without proper slope stabilization has significantly contributed to the development of slope instability in the area.

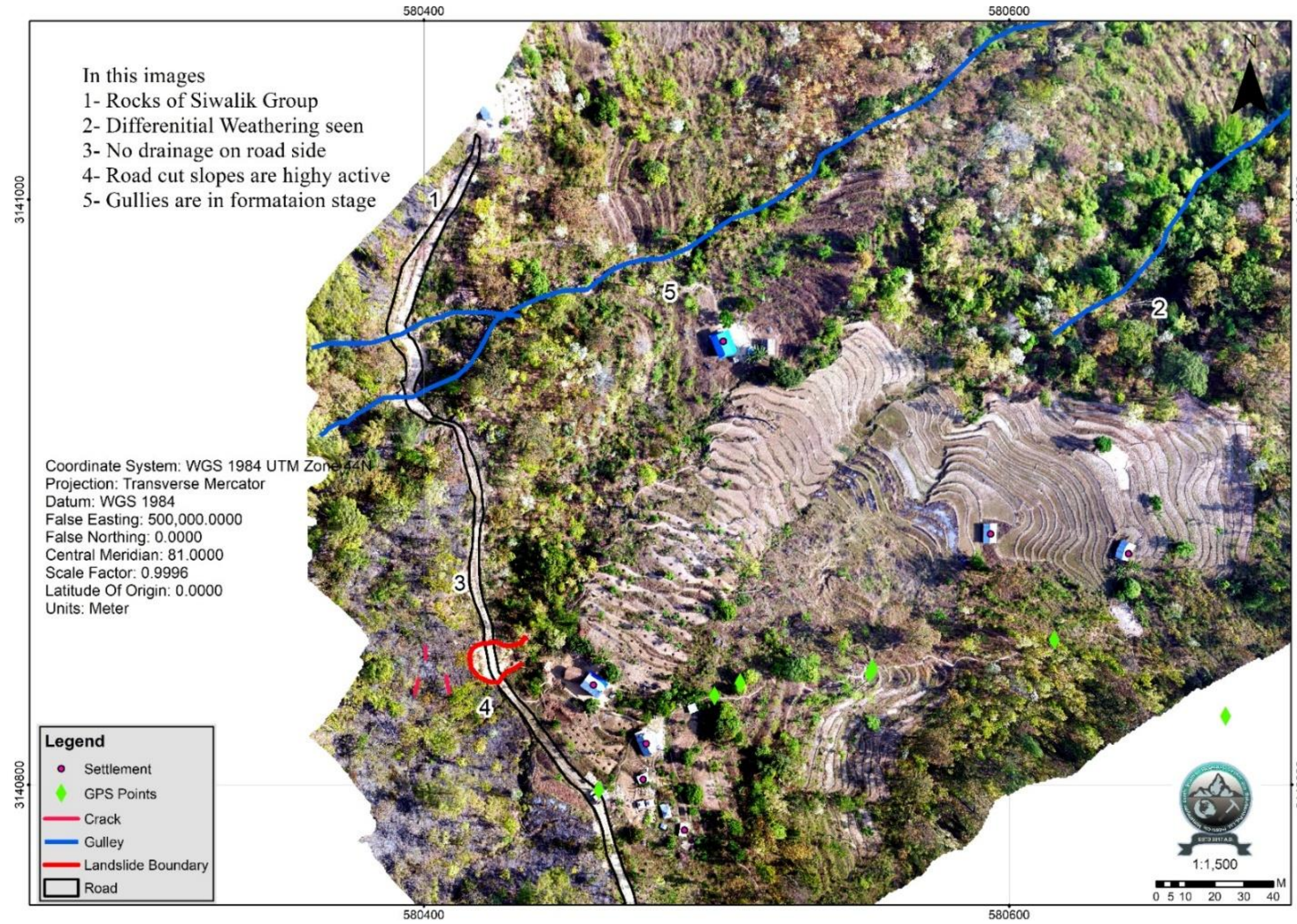


Figure 29: Photo Mosaic view with landslides boundaries from drone Images of Tilkeni/Sindhure Khola Landslide, Gurbhakot-06.

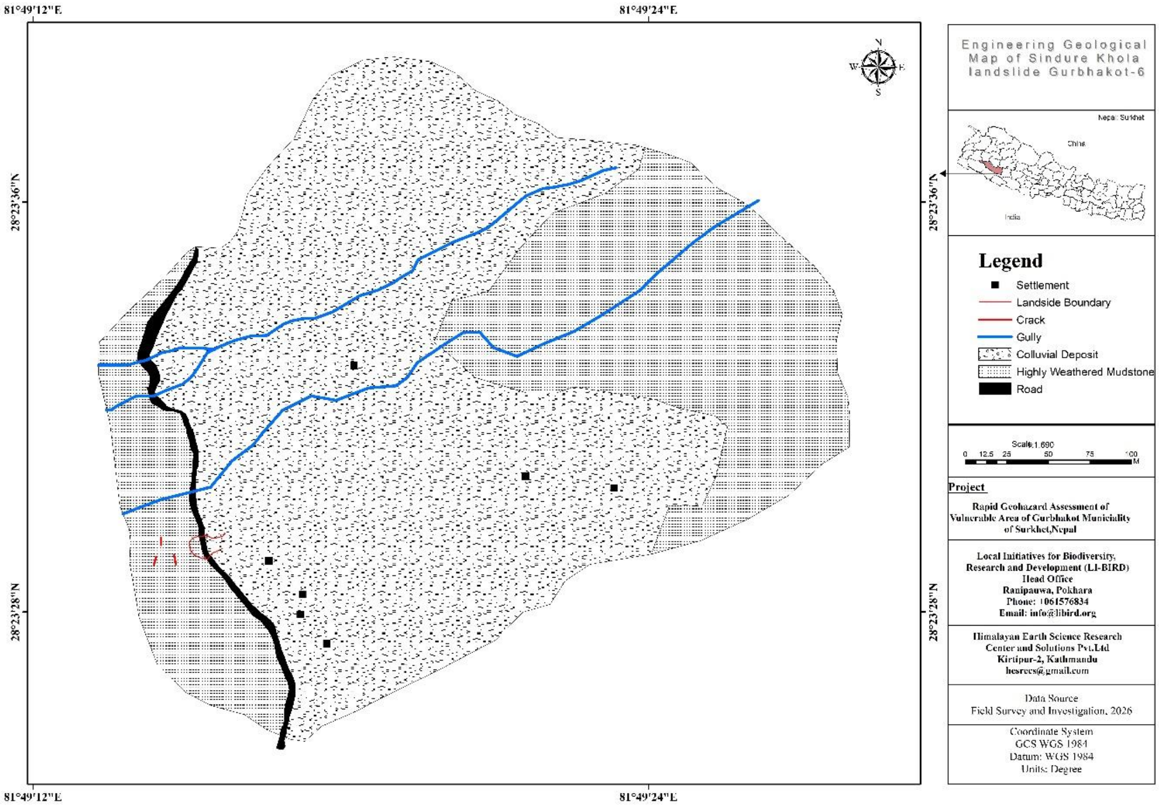


Figure 30: Engineering Geological Map of Sindhure Khola landslide, Gurbhakot-06.

4.9.3 Affected Houses and Infrastructure

The settlement surrounding the landslide consists of approximately 68 houses. Based on field observation, around five houses are considered directly vulnerable to the present geo-hazard condition due to their proximity to the unstable slope and road section. Another medium scale debris slide is also seen just 300 m downhill slope along the road section which may affected a house near the toe section.

4.9.4 Mitigation and Control Measures

Proper surface drainage management should be implemented along the road section to control uncontrolled runoff and infiltration nearby the cracks developed in the cultivated land.

4.9.5 Risk Level

Based on preliminary engineering geological assessment and field observation, the landslide is categorized as a medium-risk (Category 2) landslide. However, the probability of future landslide occurrence remains high during intense rainfall and monsoon periods due to weak geological conditions and poor slope management practices. One house should be relocated along the road section near Sindure khola along the road section.

Table 10: General characteristics of the Tilkeni/Sindure Khola landslide area

Settlement Name	Tilkeni / Sindure Khola Gau (GW6-01)
Municipality/District/Province	Gurbhakot Municipality–6, Surkhet District, Karnali Province
Location	The landslide area is located at coordinates 28°23'27.38" N latitude and 81°49'23.12" E longitude with an elevation of approximately 888 m above mean sea level.
Total Number of Houses	The settlement consists of approximately 68 houses.
Description of Landslide	The landslide is mainly associated with instability along the road cut slope. Cracks have developed in several parts of the slope, indicating active ground movement and slope deformation.
Topographical and Geomorphological Condition	The area is characterized by moderate to steep slope conditions. Proper gully protection measures were not observed, and active erosion processes are affecting different sections of the slope.
Geological and Engineering Geological Condition	The geological condition mainly consists of interbedded sandstone and mudstone formations. The mudstone layers are highly weathered and weak, making the slope susceptible to instability. Cultivated land is present around the landslide area.
History of Geo-hazard Problem	The slope instability in the area was further aggravated after the 2023 Jajarkot earthquake. Local people reported the development of new cracks and widening of existing tension cracks after the earthquake event.
Geo-hazard Condition and Associated Problems	Disturbance along the road section and development of tensional cracks were observed during field investigation.
Root Causes of Problems	The major causes of the landslide include highly weathered mudstone, low-strength slope materials, haphazard road cutting practices, and inadequate drainage management along with seismic activity

Engineering Aspects	Disturbance and instability were observed along the road section due to slope deformation and cracks are seen in the houses.
Socio-economic Condition	Nearby settlements and cultivated lands remain vulnerable to future slope movement and possible infrastructure damage.
Recommendation / Urgency of Treatment	Proper surface drainage management should be implemented along the road section. Cascading structures and gully protection measures are recommended to reduce erosion and improve slope stability.
Control Measures	Proper drainage management,
Conclusion	The landslide area remains vulnerable due to weak geological conditions, improper and poor drainage management. Detail geotechnical and geophysical works are required
Houses at Immediate Risk	Approximately 5 houses are considered directly vulnerable to the present geo-hazard condition in the upper part and 1 house along the road
Probability of Hazard Occurrence	Yes, there is high probability of future landslide occurrence, especially during heavy rainfall and monsoon periods.
Risk Level at Community	Medium-risk (Category 2)
Treatability Status	No

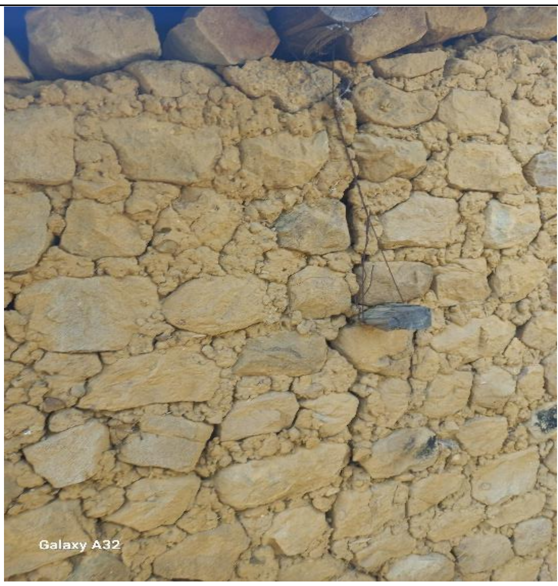


Figure 31: Cracks and displacement observed at the Tilkeni village and debris flow slides at the Sindure Khola road section

4.10 Betine / Belgaura / Hileni Landslide (GW14-01)

The Betine / Belgaura / Hileni landslide is located in Ward No. 14 of Gurbhakot within Surkhet District. The landslide area lies at an elevation of approximately 892 m above mean sea level and is situated at coordinates 28°29'07.90" N latitude and 81°51'16.05" E longitude. The area is accessible through local rural roads connecting nearby settlements and cultivated land.

4.10.1 Landslide Activity and History

According to local information and field observation, significant geo-hazard activity was noticed during 2082 B.S. Continuous creeping movement and development of cracks have been observed for a long period of time, indicating ongoing slope instability in the area.

4.10.2 Geological and Engineering Geological Conditions

The geological condition of the area mainly consists of loose colluvial soil mixed with residual soil deposits. The main lithology consists of shale and phyllite with some Amphibolite. These materials are weak, unconsolidated, and highly susceptible to deformation during rainfall and saturation conditions. The landslide is identified as a paleo-creeping type landslide showing continuous yearly creeping movement. Tensional cracks and land subsidence were observed in several locations within the landslide area. This zone is located at the thrust zone of Main Boundary Thrust (MBT) which is considered to be active fault in the Nepal Himalaya.

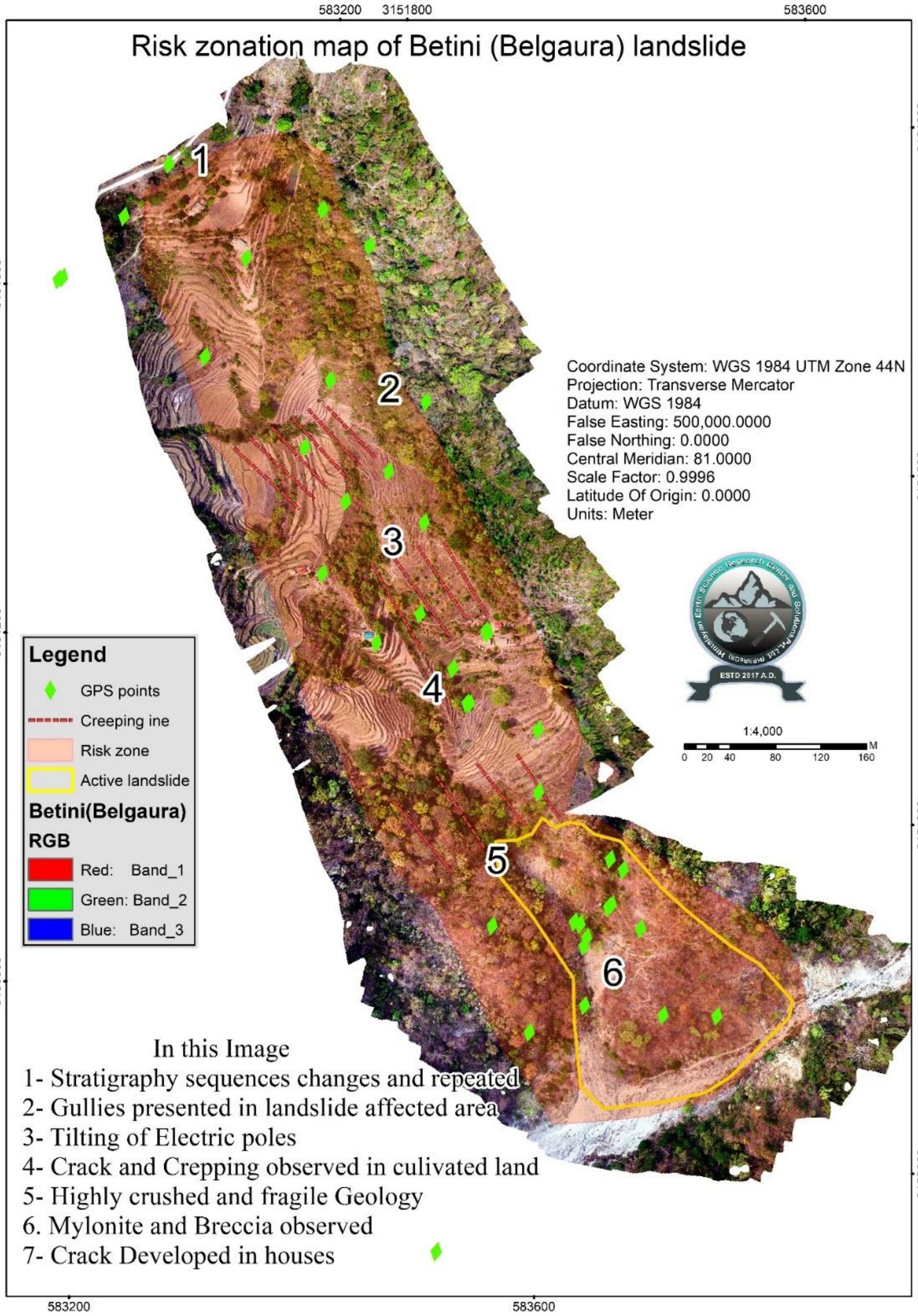


Figure 32: Photo Mosaic view with landslides boundaries from drone Images of Beteni/ Belgaura Landslide, Gurbhakot-14.

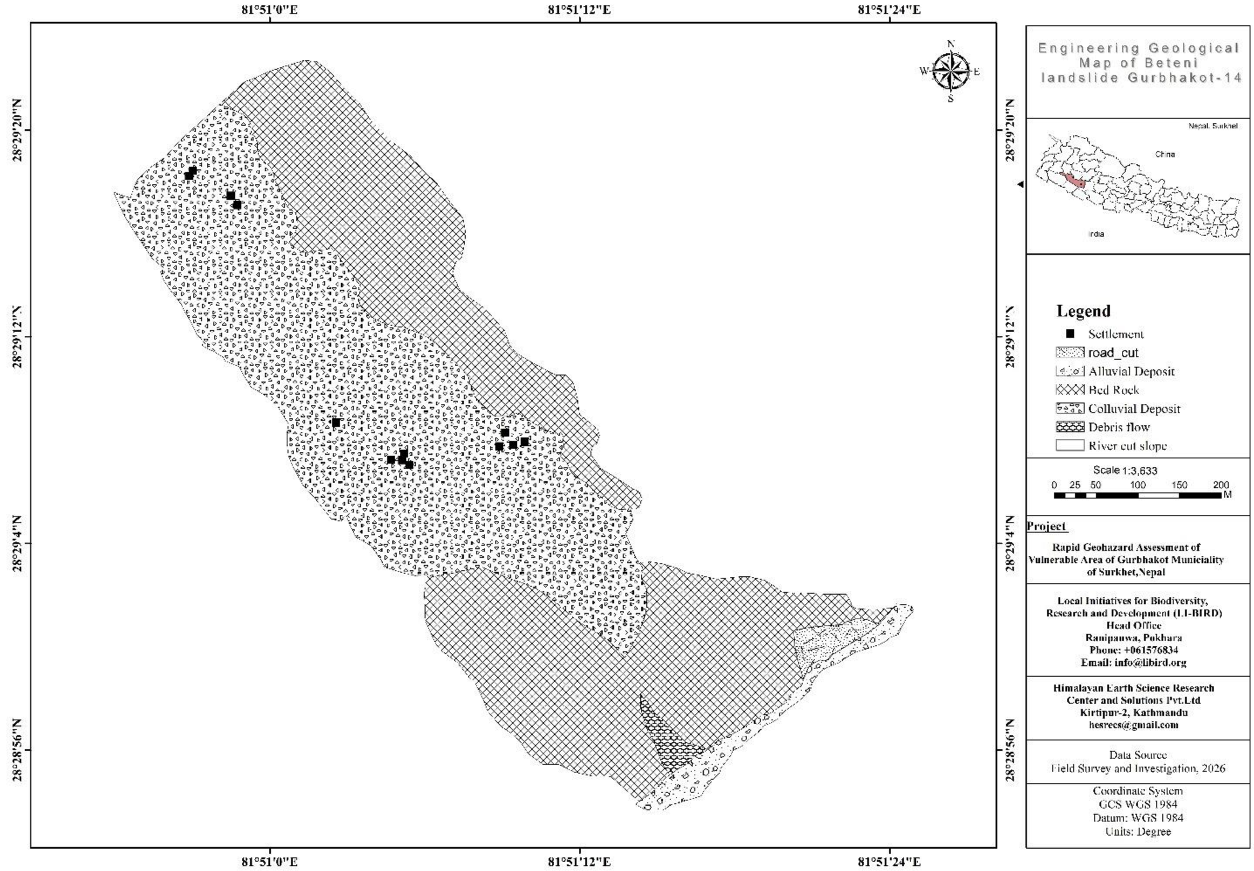


Figure 33: Engineering Geological Map of Beteni/Bel Gaira Landslide, Gurbhakot-14.

4.10.3 Affected Houses and Infrastructure

The settlement consists of approximately 7 houses, among which nearly 5 houses are considered directly vulnerable to the present geo-hazard condition. The nearby cultivated land and local infrastructure are also affected by gradual ground movement. Several cracks and displacement of houses are visible in the field. Field investigation also revealed approximately 0.4 m of ground subsidence in cultivated land. Tilting of electric poles and trees was also observed, indicating continuous long term slow ground movement. At down slope, several drinking water canal and pipes were also damaged by the movement. These conditions show progressive instability and potential future damage to local infrastructure and settlement areas.

4.10.4 Mitigation and Control Measures

Relocation of highly vulnerable houses is recommended because creeping movement has been active for a long period of time. Detailed engineering geological, geophysical and geotechnical investigation should be conducted before implementing mitigation works. Proper drainage management, and controlled slope stabilization techniques may help reduce future slope movement and land subsidence.

4.10.5 Risk Level

The landslide is categorized as a medium-risk landslide **(category 2)** based on field observation and preliminary engineering geological assessment.

Table 11: General characteristics of the Beteni/ Belgaura landslide area

Settlement Name	Betine / Belgaura / Hileni (GW14-01)
Municipality/District/Province	Gurbhakot Municipality–14, Surkhet District, Karnali Province
Location	The landslide area is located at coordinates 28°29'07.90" N latitude and 81°51'16.05" E longitude with an elevation of approximately 892 m above mean sea level.
Total Number of Houses	The settlement consists of approximately 7 houses.
Description of Landslide	The landslide is identified as a paleo-landslide showing continuous yearly creeping movement. Cracks have developed in cultivated land due to gradual ground displacement and slope deformation.
Topographical and Geomorphological Condition	The area is characterized by gentle to moderate slope conditions with evidence of long-term creeping movement and land subsidence.
Geological and Engineering Geological Condition	The geological condition mainly consists of loose colluvial soil mixed with residual soil deposits. The lithology mainly consists of shale, phyllite with amphibolite. These weak and fragile materials are highly susceptible to deformation and instability.
History of Geo-hazard Problem	According to local information and field observation, significant geo-hazard activity was noticed during 2082 B.S. Continuous creeping movement and development of cracks have been observed for a long period of time.
Geo-hazard Condition and Associated Problems	Tensional cracks and land subsidence were observed in several parts of the landslide area. Gradual ground settlement is affecting cultivated land and nearby infrastructure.

Root Causes of Problems	The main causes of the landslide are weak and fragile geological conditions, loose colluvial deposits, due to Shear zone of MBT and continuous saturation during rainfall periods.
Engineering Aspects	Field investigation revealed approximately 0.4 m of ground subsidence in cultivated land. Tilting of electric poles and trees was also observed due to continuous creeping movement.
Socio-economic Condition	The local community mainly depends on agriculture and cultivated land for livelihood. Ongoing ground deformation may affect agricultural productivity and settlement safety.
Recommendation / Urgency of Treatment	Relocation of highly vulnerable houses is recommended because creeping movement has remained active for a long period of time. Detailed engineering geological investigation is necessary before implementing mitigation measures.
Control Measures	Proper drainage management,
Conclusion	The landslide area shows continuous creeping movement and progressive ground deformation.
Houses at Immediate Risk	Approximately 5 houses are considered directly vulnerable to the present geo-hazard condition.
Probability of Hazard Occurrence	Yes, there is moderate to high probability of future hazard occurrence due to continuous creeping movement and weak geological conditions.
Risk Level at Community	The landslide is categorized as a medium-risk landslide based on field observation and preliminary engineering geological assessment.
Treatability Status	The landslide is treatable with detailed engineering geological investigation and appropriate stabilization measures.

Figure 34 Photographs showing cracks, displacement of cultivated land and electric poles at the beteni/ Belgaura landslides area

Chapter – 5

Conclusion and Recommendation

Based on the preliminary geological study of each landslide area, the following conclusions have been drawn;

- ✓ Geologically, the study area is mainly composed of rocks belonging to the Lesser Himalaya and the Siwalik Group. The dominant lithologies include red-purple shale, phyllite, quartzite, sandstone, and dolomite of the Surkhet Group. In addition, two identified landslides are developed within the sandstone and mudstone sequences of the Siwalik Group.
- ✓ The engineering geological assessment indicates that the area is predominantly covered by loose residual soil, colluvial deposits, and weak, highly weathered, and sheared rock masses. These materials are highly susceptible to erosion and slope failure, particularly under conditions of intense rainfall.
- ✓ Analysis of the size, nature, and spatial distribution of the landslides suggests that their occurrence is strongly controlled by weak geological conditions and inadequate surface drainage systems. Most of the newly developed and reactivated landslides were triggered following intense rainfall events during 2071, 2076, and 2081 B.S., indicating that heavy monsoonal precipitation is the principal triggering factor for slope instability in the area.
- ✓ Among the nine investigated landslides, one is categorized as a rockfall type (Lekh Kurule), two are complex landslides (Kalche and Pokhari Pata), two are associated with severe soil erosion (Lekh Malarani and Khola Dhab), one is primarily related to seismic activity (Tilkeni/Sindure Khola), one is characterized as a debris flow (Timure/Bhitri Gau), and one exhibits creeping behavior (Beteni/Hileni). This classification highlights the dominance of slide-related and rainfall-induced slope failures within the study area.
- ✓ Based on the hazard and risk assessment, two landslides fall under low-risk category (Category 1), four are classified as medium-risk (Category 2), and three are identified as high-risk landslides (Category 3).
- ✓ The landslide events have caused significant impacts, including loss of human lives and damage to houses, agricultural land, and rural road networks. Considering the level of risk and ongoing instability, relocation of some households in Timure/Bhitri Gau of

Ward No. 3 is strongly recommended. Similarly, settlements at Beteni/Hileni of Ward No. 14 may also require future relocation if slope conditions continue to deteriorate.

- ✓ The Pokhari Pata landslide (Ward No. 5) and Beteni/Hileni landslide (Ward No. 14) are identified as highly vulnerable sites. Therefore, detailed geotechnical and geophysical investigations are recommended prior to implementing appropriate slope stabilization and risk reduction measures.
- ✓ In Pokhari Pata landslide it is recommended to conduct the bio-engineering along with proper engineering structure for the stabilization of the slope. For engineering structure it is also recommended to conduct geophysical survey to delineate the subsurface lithology and then proper structures should be designed along with bio-engineering for the stabilization of the landslide.

References

Bhandari B. P., Dhakal S., 2018: Lithological control on landslide in the Babai Khola Watershed, Siwaliks Zone of Nepal. Am. J. Earth Sci., 5, 3, 54–64

Bhandari, G, Trends In Seasonal Precipitation And Temperature – A Review In Doti And Surkhet Districts of Nepal, 2013, International Journal of environment vol. 2, DOI: 10.3126/ije.v2i1.9227

Chigira M., Yagi H., 2006: Geological and geomorphological characteristics of landslides triggered by the 2004 Mid Niigta Prefecture earthquake in Japan. Eng. Geol., 82, 4, 202–221, doi: 10.1016/j.enggeo.2005.10.006.

Cui Y., Yang W., Xu C., Wu S., 2023: Distribution of ancient landslides and landslide hazard assessment in the Western Himalayan Syntaxis area. Front. Earth Sci., 11, 1135018, doi: 10.3389/feart.2023.1135018

Dahal R. K., Hasegawa S., 2008: Representative rainfall thresholds for landslides in the Nepal Himalaya. Geomorphology, 100, 3-4, 429–443, doi: 10.1016/j.geomorph.20 08.01.014.

Dangol V., 2006: Status of Landslide Hazard Mapping in Nepal. In: Marui H., Mikoˇs M. (Eds.): Disaster Mitigation of Debris Flows, Slope Failures and Landslides.

Delmonaco G., Falconi L., Leoni G., Margottini C., Puglisi C., Spizzichino D., 2005: Multi-Temporal and Quantitative Geomorphological Analysis on the Large Landslide of Craco Village (M118). In: Sassa K., Fukuoka H., Wang F., Wang G. (Eds.): Landslides: Risk Analysis and Sustainable Disaster Management. Springer, Berlin, Heidelberg, pp. 113–118, doi: 10.1007/3-540-28680-2 13

DMG, 1987: Geological Map of Mid-western Nepal.: Department of Mines and Geology, Kathmandu.

Galay V., 1987: Erosion and sedimentation in the Nepal Himalaya. An assessment of river processes. Ministry of water resources HMG Nepal, Report no. 4/3/012587/1/1, seq. 259.

Gerrard J., 1994: The landslide hazard in the Himalayas: Geological control and human action. Geomorphology, 10, 1-4, 221–230, doi: 10.1016/0169-555x(94)90018-3.

Hasegawa S., Dahal R. K., Yamanaka M., Bhandary N. P., Yatabe R., Inagaki H., 2009: Causes of large-scale landslides in the Lesser Himalaya of central Nepal. Environ. Geol., 57, 6, 1423–1434, doi: 10.1007/s00254-008-1420-z

Kumar V., Gupta V., Sundriyal Y. P., 2019: Spatial interrelationship of landslides, lithotectonics, and climate regime, Satluj valley, Northwest Himalaya. Geol. J., 54, 1, 537–551, doi: 10.1002/gj.3204.

Nakano T., Wada K., Yamanaka M., Kamiya I., Nakajima H., 2016: Precursory slope deformation around landslide area detected by InSAR throughout Japan. Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci., XLI-B1, 1201–1205, doi: 10.5194/ isprs-archives-XLI-B1-1201-2016.

Sigdel A., Adhikari R. K., 2020a: Engineering geological and geotechnical studies of Taprang landslide, west-central Nepal: An approach for slope stability analysis. J. Geol. Res., 2, 4, 22–35, doi: 10.30564/jgr.v2i4.2302

Upreti B. N., Dhital M. R., 1996: Landslide Studies and Management in Nepal. International Centre for Integrated Mountain Development, 87 p.

Upreti B. N., 2001: The Physiographic and Geology of Nepal and Their Bearing on the Landslide Problem. In: Li T. C., Chalise S. R., Upreti B. N. (Eds.): Landslide Hazard Mitigation in the Hindu Kush-Himalaya. International Centre for Integrated Mountain Development, Kathmandu, pp. 31–49.

Varnes, D. J. (1978). Slope movement types and processes. In R. L. Schuster & R. J. Krizek (Eds.), *Special Report 176: Landslides: Analysis and Control* (pp. 11-33). Washington, D.C.: Transportation Research Board, National Academy of Sciences

Annex: Field Photographs:

Highly weathered and fractured bedrock exposed in Khola Dhab.

Highly weathered purple shale observed in the top portion of Lekh Malarani.

Bedrock exposed in Hile landslide in the road cut section.

Deformed slope mass in Hile landslide down slope of the road.

Subsidence and crack seen in the downslope of the road near gully of Hile landslide.

Public consultation.

Bedrock exposed and data measurement in Lek Kurile landslide.

Landslide overview of Lek Kurile landslide.

Public consultation, Lek Kurile.

Disturbed bio-engineering structures present in the up slope of the road in crown part of Pokharepata Landslide.

Small scarp initiated by Jajarkot earthquake, downslope of the settlement, Sindhure khola

Debris flow, Sindhure khola.