Developing a Community Centric Early Warning Protocol for Landslide Early Warning System (EWS) to build resilience of communities exposed to hydro-climatic hazards in Bagmati Province of Nepal

BASELINE REPORT

Executive Summary

The Helambu and Panchpokhari Rural Municipality in Sindhupalchok District confront a pressing challenge as their picturesque landscapes belie a heightened susceptibility to landslides. The topography of these areas is classified as moderate to highly susceptible, and the occasional rainstorms that characterize the region further exacerbate the potential for slope instability. The absence of a historical landslide database poses a significant hurdle in accurately assessing and mitigating landslide risks, hampering the development of targeted strategies for risk reduction and management.

The two rural municipalities in Sindhupalchok District is known for landslide susceptible and the population are under the risk of landslide hazards. The rural municipalities are the home of 5,914 and 4,690 households (HH) respectively in Panchpokhari-Thangpal and Helambu. The population in the municipality is estimated to be 38,494 (M: 19,395, F: 19,099) according to the 2078 censes. Out of the total population it was found 2.6% (1012; M: 562, F:450) population have some kinds of disabilities. The area of the municipality including the National Park is estimated to be 286 and 436 km^2 respectively Helambu and Panchpokhari-Thangpal. National part contains considerable area of about (~368 km^2). Including the National Park, delineated within the rural municipalities forest is the dominant landuse (58%) followed by bare land (~11%), crop land (~8%) among others. Small area in the upper reaches of the geographic area comprise snow cover mountains. The dominant slope class (over 40 degrees) is steep to very steep (~31%) and moderate slope class of 15-30-degree (31%) followed by 30-40-degree class (~28%). The classification indicated that considerable landscape comprises of steep to very steep slope. The area of the municipality excluding National Park is estimated to be 355 km^2 (Helambu: 168.5 km^2 and Panchpokhari-Thangpal: 186 km^2).

Landslides are the common natural phenomena in the hilly/mountainous terrain of the two municipalities. However, historical landslide database is limitedly maintained. The popularly known Melamchi disaster of 2021 is the eye opener of the disaster impact in the region since then disaster databases have been initiated. Landslide inventory depicted 77 number of past landslide events out of which 30 were in Panchpokhari and 47 in Helambu.

Among many different factors, rainfall is considered as an important factor that caused landslides. Rainfall patterns in the region are marked by non-uniform and intense, making the landscape particularly vulnerable to landslides triggered by even moderate precipitation events. Rain, therefore, stands out as a primary factor influencing landslide occurrence in these areas. Compounding this vulnerability is the impact of human activities, notably the unplanned

development of rural roads. Such infrastructure projects, lacking proper planning and construction practices, significantly contribute to slope destabilization, increasing the overall susceptibility of the terrain.

There are five functional meteorological stations in the area located in Dhap, and Nawalpur in Panchpokhari-Thangpal and Sermathan, and Tarkeghang in Helambu. One more meteorological station in located at Duwachaur, in Melamchi Municipality in the boundary of the two municipality. The data from these stations can be considered to be representative. However, study indicated that the region has micro-climatic variation, which is yet to be assessed. Historical data show maximum daily rainfall in the region was 421 mm (in 24 hrs) recorded in Dhap (Index No. 1078) station. The rainfall records indicated the high variability of the range of

142 – 421 mm of recorded maximum daily rainfall. The long term annual average rainfall in the stations was 2409 mm to 3400 mm respectively recorded at Nawalpur and Sarmathang. The data indicated that rainfall is relatively high in Helambu area than in Panchpokhari-Thangpal.

In order to reduce the risk of landslide hazards different measures are in practices among which structural measures are particularly used. However, there are non-structural measures such as landslide susceptibility mapping, risk sensitive landuse plan, landslide early warning system (LEWS), education and awareness, etc. Recent advancements in landslide prediction and early warning systems have been extensively documented in various research papers around the globe. LEWS is limitedly known in the context of Nepal, particularly in the two municipalities. In Nepal a few studies have been carried out to wards developing rainfall threshold for landslide. Yet, these studies are based on coarse historical database such as daily rainfall and limited numbers of past landslides events.

This study is focused to assess what have been done toward developing LEWS in the past and data requirement for developing LEWS in the two rural municipalities in Sindupalchok District. Effort have been made to assess the date of the past landslides events, through community consultation (HH Survey, FGD and KII), records in the Ministry of Home Affairs, District Administration Office, published and unpublished literatures and reports. The efforts depicted 11 landslide date of past events in the two municipalities out of which two were in Panchpokhari-Thangpal. With the data of the landslides, it was possible to assess the amount of the rainfall of the day on which the landslide was triggered.

Similarly, there was no systematic research on loss and damage caused by landslides in the municipalities. A brief study related to loss and damage of Melamchi disaster stated that about US $ 62 Million was the economic losses in Helambu Rural Municipality alone. In terms of human causalities one person was declared dead and 23 were missing. During this study an effort was made to assess the loss and damage through HH survey, FGD and KII reveals that about 47.68 and 25.73 million rupees of economic losses was reported respectively in Helambu and Panchpokhari-Thangpal.

IN this study prepared a Landslide Susceptibility Model (LSM) of the two municipality using the statistical method as there was no systematic LSM prepared in the past. The model was classified in to five classes from very low to very high depicted that about 19.4% and 21% of the landscape respectively in Helambu and Panchpokhari-Thangpal is high to very susceptible to landslide. In addition, effort was made to assess the safer area considering the slope degree and landslide susceptibility depicted that about 36.9% and 37.3% of the landscape respectively unsafe in

Helambu and Panchpokhari-Thangpal. Further, there are 31,286 building like structures in the two municipality obtained from Open Street Map (OSM) out of which 63.13% (Nr. 11,333) and 62.67% (Nr. 10862) were located in safer landscape respectively in Helambu and Panchpokhari-Thangpal. The number of building like structures are not only the residential houses but also includes all cow-sheds, schools, health-posts, temporarily shelters, etc.

Road is one of the important infrastructures that provides access to health care, education, among others. The estimated length of the roads in the municipality is about 816 km out of which 429 km is in Helambu and 387 km in Panchpokhari-Thangpal. The road is also passing through the unstable landscape. Considerable road length (142 km) is under moderately sable landscape followed by 40 km road is running through the highly unstable landscape.

Study shows that there are efforts made to reduce the landslide risk, however, these efforts are mostly structural measures. Field observation indicated that the structural measures are poorly designed often collapsed during the monsoon season. The sue of Nature-based Solutions (NbS) limited in use. Majority of the local people prefer structural measures because of the limited knowledge about the benefits of the NbS measures. More recently NbS has been considers to be a sustainable means to reduce the risk of landslides. The representative of local government in other hand have shown interest on the sue of the NbS because of its low cost and effectiveness to reduce the risk of slope failure and soil erosion.

To address these challenges, a set of comprehensive recommendations has been proposed. These include the establishment and regular updated of a landslide susceptibility map as the database improves, leveraging advanced remote sensing and GIS technologies. The creation of a historical landslide database is deemed essential for understanding patterns and triggers, providing a foundation for informed decision-making through developing LEWS. LEWS are useful to alert local communities to potential landslide-triggering rainfall events, minimizing the risk of casualties through timely evacuation.

Critical to long-term resilience is the implementation of stringent land-use planning and zoning regulations. These measures would serve to restrict construction in high-risk landslide areas, promoting sustainable land-use practices and enforcing adherence to building codes. Infrastructural development and maintenance, along with community awareness and capacity-building programs, constitute integral components of the proposed strategy. Vegetation management, monitoring and early detection systems, and collaboration among stakeholders further augment the effectiveness of the overall landslide risk management approach.

In summary, the Helambu and Panchpokhari regions face a multifaceted challenge, necessitating a comprehensive strategy that encompasses hazard mapping, early warning systems, sustainable land-use planning, resilient infrastructure, and community engagement. The proposed recommendations seek to address the immediate threats posed by natural and anthropogenic factors, fostering long-term resilience and safeguarding the communities inhabiting these vulnerable landscapes from the looming spectre of landslides.

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Abbreviations and Acronyms

CBS	: Central Bureau of Statistics
CDMC	: Community Disaster Management Committee
DEM	: Digital Elevation Model
DHM	: Department of Hydrology and Meteorology
FCHVs	: Female Community Health Volunteers
FGD	: Focused Group Discussions
FR	: Frequency Ratio
GIS	: Geographical Information System
ICIMOD	: International Center for Integrated Mountain Development
IUCN	: International Union for the Conservation of Nature
KI	: Key Informants
KII	: Key Informants Interview
LEOC	: Local Emergency Operation Centre
LEWs	: Landslide Early Warning Systems
LSM	: Landslide Susceptibility Map/Model
LULC	: Land use and Land Cover
masl	: meter above sea level
MOHA	: Ministry of Home Affairs
NbS	: Nature-based Solutions
NDRRMA	: National Disaster Risk Reduction Authority
NDVI	: Normalized Difference Vegetation Index
OSM	: Open Street Map
PWD(s)	: Persons with disabilities
RM	: Rural Municipality
Sop	: Standard Operation Procedure
ToR	: Terms of Reference
TRI	: Terrain Roughness Index
TWI	: Terrain Wetness Index
WB	: World Bank
WDMC	: Ward Disaster Management Committee

Section 1. Introduction

1.1 Background

Nepal, the mountainous country with almost 15% of the area covered by snow-capped mountains and known as the Himalayas (altitude 4800-8848masl), 68% area by hills and mountains including inner valleys, (altitude 610-4877masl) and the remaining 17% by flat land known as Terai (altitude 60-610m). With the rugged mountain topography and fragile geology of the young Himalayan mountains, the country is exposed to a multitude of disasters especially landslides of various types such as debris flow, shallow translational, slow-moving creeping type deep-seated landslides, and rock fall among others. Further, the anthropogenic activities and increasing trend of intense monsoonal rainfall (Devkota et al., 2018; Karki et al., 2017) have a considerable impact on the landscape slope stability often aggravating the mass wasting scenarios in the form of landslides.

The Mid-hill region also known as lesser Himalayas in the central region of the country runs east to west across the country is known as the most fragile hill slope depicted landslide prone. The region is characterized by complex geology, steep terrain, and a range of geological processes that contribute to the occurrence of landslides. The geological setting of this region is primarily influenced by the ongoing tectonic activity, which has significant impact on the slope stability. The region comprises a diverse range of rock types, including sedimentary, metamorphic, and igneous rocks. The varying strength and stability of these rocks influence landslide susceptibility. Weaker rocks, such as shale and mudstone, are more prone to landslides than more competent rocks like granite (Dhital, 2015).

Besides the geology the region is also impacted by the monsoonal rainstorms and undergoing climate change impacts. The region experiences a monsoonal climate with intense rainfall during the summer months (June-Sept). Prolonged and heavy rainfall can saturate the soil, reducing its stability and triggering landslides.

1.2 Rational

The impact of landslides in the hilly terrain is considerable, often causing substantial damage to critical infrastructure such as roads and bridges, thereby hindering transportation and communication. In response to this ongoing challenge, Practical Action is executing a project, “Developing a Community-Centric Early Warning Protocol for Landslide Early Warning Systems (LEWS)”, in the Bagmati Province's Helambu and Panchpokhari Thangpal Rural Municipalities. This initiative, supported by the Australian Embassy, is directed towards establishing a rainfall threshold for landslides, aiming to safeguard the lives and livelihoods of communities at risk.

The project emerges from the recognition of landslide vulnerability in Nepal's hilly regions and the absence of an effective LEWS. This lack of early warning systems exacerbates the impacts on development and infrastructure, including roads, transportation, hydropower plants, and human settlements. The goal is to minimize the loss of lives and property by developing a functional LEWS. The initiative will integrate current scientific understanding of landslide hazards and early warning systems with community-level risk reduction strategies.

Different studies reported that the landslide phenomena in the hilly terrain have increased (KC et al., 2024; Muñoz-Torrero Manchado et al., 2021). Although there is no systematic research on loss and damage caused by natural disasters in Nepal such as landslides, it has been reported that the losses are considerably high. van der Geest and Schindler (2016) stated that the loss and damage caused by the landslides over the past, that have caused significant loss of life and economic damages. The landslide risk reduction measures are mostly conventional type such as structural measures (e. g. gabion, stone or concrete retaining wall). There are non-structural landslide risk reduction measures such as developing landslide susceptible mapping (LSM), risk sensitive landuse plan (RSLP), landslide early warning system (LEWS), education and awareness, etc. Among the non-structural landslide risk reduction measures LEWS is limitedly known in Nepal and thus the project is motivated to develop functional LEWS to reduce the risk of landslides in the two municipalities (i. e. Helambu and Panchpokhari) in Sindhupalchok District. This report is the baseline dealing with the requirement for developing landslide early warning system in the two rural municipalities.

1.3 Objectives and Scope

1.3.1 Objectives

The primary objective of the baseline study is to gather baseline information and update the **project's log frame, including socio-economic data, community risks, vulnerabilities,** and an assessment of local institutional capacities. Specific objectives include:

1. Reviewing existing rainfall thresholds and analyzing associated hazards.
2. Identifying current community-centric, gender-responsive, and disability-informed approaches to early warning systems.
3. Assessing the capacity of communities and local governments to respond to landslide risks and implement risk reduction strategies.
4. Exploring nature-based solutions for landslide risk reduction.
5. Investigating opportunities to co-create LEWS through citizen science and policy integration.

1.3.2 Scope of the Study

The study focuses on four main aspects:

1. Assessing landslide risks and creating a landslide map for the project area.
2. Understanding community and stakeholder perceptions of landslide risks and vulnerabilities.
3. Exploring rainfall thresholds using scientific methods to develop an effective LEWS.
4. Suggesting ways to operationalize the LEWS using available scientific knowledge.

Key activities include identifying at-risk communities, developing a science-informed, GIS-based landslide susceptibility map, identifying the vulnerable households, understanding community perceptions of LEWS, and evaluating local government views on nature-based solutions and anthropogenic factors contributing to landslide risks.

Section 2. Study Area

2.1 Introduction

Panchpokhari-Thangpal and Helambu Rural Municipalities (Figure 2-1), located in the Sindhupalchok District of Bagmati Province, Nepal, showcase diverse geographical and cultural landscapes. Panchpokhari-Thangpal, established in 2017, consists of 8 wards over 187.29 km² and has a population of 20,986, (M: 10,614 and F: 10,383) primarily following Buddhism and Hinduism. Tamang is the most spoken language, and the area has a relatively low education rate of 46.03%.

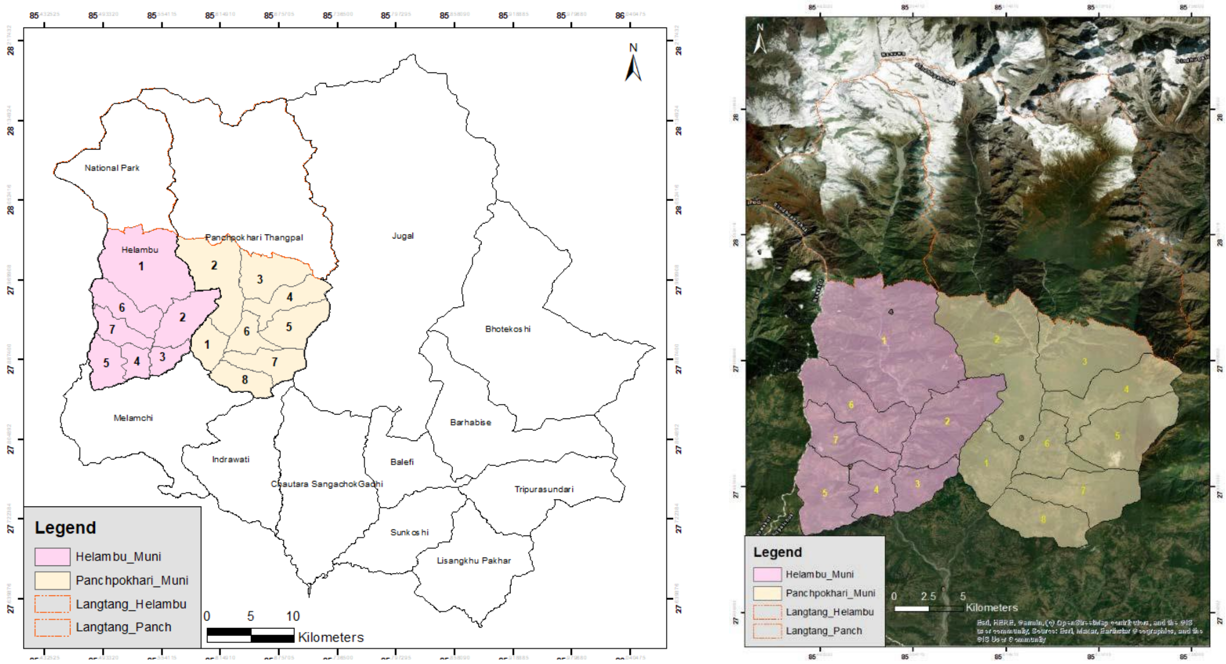


Figure 2-1 Location map of the study area

Helambu, known for its monasteries, comprises seven wards in a 169 km² area, with elevations ranging from 1000 to 5000 meters. Its population of 17,497 (M: 8,781, and F: 8,716) exhibits a literacy rate of about 63.5%, with agriculture and animal husbandry as primary occupations. Forests cover about 46% of Helambu, and it's home to diverse ethnic groups, including Sherpa, Tamang, Newar, Tamang with Brahmins, Chhetri. Tamang is being the predominant language. These municipalities reflect the rich ethnic and cultural diversity of rural Nepal.

Following section discussed about the general overview of the municipality.

2.1.1 Geology

The geology of Panchpokhari-Thangpal and Helambu Rural Municipalities in Sindhupalchok (Figure 2-2) is marked by the intricate composition of the Himal Group, featuring a variety of metamorphic rocks. This group includes garnet biotite gneisses and kyanite biotite gneisses, both known for their distinct mineral content and formation under high-pressure conditions. Additionally, the area contains garnetiferous mica schists, augen gneisses, and micaceous quartzites, each contributing to the area's geological diversity. Thin bands of marble intersperse these formations, adding to the complex and varied geological tapestry that defines the region's rugged terrain. This mix of metamorphic rocks is indicative of the dynamic geological history and processes that have shaped the landscape of this part of Nepal.

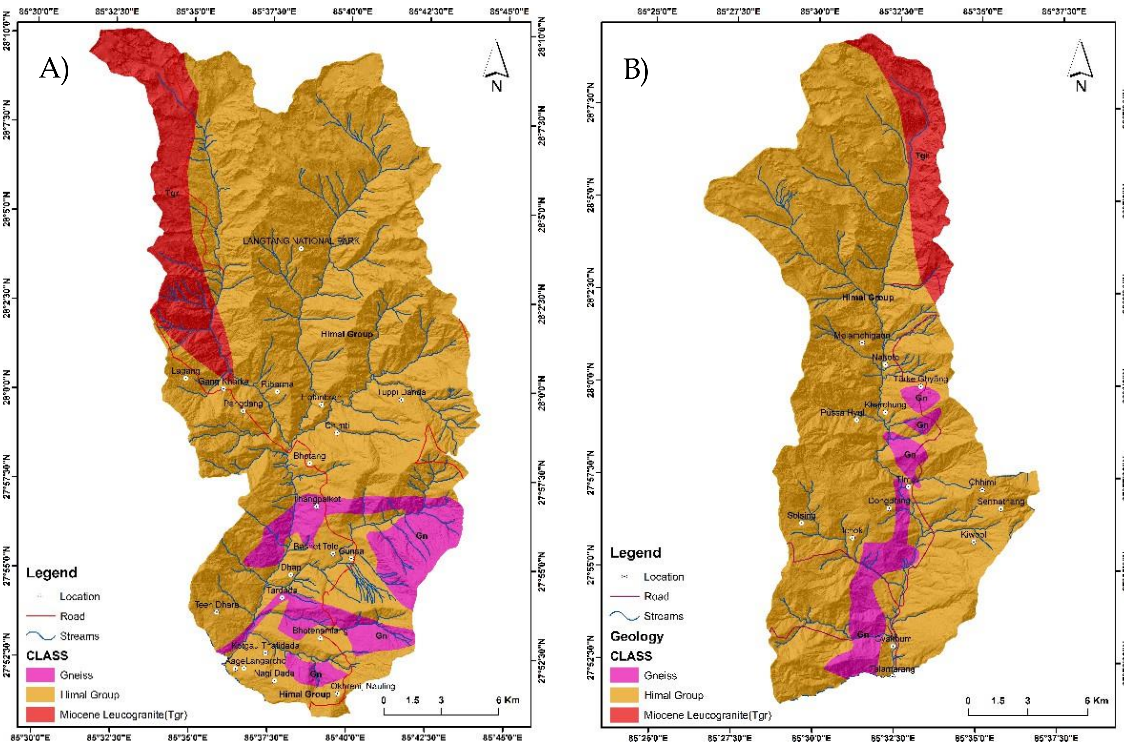


Figure 2-2 The geological maps; A) Panchpokhari Thangpal and B) Helambu Rural Municipality (note-the map includes the National Park area).

The significance of Geology towards landslide initiation in the municipalities can be described as follows:

- **Metamorphic Rock Composition**: The presence of garnet biotite gneisses and kyanite biotite gneisses, which form under high-pressure conditions, indicates a geologically active region. These rock types can be brittle and prone to fracturing, potentially increasing landslide susceptibility, especially under stress from seismic activity or heavy rainfall.
- **Varied Rock Types and Structural Weaknesses**: The diversity of rock types, including garnetiferous mica schists, augen gneisses, and micaceous quartzites, suggests varied mechanical properties and differential weathering rates. This heterogeneity can create zones of weakness where landslides are more likely to initiate, particularly where softer rocks are underlain by harder, more resistant layers.
- **Erosion and Weathering**: The intricate composition of these metamorphic rocks also implies varying rates of erosion and weathering. Some rock types may erode more

quickly than others, leading to unstable slopes and increased landslide risk.

- **Seismic Activity**: Given the Himalayan region's seismic activity, the presence of these metamorphic rocks, especially those formed under high-pressure conditions, suggests a heightened susceptibility to landslides triggered by earthquakes.

- **Hydrological Factors**: The permeability and porosity of these rocks can influence water infiltration, which plays a crucial role in landslide occurrence. Saturated rocks, particularly those less resistant to water, like some schists, are more prone to sliding.

- **Slope Stability**: The layering and orientation (dip and strike) of these rocks can significantly impact slope stability. If rock layers are parallel to the slope surface, they may facilitate sliding, increasing landslide risk.

Given these geological factors, the mid-hill region of Nepal is highly susceptible to landslides, and they pose significant challenges to infrastructure development, human settlements, and environmental sustainability in the region.

In conclusion, the complex geological composition of Panchpokhari-Thangpal and Helambu municipality contributes to a landscape that is both geologically fascinating and prone to landslides. Understanding these geological characteristics is crucial for assessing landslide risks and implementing effective disaster risk reduction strategies in the region.

2.1.2 Landuse

The figure below (Figure 2-3) and Table 2-1 shows extensive areas of forest (58.70%) and grassland (19.77%), with bare rock (9.41%) and cropland (6.35%) regions as well. Notable features include snow and glacier coverage at the higher elevations toward the northern region, in Langtang National Park.

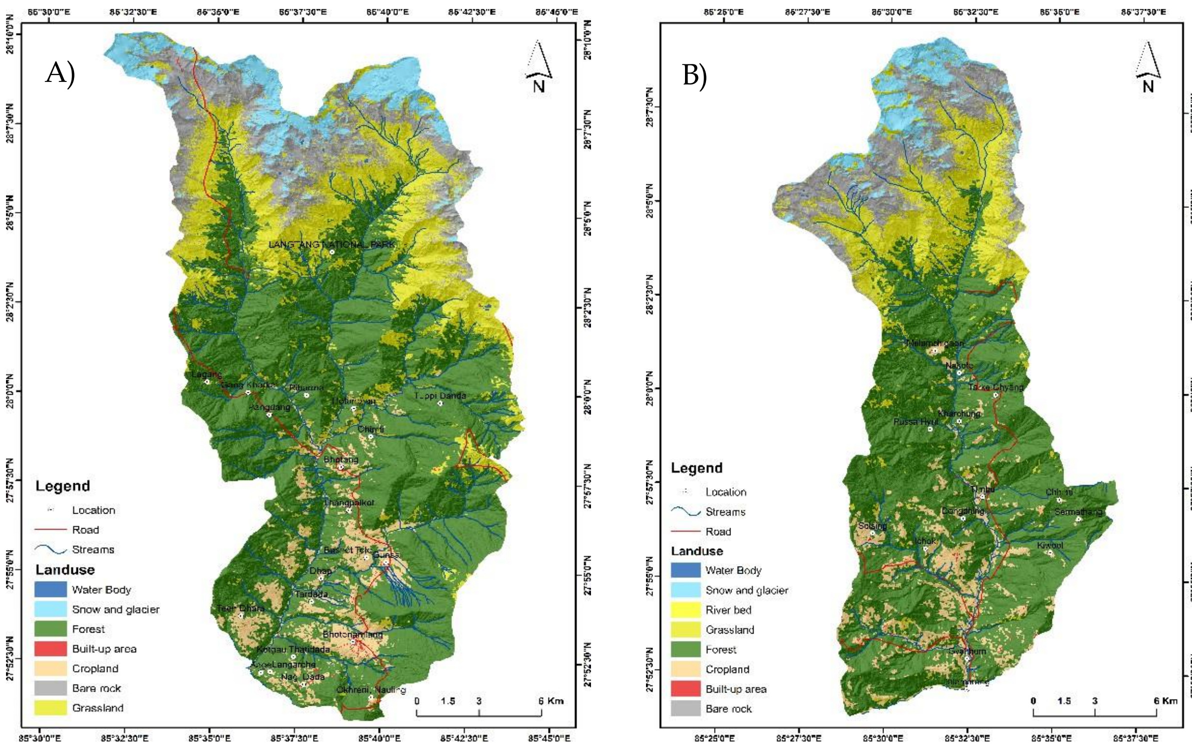


Figure 2-3 The landuse-landcover maps; A) Panchpokhari-Thankgpal, and B) Helambu Rural Municipality (note – the map includes the National park Area).

The built-up areas, indicating human settlements, are scattered throughout, with water bodies interspersed within the landscape. Major area of the municipality is protected under Langtang National Park.

In contrast Figure 2-3 (B) displays a similar composition with vast stretches of forest and cropland. There are also significant snow and glacier areas, particularly in the northern sections, which are likely at higher altitudes. Built-up areas in Helambu RM are also spread across the region, along with several water bodies. Both regions depict a landscape dominated by natural vegetation with pockets of agricultural activity and human habitation, indicative of a rural mountainous environment.

Table 2-1 Land use area coverage of Panchpokhari-Thangpal and Helambu Rural Municipality

Landuse	Panchpokhari-Thangpal		Helambu	
	Area (km²)	**%**	**Area (km²)**	**%**
Water Body	0.22	0.1%	0.0626	0.02%
Snow and glacier	24.18	5.5%	14.0822	4.90%
Forest	256.04	58.7%	167.0033	58.10%
Built-up area	0.79	0.2%	0.519475	0.18%
Cropland	27.7	6.4%	23.61223	8.21%
Bare rock	41.04	9.4%	32.2523	11.22%
Grassland	86.22	19.8%	49.90883	17.36%
Total	**436.19**		**287.442**	

2.1.3 Topography

Elevation:

Elevation plays a crucial role in landslide susceptibility. Higher elevations often experience steeper slopes, increasing the likelihood of landslides. Steeper slopes are prone to gravitational forces, making the terrain more susceptible to mass movements. Additionally, elevation influences factors like soil moisture and vegetation, impacting slope stability. Studies highlight elevation as a key topographic factor alongside slope angle and aspect in landslide risk assessment.

The Helambu and Panchpokhari-Thangpal Rural Municipalities consist of diverse physiographic divisions. Helambu RM features elevations reaching higher than 4000 meters, indicative of its rugged terrain which includes the trekking routes through places like Kutumsang and Tharepati. Meanwhile, Panchpokhari-Thangpal, known for its sacred lakes, contributes to the hydrology of the area with rivers such as the Indravati originating from there. The table below (Table 2-2 & **Figure 2-4**) presents the summary of the elevation class of the two municipalities, depicted majority area is under 2000 to 3000 masl.

Table 2-2. Summary of elevation classes of the municipalities.

Elevation Class (Masl)	Panchpokhari		Helambu	
	Area (m²)	**%**	**Area (m²)**	**%**
870-1500	34216900	7.8%	35795900	12.5%
1500-2000	61677200	14.1%	51265400	17.8%
2000-3000	138993000	31.9%	82347900	28.6%
3000-4000	108100000	24.8%	49746800	17.3%
Elevation Class (Masl)	**Panchpokhari**		**Helambu**	
	Area (m²)	**%**	**Area (m²)**	**%**
>4000	112703000	25.8%	68286500	23.8%
Total	**436090600**		**287442500**	

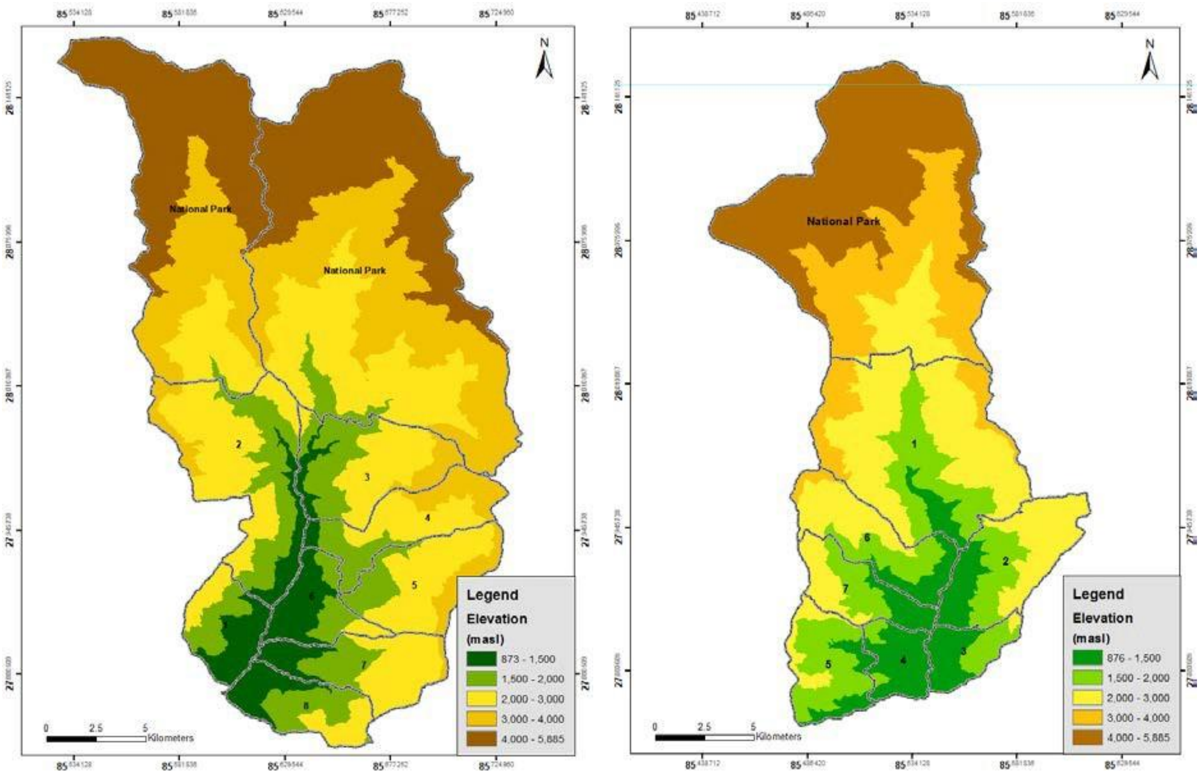


Figure 2-4. The elevation Model: A) Panchpokhari-Thangpal and B) Helambu Rural Municipality.

Slope:

Slope is a critical factor in landslide assessment due to its influence on gravitational forces and stability. Steeper slopes are more prone to landslides as gravitational stress overcomes the cohesive forces within the soil. Additionally, slope angle affects water runoff, impacting soil saturation and triggering landslides. Geotechnical analyses, including slope stability assessments, consider slope characteristics to identify potential indicators for failure.

The review indicated that the topography of the municipality is varying, however, the slope is steep to very steep (Table 2-3 and).

Table 2-3. Terrain slope class and area under each class of the municipalities.

Slope Class	Panchpokhari		Helambu	
	Area (m^2)	%	Area (m^2)	%
0-15	40375600	9.3%	26229900	9.1%
15-30	130850000	30.0%	89968300	31.3%
30-40	120198000	27.6%	80905800	28.1%
>40	144667000	33.2%	90338500	31.4%
Total	**436090600**		**287442500**	

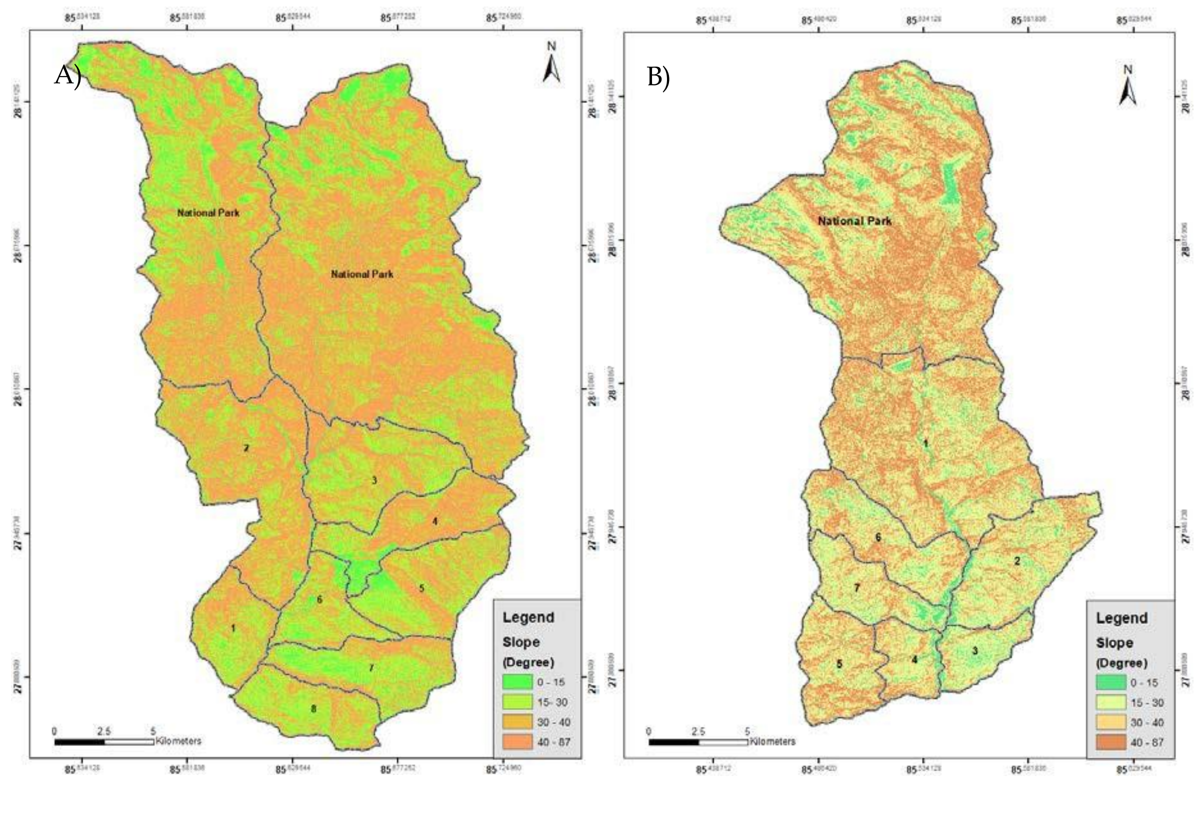


Figure 2-5. Slope map of the municipality; A) Panchpokhari-Thangpal and B) Helambu.

Drainage Network:

Drainage network is crucial for landslide assessment due to its significant role in water management. Adequate drainage helps mitigate landslides by preventing water accumulation, which can saturate the soil and increase its susceptibility to failure. Studies emphasize the importance of drainage measures in both existing and potential landslide mitigation strategies, highlighting water drainage as a key element.

The natural drainage network plays an important role in determining landslide occurrence and distribution, emphasizing the interconnected relationship between water movement and slope stability. Natural Drainage network of the two municipalities were assessed and delineated in GIS with the help of 12.5 meter resolution DTM. The assessment reveals that the stream order were from 1 to 4. The estimated total length of the stream is in Helambu is 188 km and 375 km in Panchpokhari municipality with the drainage density of 0.65km/km^2 and 0.86km/km^2 respectively in Helambu and Panchpokhari municipality (Figure 2-6).

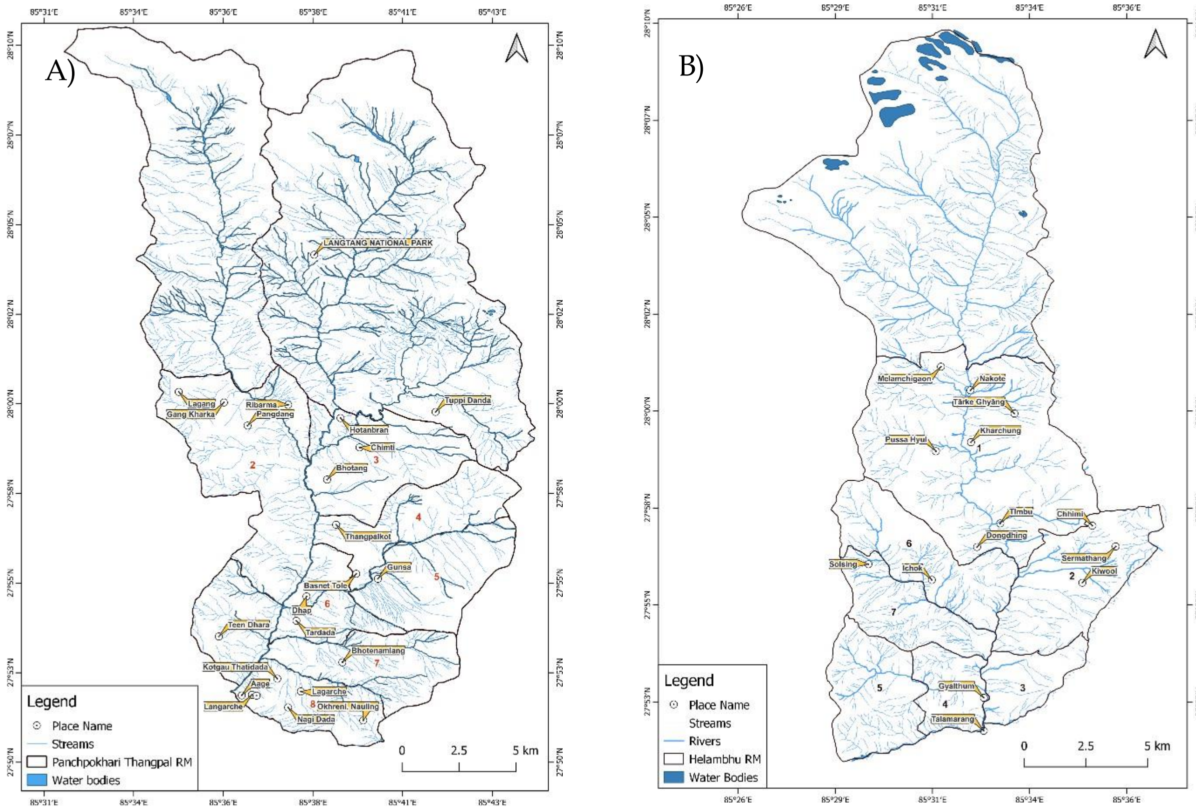


Figure 2-6. Drainage network map; A) Panchpokhari-Thangpal and B) Helambu rural municipalities.

2.2 Demography

The dataset provides a snapshot of eight wards of Panchpokhari Rural Municipality, revealing variations in key demographic indicators. The number of households ranges from 556 to 982, and populations differ from 1696 to 3640, representing diversity across the wards. Average household sizes exhibit a range from 3.05 to 3.98, reflecting differences in living arrangements. Notably, the sex ratio, depicting the number of females per 100 males, varies from 93.03 to 114.14 across the wards, suggesting distinct gender distributions. Panchpokhari Rural Municipality comprises 5,914 households and 20,997 individuals, with 10,614 males and 10,383 females (Table 2-4). Figure 2-7 illustrates the demographic situation of Panchpokhari Rural Municipality.

Table 2-4 Population census based on Sex, average household size, and sex ratio of Panchpokhari Rural Municipality

Ward	Number of households	Population			Average household size	Sex ratio
		Total	Male	Female		
1	652	2092	1063	1029	3.21	103.30
2	556	1696	904	792	3.05	114.14
3	824	3003	1561	1442	3.64	108.25

Ward	Number of households	Population Total	Male	Female	Average household size	Sex ratio
4	760	2687	1372	1315	3.54	104.33
5	575	2288	1162	1126	3.98	103.20
6	924	3236	1622	1614	3.50	100.50
7	982	3640	1795	1845	3.71	97.29
8	641	2355	1135	1220	3.67	93.03
Total	**5914**	**20997**	**10614**	**10383**	**28.30**	**824.05**

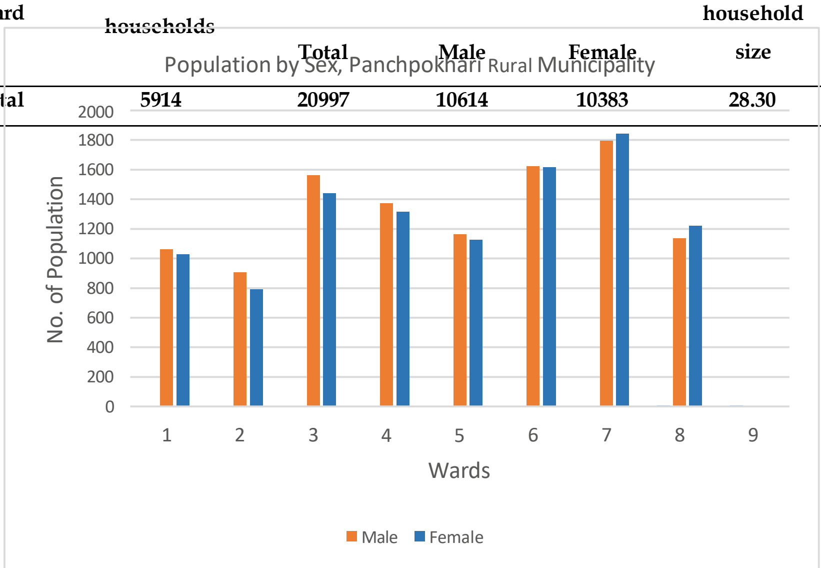


Figure 2-7 Graphical representation of Population distribution of Panchpokhari Rural Municipality

Similarly, the dataset (Table 2-5) provides insights into seven wards of Helambu Rural Municipality, highlighting variations in key demographic indicators. The number of households ranges from 537 to 782, reflecting diversity in residential structures. Total populations vary from 1929 to 2995, representing differences in overall community sizes. Average household sizes range from 3.26 to 4.32, indicating varying living arrangements across the wards. Notably, the sex ratio (females per 1000 males) ranges from 92.78 to 107.82, suggesting distinctive gender distributions. The total dataset encompasses 4690 households and 17497 individuals, with 8781 males and 8716 females. Figure 2-8 provide a comprehensive overview of the demographic landscape in the surveyed wards, offering valuable insights for further analysis and community planning.

Table 2-5 Population census based on Sex, average household size and sex ratio of Helambu Rural Municipality (CBS, 2021)

Ward	Number of households	Population Total	Male	Female	Average household size	Sex ratio
1	709	2311	1199	1112	3.26	107.82
2	782	2750	1399	1351	3.52	103.55

3	537	1929	942	987	3.59	95.44
4	549	2057	990	1067	3.75	92.78
5	610	2633	1300	1333	4.32	97.52
6	762	2822	1461	1361	3.7	107.35
7	741	2995	1490	1505	4.04	99
Total	**4690**	**17497**	**8781**	**8716**	**3.73**	**100.75**

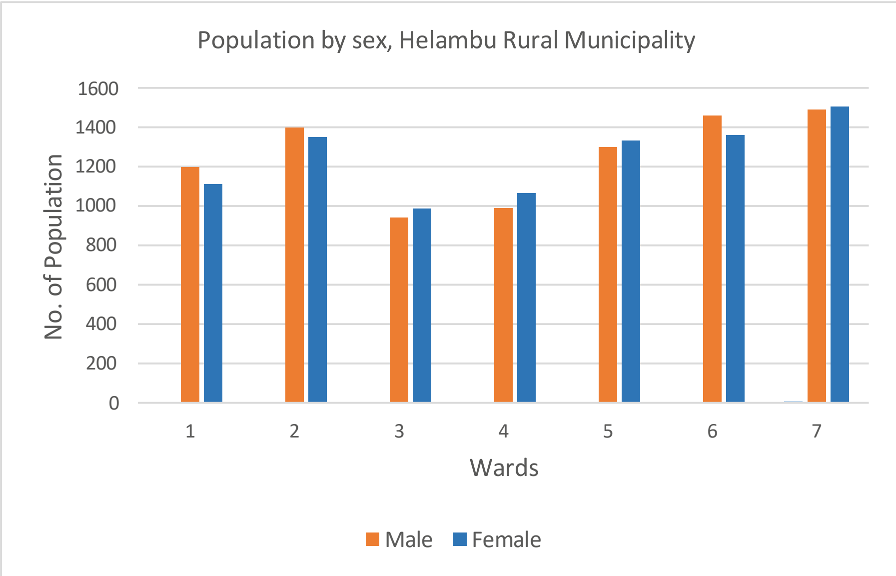


Figure 2-8 Graphical representation of Population distribution of Helambu Rural Municipality

2.1.4 Disabilities

Persons with disabilities (PWDs) play an important role while evacuation during emergency such as sudden triggering of landslide due to their vulnerability. The resilience of PWDs to landslide risks is influenced by factors such as risk exposure, socioeconomic capacity, and individual characteristics. Landslide events can disproportionately impact PWDs, especially in rugged landscapes, making their inclusion in assessments vital. Understanding the susceptibility of households with PWDs to landslides, considering factors like slope positions, is essential for effective risk management. Recognizing and addressing the specific needs of PWDs in landslide-prone areas contributes to comprehensive risk reduction strategies.

This assessment depicted considerable families comprises different disabilities in the two municipalities shown in the following table. The review of published documents and CBS report (CBS 2021) reveals that about 2.1% (Nr. 361) and 3.1% (Nr. 651) population in Helambu and Panchpokhari-Thangpal has some kinds of disabilities (Table 2-6). The data indicated physical disabilities is the heights among all followed by low vision in both the municipalities.

Table 2-6. Type and number of disabilities in Panchpokhari and Helambu municipality.

Type of Disability	Panchpokhari			Helambu		
	Total	Male	Female	Total	Male	Female
Physical	218	118	100	151	91	60
Low Vision	112	58	54	49	31	18
Blind	41	16	25	19	9	10
Deaf	39	22	17	39	23	16
Psycho-Social disability	31	16	15	8	7	1
Hard of hearing	46	22	24	36	19	17
Deaf and blind	18	13	5	6	4	2
Speech impairment	32	15	17	9	7	2
Intellectual disability	14	3	11	3	2	1

Hemophilia	5	2	3	4	3	1
Autism	2		2	3	1	2

Type of Disability	Panchpokhari			Helambu		
	Total	Male	Female	Total	Male	Female
Multiple disability	93	60	33	34	20	14

2.3 Rainfall

Climate, especially rainstorms is a critical factor in landslide assessment and early warning systems. Changes in climate patterns, including increased rainfall or prolonged droughts, can significantly impact slope stability, influencing the likelihood of landslides. Early warning systems often incorporate climate data to monitor and predict conditions conducive to landslides. The connection between climate events and landslide occurrences underscores the importance of considering climate variables in risk assessment and implementing timely warnings.

There are altogether 5 rainfall stations Table 2-7 around the study area. Sarmathang has an elevation of 2574 meters and experiences a maximum annual rainfall of 200.4mm, with a mean annual rainfall of 3400.88mm. Dhap (Thangpal) is situated at an elevation of 1284 meters, with a maximum annual rainfall of 280mm and a mean annual rainfall of 2352.37mm. Tarke Ghyang, at an elevation of 2596 meters, receives a maximum annual rainfall of 234.9mm and a mean annual rainfall of 3286.99mm. Dhap (Tarnamlang) has an elevation of 1362 meters, with a maximum annual rainfall of 421mm and a mean annual rainfall of 2923.58mm. Nawalpur, situated at 1653 meters, experiences a maximum annual rainfall of 142.2mm and a mean annual rainfall of 2409.31mm. These figures provide a concise overview of the rainfall patterns at different stations, offering valuable information for climate analysis and regional planning.

Table 2-7 Rainfall stations with their maximum and mean annual rainfall value of the study area

Station Index	Station Name	Latitude	Longitude	Elevation	Recorded Extreme rainfall (mm) in a day	Mean annual rainfall (mm)
1016	Sarmathang	27.94456111	85.59513611	2574	200.4	3400.88
1025	Dhap (Thangpal)	27.91245194	85.633379	1284	280.0	2352.37
1058	Tarke Ghyang	27.999318	85.554444	2596	234.9	3286.99
1078	Dhap (Tarnamlang)	27.901559	85.632553	1362	421.0	2923.58
1008	Nawalpur	27.8127	85.6242	1653	142.2	2409.31

2.4 Road Network

Roads play a crucial role in assessing slope stability, as they are often built on or cut through hilly terrain. The stability of road slopes is vital for infrastructure safety and public well-being.

Engineers and geologists assess factors like soil composition, water infiltration, and geological conditions to determine the stability of road slopes. The results of these assessments guide construction practices, ensuring that roads are built on stable ground, preventing landslides and slope failures. Monitoring and analyzing road cut slopes provide valuable insights into potential hazards, allowing for the implementation of preventive measures and maintenance to enhance slope stability and road safety. However, rural roads in Nepal is known for landslide as they are often built without considering the local geology and engineering aspect of roadside slope stability.

Local government has given priority in road construction depicted the progressive increment in the road length. The review indicated that the road length is about 390km and 356 km respectively in the Helambu and Panchpokhari-Thangpal Municipality.

2.5 Landslide Inventory

Landslide inventory is crucial for the development of landslide early warning systems as it provides essential data on past landslide events. This historical information helps in understanding the characteristics, patterns, and triggers of landslides in a specific region. By analyzing the landslide inventory, helps to assess the vulnerable areas risk factors, and also contribute to model potential future landslide scenarios. This knowledge is fundamental for designing effective early warning systems tailored to the unique geological and environmental conditions of a particular area. Landslide inventor, more specifically the inventory with the landslide date and corresponding rainfall serves as a foundation for predictive models and real-time monitoring systems, enabling authorities to issue timely warnings and mitigate the impact of potential landslides.

The field observation and review of Remote Sensing images and published literatures, reveals that the landscape slope was highly impacted by the Gorkha Earthquake. Besides the earthquake, rain induced landslides were also found considerable. Following figure (**Figure 2-9**) show that the landscape in the upper reaches of the municipality contains considerable numbers of landslides. The assessment depicted that the numbers of landslides in Panchpokhari was about 1670 and that in Helambu was about 581.

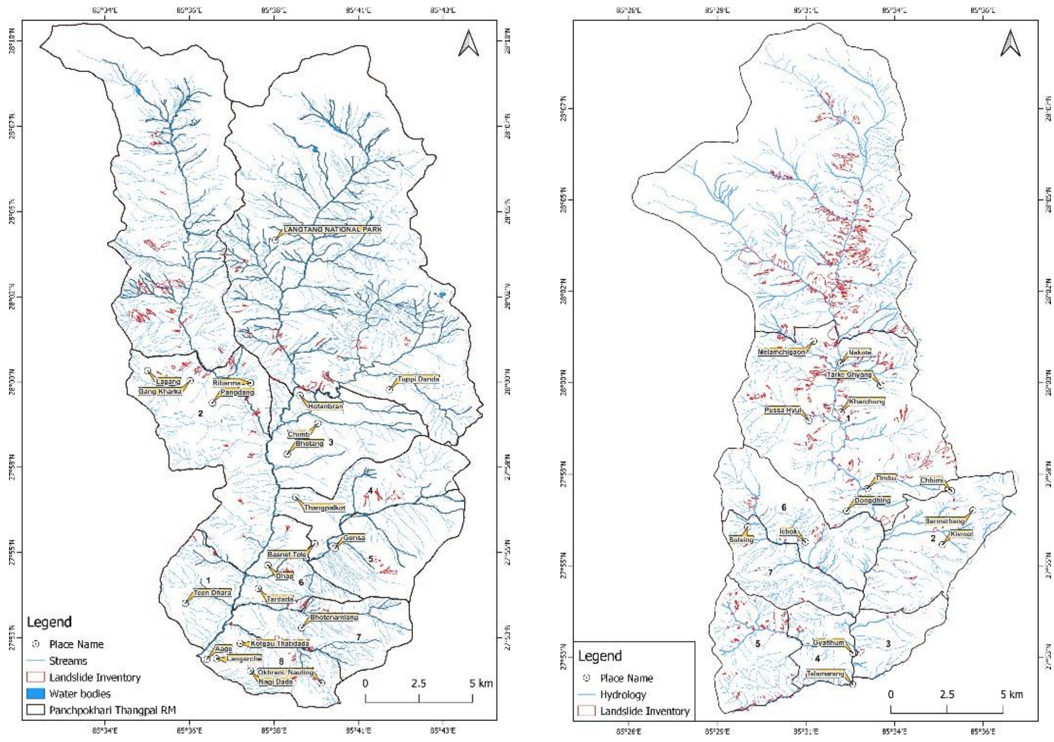


Figure 2-9. Landslide inventory map of A) Helambu and B) Panchpokhari Thangpal Rural Municipality including the National Park Area obtained from secondary sources (ICIMOD, 2016).

However, landslides are more in National park area than in the settlements as indicated in the figure. Ward level landslide inventory prepared during this study is shown in the following figure (Figure 2-10).

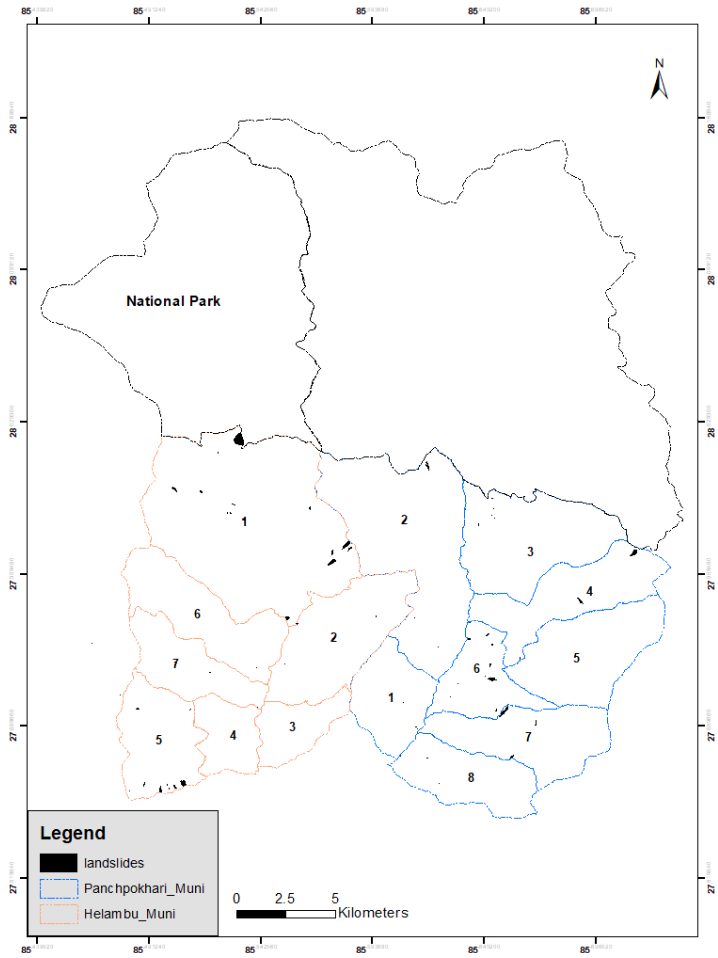


Figure 2-10. Ward Level Landslide Inventory of Helambu and Panchpokhari-Thangpal Rural Municipality (note – the black polygons are the landslides).

The inventory indicated that about 70 landslides (41 in Helambu and 29 in Panchpokhari) of different types observed in the two rural municipalities.

The two municipalities, experience significant hydro-meteorological challenges, including landslides and floods. Due to heavy rainfall, areas in Helambu have been inundated, and essential roadways have been obstructed, affecting local communities and festivities. This has prompted local authorities to advise residents to relocate to safer areas to avoid the risks associated with these natural disasters. These events underscore the vulnerability of these regions to such hazards, which are exacerbated by their complex topography and the changing courses of rivers during monsoon seasons.

Section 3. Review of Past Studies

3.1 Published Literatures

According to Zhuang et al. (2022) there were not many landslides in Melamchi and Indrawati basin before the April 2015 Gorkha Earthquake (GE 2015) but the numbers increased during and after the GE 2015. They have modelled the basin's slope stability and found that the landslides were more clustered in the upstream area of the basins located in Helambu and Panchpokhari municipalities. Further, Zhuang et al. (2022) observed that the area is one of high rainfall zone in central-eastern Nepal; however, there was no such extreme rainstorms during the Melamchi debris flow. The recorded maximum rainfall in 24 hours was about 100 mm which is the normal rainfall (Zhuang et al., 2022). The likely trigger of Melamchi debris flow was infiltration of rainwater in the cracks and destabilized by the GE 2015. Thus, the debris flow was the cascading effect of primary hazards such as earthquake, avalanche and landslide often caused secondary hazards (e. g. landslide dam, debris flow, and flooding) compounding the risks to human settlements, infrastructures, and ecosystems (KC et al., 2024).

Review of literature reveals that there was less intense but continuous rainfall of several days in the area. Most of the study were carried out based on the events-based rain-on-grid approach to generate the events-based hydrograph thereby the inundation model. The estimated rain intensity as depicted in Schindler et al. (2012) was about 30 mm in half an hour. However, the area is said to be one of higher rainfall zone in the region which is also indicated in the DHM data base. The probably rainfall intensity if derived using the historical rainfall database of 24 hours, the hazards can be better predicated.

3.2 Melamchi Disaster

A recent debris flow and sediment disaster in Melamchi on June 15, 2021 was a fatal example, that killed many people, destroyed human settlements and infrastructures of national importance. A large area of land was eroded along with the deposition of debris in Melamchi town and along the Melamchi riverbed causing loss of property having value of millions of dollars. The difference before and after the June 15, 2021 event at Melamchi town can be seen in **Figure 3-1**. The debris flow also damaged the headworks of Melamchi Water Supply Project - a critical project that supplies water for more than 3 million people in Capital City-Kathmandu. Likewise, most of the river crossing structures, for instance bridges in Melamchi River have experienced heavy sediment loading with notable decrease in vertical clearance. The impact of decrease in vertical clearance can be immediate and cause the flow to overtop the bridge even in normal flow and in flood events the bridges can be washed away.

The Melamchi flood disaster is one of the eye-opening events in the mid-mountain region of Nepal. Over the past quite a few studies were carried out (Masi et al., 2021; Schindler et al., 2012; Zhuang et al., 2022). These studies stated that the flash flood was caused by continuous rainstorms of several days that caused landslide dam in the upstream of the Melamchi River and at some point, the dam was breached. The breach was sudden caused huge debris flows.

Figure 3-1. (left) Melamchi town before the debris flow event and (right) after the debris flow event (Masi et al., 2021).

3.2.1 ICIMOD

Masi et al. (2021) stated that the Melamchi disaster cannot be attributed to a single factor and argued that the disaster was a result of multiple factors and processes that occurred at various locations along the Melamchi river. They produced map indicating different processes in the Melamchi River course (Figure 3-2) and contributing factors for the disaster such as:

a. weather conditions-continuous rainfall for several days,
b. processes in the high-altitude glacial environment,
c. processes at the Bremthang old landslide site,
d. formation of a new landslide at Melamchigaon, river damming and outburst flood, and
e. riverbank erosion and debris deposition.

These hazards, both alone and in combination with others, amplified the scale of the disaster in downstream areas.

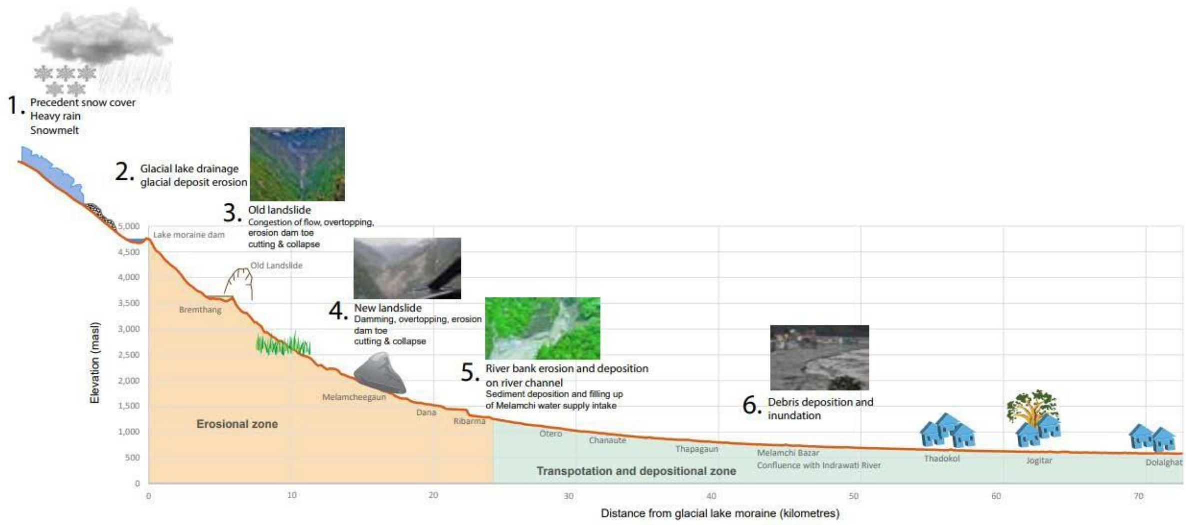


Figure 3-2. Longitudinal profile of the Melamchi-Indrawati River showing various processes leading to the disaster (Source: ICIMOD 2021).

Masi et al. (2021) stated that the Melamchi and Indrawati basins started receiving rainfall from 9 June as recorded in the automatic weather station of the Department of Hydrology and Meteorology (DHM) in Sermathang, at an elevation of 2625 metres above sea level (masl). While the highest hourly precipitation on 10 June was 22 mm, by 11 June, it had increased to 37 mm per hour. On 14 and 15 June, some rainfall was recorded at around a maximum of 10 mm per hour. On 11 June, Semathang recorded more than 100 mm of rainfall in 24 hours. During the 6-day interval, the station had, therefore, received more than 200 mm of rainfall (Masi et al., 2021). According the data obtained from DHM, precipitation in the region increased with the elevation. The recorded maximum annual precipitation in Mealmchi-Indrawati basin was about 4000 mm.

Further, Masi et al. (2021) of ICIMOD stated that there was a landslide at Bremthang located at 1.8 km downstream of the confluence of Pemdang Khola and Melamchi Khola. They have also analyzed temporal satellite images indicate that debris flows have occurred in this stretch in the past too as seen by a large fan deposit and a number of talus deposits beside the Pemdang Khola, which are marked in following figure (**Figure 3-3**).

Figure 3-3. Photo-showing the outer slope of the Bremthang landslide dam and the area downstream (Source: ICIMOD, 2021).

The water and debris mixed flow originating from the headwaters of Pemdang Khola and Melamchi Khola then filled the 1 km wide plain behind the Bremthang landslide dam (Masi et al., 2021). When the flow reached the crest of the landslide dam, it led to congestion within the existing river outlet.

Besides, Masi et al. (2021) stated that a new landslides of about 450 m wide in the middle and 550 m wide at the bottom and 450 m long was triggered that blocked the Melamchi River. After sometime the landslide mass was filled up and saturated initiate the debris flowing from the upstream area. Eventually, the river would have overflowed the landslide by eroding and cutting the damming material and breached out, causing the catastrophic flood that resulted in major damage in the downstream areas (**Figure** 3-4). According to Masi et al. (2021) the landslide mass was about 670,000 m^3 in volume.

Figure 3-4. Sediment deposition in the a. upstream part about 1 km upstream from Chanaute Bazaar and b. downstream part (Melamchi Bazaar) of the watershed (Source: ICIMOD 2021).

3.2.2 World Bank/NDRRMA

Following the debris flow disasters, World Bank carried out assessment of Melamchi Watershed with the goal to support National Disaster Risk Reduction Authority (NDRRMA); to bring the concerned stakeholder in a place and assess the degree of disaster and prepare recovery plan.

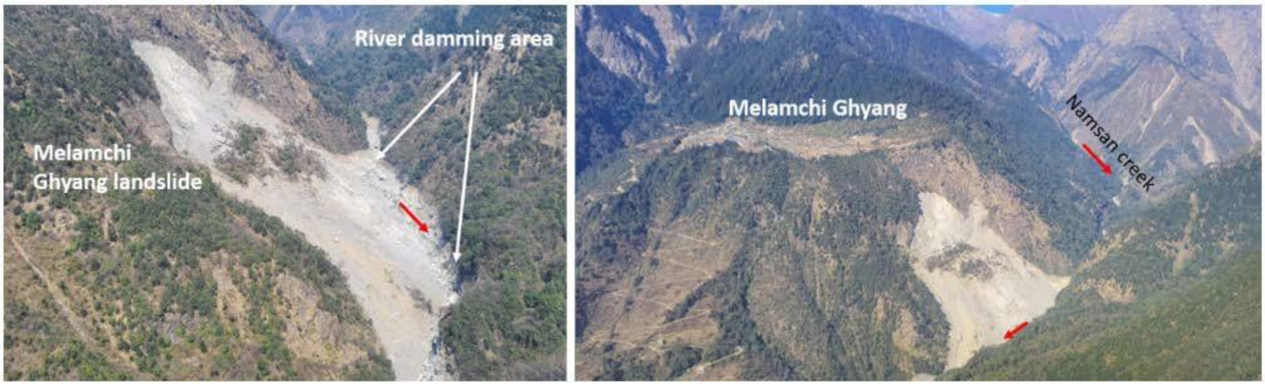


Figure 3-5. View of Melamchi Ghyang Area and landslides that caused landslide dam (Sources WB, 2021).

Firstly, they carried out mapping of the area using the Drones and secondly assess the amount of the debris deposited in the downstream area followed inundation modeling of the area. They implemented events-based Rain-on-Grid Model in HEC-RAS to derive the hydrograph, which was used to model the inundation areas (Schindler et al., 2012)

The study concluded that the disaster was caused by continuous rainstorms of several days that trigger landslides and create landslide dam (**Figure 3-5**) in the upstream area (i. e. Melamchi-Ghyang of Helambu Rural Municipality). The landslide dam was breached after some time triggered massive debris flows. The debris flow caused huge damage on its way to Melamchi Bazaar. Modified the river flow channel due to the sedimentation. The depth of sediment was several meters. They have sued 40mm rainstorms of 1.5 hours events to model the flood disasters.

In conclusion Schindler et al. (2012) stated that the Melamchi flood, is a combined effect of heavy rainfall, temperature change in snow line, erosion in end moraine of Pemdan lake, possible breach of the natural dam responsible for the lake, cascading effects of natural dam breach along with erosion and series of landslides along the Melamchi River.

The review indicated that the in terms of geological hazards the Melamchi region which includes Helambu and Pamchpokhari-Thangpal municipalities, is limitedly studies. Most of the studies were after the Melamchi disaster in 2021. The disaster was triggered by the rainstorms where the landscape slope was destabilized by the Gorkha Earthquake 2015. In addition, there might have contribution of and human activities for Melamchi 2021 disaster.

3.3 Losses and Damage

There was no system research on loss and damage caused by the Melamchi disaster. However, a brief study of Parajuli et al. (2023) stated that about US $ 62 Million was the economic losses in Helambu Rural Municipality alone. In terms of human causalities one person was declared dead and 23 were missing in Helambu.

3.4 Landslide-Rainfall Threshold

3.4.1 Global Context

Recent advancements in landslide prediction and early warning systems have been extensively documented in various research papers. Calvello and Pecoraro (2021) introduced a novel approach for identifying rainfall thresholds for landslide occurrences, utilizing satellite data for enhanced accuracy. Kim et al. (2020) explored the impact of antecedent rainfall conditions on landslide-triggering thresholds in South Korea, emphasizing the significance of prior rainfall patterns in landslide prediction. Jordanova et al. (2020) focused on establishing empirical rainfall thresholds for shallow landslides in Slovenia, employing an automatic tool for more precise predictions. Satyaningsih et al. (2023) developed dynamic rainfall thresholds for landslide early warning in Indonesia's Progo Catchment, highlighting the need for high-resolution rainfall data in regional forecasting. Naidu et al. (2017) developed an early warning system for landslides in Kerala, India, combining cluster and regression analysis to identify critical rainfall thresholds. Floris and Bozzano (2008) proposed a modified rainfall threshold model for assessing landslide reactivation probability, offering a nuanced approach to landslide risk assessment. Lastly, Marra et al. (2016) examined the spatial organization of debris flows-triggering rainfall in the Italian Alps, addressing the challenges in estimating rainfall thresholds due to spatial variability. These studies collectively represent significant contributions to the field, demonstrating the complexity and regional specificity of rainfall-landslide relationships. Magrì et al. (2023) modeled rainfall-induced landslides at a regional scale in Italy using a machine learning-based approach, specifically a polynomial Kernel regularized least squares regression algorithm. Nocentini et al. (2023) optimized rainfall thresholds for landslide early warning in Italy through false alarm reduction and a multi-source validation, addressing operational challenges in landslide forecasting models.

Liu et al. (2023) discussed landslide prediction using low-cost and sustainable early warning systems integrated with the Internet of Things (IoT). Doerksen et al. (2023) proposed using

Machine Learning and Deep Learning techniques for precipitation-triggered landslide prediction in Nepal, utilizing space-based data for enhanced prediction capabilities. Palazzolo et al. (2023) investigated the use of principal component analysis to incorporate multi-layer soil moisture information in hydrometeorological thresholds for landslide prediction, a methodology that could be relevant for regions like Nepal. Guo et al. (2022) analyzed rainfall thresholds for shallow landslides using physically based modeling in Nepal's Rasuwa District, employing remote sensing data and field investigations. Chiang et al. (2022) used deep learning algorithms to determine landslide rainfall thresholds in Taiwan, aiming to develop an early warning system. Guo et al. (2022) enhanced the performance of rainfall thresholds for landslide warning using distributed root soil moisture data. Germain et al. (2021) analyzed empirical rainfall thresholds for landslide occurrence in Brazil, providing insights into the spatial and temporal dynamics of landslides and rainfall conditions. Mansor Maturidi et al. (2021) reviewed the development of landslide thresholds from the perspective of rainfall and climate patterns, studying different rainfall parameters for landslide prediction.

3.4.2 National Context

Rainfall threshold is highly recognized to detect landslides in advance and to develop landslide early warning system. Many research has been accomplished around the globe discussed above section. However, in Nepal it is limitedly known or limited in research. The first of this kind was published by Dahal et al. (2008), who proposed rainfall threshold for Nepal's Lesser Himalayan region. According to Dahal et al. (2008) the rainfall threshold in Nepal Himalaya is as given below:

$$I=73.9D^{-0.79}$$

where I is the rainfall intensity and D is the duration of rainfall.

Similarly, Guo et al. (2022) analysed rainfall thresholds for shallow landslides using physically based modeling in Nepal's Rasuwa District, employing remote sensing data and field investigations. Guo et al. (2022), stated that the rainfall threshold for landslide can be better derived considering the antecedent rainfall of 5, 10 or 15 days. According to them the threshold in the mountainous region of Rasuwa is;

$$I=5.00+943.90*0.95^{R_5}$$ – 5 Days antecedent rainfall

$$I=3.95+674.32*0.97^{R_{10}}$$ – 10 Days antecedent rainfall

$$I=1.89+520.13*0.98^{R_{15}}$$ – 15 Days antecedent rainfall

where I is the average daily rainfall, R_n is the antecedent rainfall of n days.

Further, in 2017, UNDP conducted a research for developing landslide threshold for the two medium size watersheds in Sindhupalchok and Surkhet districts respectively Sindhukhola and

Sotkhola. They have proposed five days' antecedent rainfall to trigger the landslides. They have proposed following equation:

$$TR = 180 - 1.07 * RR_{TT_{5aaaaaa}}$$

where TR is the threshold rain, R_T is exceedance rainfall of 5 days. Exceedance rainfall can be obtained deducting the daily rain to the sum of 5 days accumulated rain.

Section 4. Approach and Methodology

4.1 Approach

The Consultant ensures the quality delivery by using relevant international and national codes, practices, guidelines and standards related to document the baseline for developing landslide early warning system for the two municipalities. Similarly, the Consultant has made an optimum use of its experience and expertise to assess data to gather from different sources and field consultation.

While executing the tasks of the assignment, the Consultants strictly followed the scope of work outlined in the Terms of Reference (ToR). For any matters which are not covered in ToR, the Consultant consulted with the Practical Action's team of expert and also followed national and international guidelines and references.

4.1.1 General Approach

Based on the understanding of the scope of work as stated in the ToR document, the general approach to carry out the job is based on the followings:

- Collect and review of secondary data, (e.g. hydro-meteorological data, previous study reports and scientific publications related to landslides), study of topographical and geological maps, remote-sensing data, related guiding documents relating to the landslide and landslide early warning system;
- Review Remotes Sensing Images and prepare the landslide inventory as a part of reconnaissance survey of the two municipalities and assess the topographic characteristic, vulnerable locations and soil erosion and slope stability of the landscape;
- Analysis of long-term meteorological data, assess the trend, prepare the landslide inventory, and suggest the requirements for the rainfall threshold for landsliding;

The Consultants used the available and applicable information such as previous study reports, maps/drawings, specifications, guidelines, plan and policies and any other relevant information obtained in the course of study.

4.1.2 Technological Approach

Following the scope of work outlined in the ToR; the consultant adopted national and international guidelines to assess, gather and evaluate the data. The Consultants has also used its own library, where books, reports, and scientific articles related to the study. Consultant's experience on landslide assessment, mapping and slope stability modelling in the digital environment, were extensively used in the study.

GIS and RS data are the baseline for this study while the inventory and climate data such as rainfall data is the prerequisite for developing LEWS for which the study was focused. Most relevant and advance technical approach have been adopted to accomplish the assignment.

4.1.3 Management Approach

Planning and Scheduling

A time management approach that stipulates 'timely and efficient mobilization of resources that includes manpower, financial and logistics to accomplish the assigned field and office tasks within stipulated contract period keeping in mind the approved milestones. This includes detailed programs administration, accounting, logistics, quality assurance, mobilization, work location, operation and control, meetings and discussions. To achieve the work schedule and professional mobilization plan was developed and adopted.

Quality Control and Quality Assurance

The Consultants have their quality control management system and ensure the Client to render its service with reasonable quality within specified time frame and available data and resources. The Consultants believe that frequent interactions with the Client and other stakeholders help to deliver the best value of the service. The quality of output was improved by the feedback and review by the panel of experts managed by the Consultant. The Consultants believe in protection of human rights, environment, labour rights and is against any bribery activities. These issues have been dealt according to law of land. Any entity or personnel engaged were made aware of these issues and instructed to the team involved. Quality assurance system include but not limited to the following:

- Ensures to complete each task of the assignment by qualified and experience experts;
- Uses all the relevant and latest available technologies to ensure its quality service to the Client;
- Uses the appropriate national and international codes, guidelines for the best possible output;
- Sufficient sampling and testing to verify the results;
- Survey and measurement checks;
- Local consultation especially to the local governments and community people;

It is essential to collect data from reliable sources and to ensure that it is up-to-date. Geological maps, aerial and satellite imagery, historical records of landslides/debris flows, flash flood, topographic data, and precipitation data are some of the important secondary data sets to be used to assess the flood hazard and to delineate the hazard prone areas.

4.2 Methodology

The baseline study for developing rainfall threshold to reduce the risk of landslides can be considered to be comprehensive as many factors associated to landslides. Considering the complexity of landslide phenomena and developing rainfall threshold for landslide requires multitude of data and information. The adopted methodology to achieve the objectives of the study is discussed in the following sections.

4.2.1 Preparation of Field Checklist and Guiding Questions for the FGD

The experts were engaged in developing checklists and guiding questions for the FGD. The guiding questions are focused to capture the information relevant to developing LEWS such as demographic, vulnerability, exposure of disability, minority and other underrepresented social groups and the impact of climate extremes such as landslides, flash floods, and drought. One FGD was performed in each ward to collect the required data and information such as climate-induced hazards (e. g. landslides, flash floods, drought, etc.) availability of water sources and uses, forest resources, degraded land, community buildings, health and education buildings etc. During the FGD the participants were firstly asked to list out the landslide and flash flood impacts, degraded agriculture and forest land, drinking water sources, impacts of drought, etc. in the tabular form and secondly, they were asked to locate the area of interest (i. e. for example landslides, flood, degraded land, drinking water sources, etc) in the google earth imagery.

4.2.2 Preparation of Questionnaire for Key Informants Interview

Key-Informant's Interview (KII) is the tool to assess the local-level information required for developing baseline for LEWS. KII has been used for a long time for data collection at the community level. The selection of Key-informants (KI) is important, and generally identified in consultation with the local government representative and local leaders. The local senior citizen, local school teacher, and social workers hold valuable sources of information. In order to capture the reliable information and data relevant to prepare the Baseline for LEWS of Panchpokhari-Thangpal and Helambhu rural Municipalities, Key-Informants were identified in consultation with the local government representatives such as the ward chairperson or ward members. A set of questionnaires was developed for the KII to perform. At least one KI was identified in each ward and the KII was conducted.

4.2.3 Preparation of Landslide Susceptibility Map (LSM)

The methodology for preparing a Landslide Susceptibility Map (LSM) of terrain, as derived from scientific literature, is a multi-faceted process that involves several sophisticated steps. Initially, LSMs are created using a variety of methods like logistic regression, analytical hierarchy process, frequency ratio, and index of entropy, each categorizing susceptibility from extremely low to extremely high. In this study, Frequency Ratio (FR) was found to be representative and accurate method to assess the susceptibility of the terrain. FR utilized the landslide conditioning factors and inventory of the landslide and assess the slope stability pixel to pixel.

The process includes critical steps like data preparation, which involves forming training and validation datasets, and feature selection, where conditioning factors are determined. The LSM integrates multiple thematic layers, including those derived from Digital Elevation Model (DEM) of 5meter resolution (elevation, slope, aspect) and parameters like lithology, geomorphology, and land use/land cover.

Frequency Ratio Method for LSM

The LSM was developed using the widely used FR method as adopted by other researchers (Ding et al., 2017; Kalimuthu et al., 2015; Solaimani et al., 2013). The FR is a bivariate statistical data driven method, and relies on historical landslide database and the spatial distribution of various influencing factors, such as geological, topographical, meteorological, and land-use commonly used for assessing the landslide susceptibility of a geographic area (Ding et al., 2017; Solaimani et al., 2013). The method correlates the past landslides with the different landslide conditioning factors and provides the extent to which each factor affects the occurrence of landslide (Polat, 2021). This makes the FR a useful tool for assessing landslide susceptibility based on empirical evidence. The LSM was then classified in to five classes (i. e. very low, low, moderate, high and very high) with the natural break function in GIS.

The landslide inventory was divided into 70% and 30% respectively for the training and the testing datasets. To implement the FR model (Equation 1 and 2) in GIS, PYTHON code was developed. With the landslide conditioning factor maps and training datasets of the landslides were fitted into the model to generate LSM. The quality of the LSM was then evaluated with the testing datasets achieved Receiver Operating Characteristic (ROC) curve and Area Under the Curve (AUC) (Sahin et al., 2020; Vakhshoori et al., 2018).

Equation 1

$$FR_i = \frac{A_i/A}{(AL_i/AL)}$$

And Relative Frequency RF was calculated as

Equation 2

$$RF_i = \frac{FR_i}{\sum FR}$$

where,

FR_i = frequency ratio of the parameter/factor

RF_i = relative frequency of the considered factor

A = total study area

A_i = Area of the considered factor

AL = total landslide area in the study area

Al_i = landslide area in the Ai

4.2.4 Assessment of Elements at Risk

The elements such as household were obtained from Open-Street Map (OSM) and infrastructures mainly the road network were digitized from the Google Earth. These data were later field verified. These two elements were considered to be the critical to understand the impacts of landslide hazards in the municipalities.

The LSM was used to assess the likely impacts of landslides over the households and roads. The elements were overlaid on top of the LSM to visualize the hazard impacts.

Section 5. Results and Discussions

5.1 Rainfall: Extreme Events & Trend

Helambu and Panchpokhari-Thangpal Rural Municipalities in Sindhupalchowk, experience significant rainfall variation, particularly during the monsoon season (June-Sept). The region's complex topography, with varying elevations, makes it susceptible to hazards such as landslides and floods triggered by heavy rains. The changing courses of rivers further contribute to these challenges, impacting roadways and communities. The local population is at risk during monsoons, prompting authorities to advise precautionary measures and relocation to safer areas. These trends highlight the need for proactive disaster preparedness and mitigation strategies to protect the residents of these vulnerable mountainous regions.

An effort was made to assess the rainfall trend and extreme events analysing over 30 years of daily data obtained from Department of Hydrology and Meteorology (DHM). The historical rainfall data of five rain gauge stations were collected and analysed depicted the following results (Table 5-1).

Table 5-1. List of rain gauge stations and historical extreme events.

Station Index	Name	Lat.	Long.	Elv. (masl)	Recorded Daily Extreme (mm)	Mean Annual (mm)
1016	Sarmathang	27.94456111	85.595136	2574	200.4	3400.88
1025	Dhap (Thangpal)	27.91245194	85.633379	1284	280	2352.37
1058	Tarke Ghyang	27.999318	85.554444	2596	234.9	3286.99
1078	Dhap (Tarnamlang)	27.901559	85.632553	1362	421	2923.58
1008	Nawalpur	27.8127	85.6242	1653	142.2	2409.31

Among the five rain gauge stations, Dhap (Index No. 1078) recorded highest daily rainfall (~ 421mm) followed by Dhap (Index No. 1025) and then Tarkghyang (Index No 1058). The mean annual rainfall of over 30 years was highest in Sarmethang (Index No. 1016) followed by Tarkeghyang (Index No. 1058).

While analysing the rainfall, the obtained historical data, quality assessment was performed in terms of consistency and missing values. Missing values were interpolated, however, missing data of over 5% was discarded from the analysis. The Dhap (Index No. 1078) was discarded from the analysis as it contained over 5% of missing data.

The data indicated that the recorded annual rainfall was minimal in Dhap (Index No. 1025) and Nawalpur (Index No. 1008) in comparison to other stations. It can be concluded that the rainfall is high in Helambu region (i.e. Melamchi River Watershed) than Panchapokhari-Thangpal municipality (i. e. Indrawati River Watershed).

Analysing the Thiessen Polygon (Figure 5-1) reveals that major area of Helambu municipality is under the rainfall scenario of Tarkeghyang in Helambu and Nawalpur in Panchpokhari-Thangpal municipality.

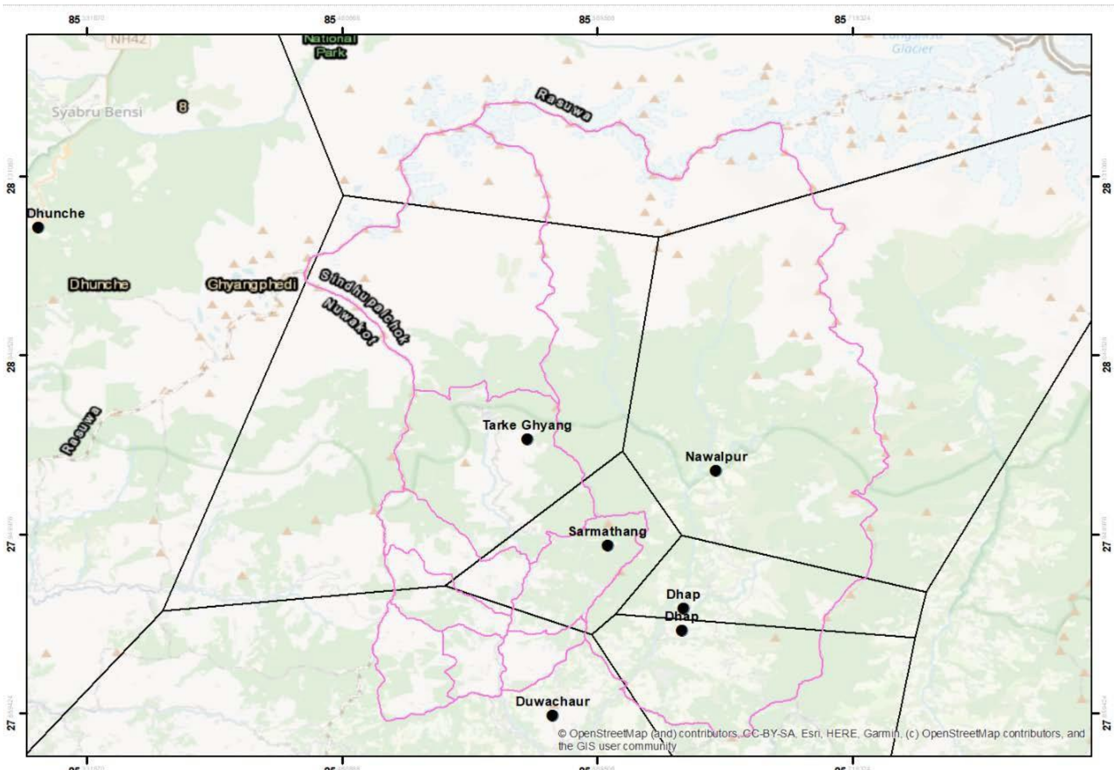


Figure 5-1. Thiessen Polygon model of the two municipality indicating the rain gauge stations and area occupied.

The maximum rainfall as discussed earlier was recorded in Sarmathang and lowest was in Nawalpur. There was no distinct and significant trend of rainfall in the region rather it was monotonous (**Figure 5-2**).

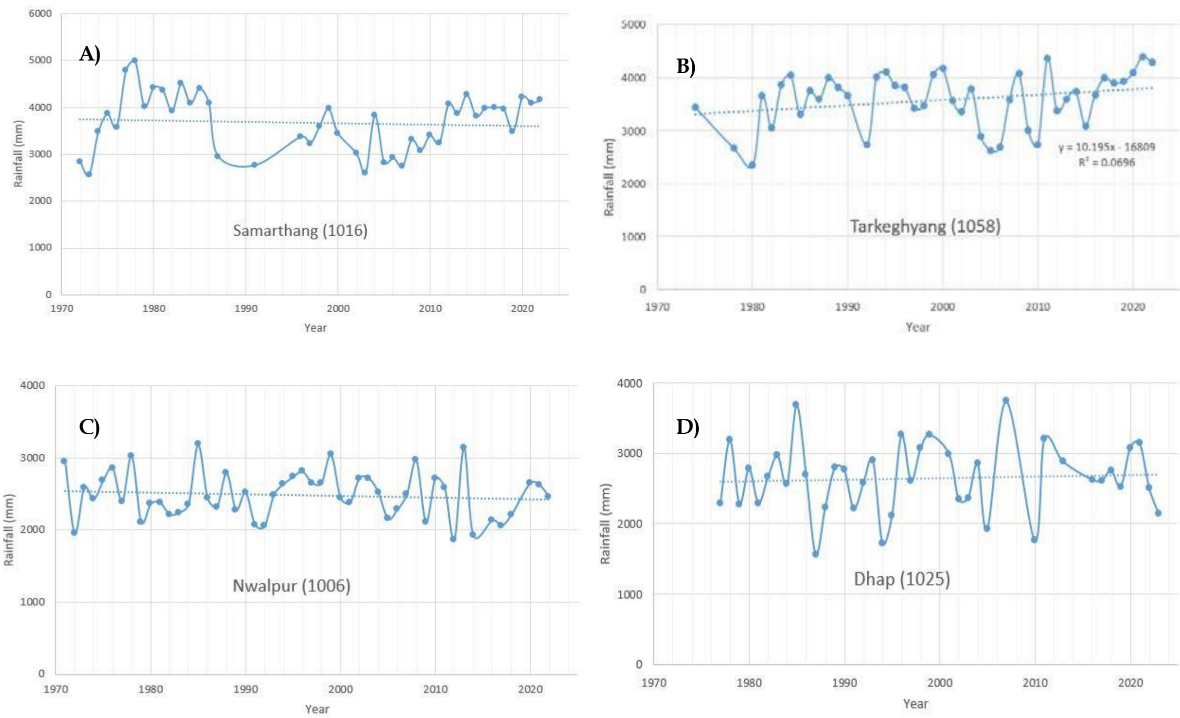


Figure 5-2. Historical rainfall trend; A) Sarmathang, B) Tarkeghyang, C) Nawalpur and D) Dhap.

Among the four stations, the historical annual total rainfall in Sarmathang and Nawalpur depicted to be decreasing with very low significance while Tarkeghyang indicated increasing trend. Over 50 Years data of Dhap does not show any trend.

5.2 Rainfall and Landslide

Landslides and rainfall are closely interconnected in mountainous regions like Helambu and Panchpokhari-Thangpal Rural Municipalities. Heavy rainfall, especially during the monsoon season, saturates the steep slopes, increasing soil instability. This heightened moisture content, combined with the weight of the soil and rock above, can trigger landslides. The dynamic relationship between precipitation and landslides underscores the vulnerability of these areas to such hazards. Monitoring rainfall patterns and implementing effective early warning systems are crucial for mitigating landslide risks and ensuring the safety of the local population in these regions.

However, historical landslide database is limitedly available and many landslides are unreported. The limitation of proper database impacted this study considerably. An effort was made to assess different sources and listed out following landslide in the two municipalities (Table 5-2). The total of 11 landslide dates was obtained from the MOHA and DisInventor (1970-2013) and the corresponding rainfall taken from the DHM records.

Table 5-2. Landslide Dates and rainfall.

Village(Municipality & Ward No.)	Date of Landslide	Precipitation (24 hrs.)		
		Dhap (1025)	**Dhap (1078)**	**Nawalpur (1006)**
Lagarche (Panchpokhari-8)	8/8/1996	16.4		44
Lagarche (Panchpokhari-8)	6/24/2002	40	41	29.6
Helambu (Helambu-1)	6/23/1972	24		24
Ichok (Helmabu-6)	6/26/1990		42	42
Mahankal (Helambu-5)	7/27/1977	25.5		25.5
Mahankal (Helambu-5)	8/4/2002	33.4	21.2	27.3
Mahankal(Helambu-5)	8/5/2002	40	69.9	54.95
Mahankal (Helambu-5)	8/5/2002	40	69.9	54.95
Mahankal (Helambu-5)	8/12/1977	24.1		24.1
Mahankal (Helambu-5)	8/12/1977	24.1		24.1
Mahankal (Helambu-5)	8/18/2002	40.2	57.5	48.85

Sources: DisInventor and MOHA

Above data illustrate that the landslides were triggered unc nfall indicated impact of antecedent rainfall in the region has caused the slope failu

5.3 Landslide Inventory

Landslide Inventory was prepared adopting local consultation especially the ward chairman and rural municipality council members which then followed by field observation and community consultation. There were 30 records of landslides identified in this study. Most of them were shallow in nature. Among them 13 were reported to be active, some of them are naturally stabilized (e. g. natural grow of plant species). The summary of the landslide in each ward and their status are shown in Table 5-3 below;

Table 5-3. Summary of landslide inventory of Panchpokhari-Thangpal Rural Municipality.

Ward No	Name of Landslide	Location & Name	Date on which the landslide Triggered	Damaged Caused	No. HH Damaged/ Relocated	Mitigation Measures adopted	Still Active
1	Bhakte Bari Landslide	Baskharka, Bhakte bari	Long time ago	-	-	Done nothing yet	Still active
	Barje Tole Landslide	Baskharka Jatan	4/30/2077	Damaged the animal shelter and death of one ox	Damaged the animal shelter	Gabion wall and plantation of Amriso (by Melamchi drinking water scheme)	Now stable
	Jantare Tole landslide	Baskharka, Jantare tole	-	-	-	Done nothing yet	Partially stable
	Missepa Landslide	Baskharka	4/30/2077	Damaged the irrigation channel	-	Done nothing yet	Now stable due to naturally grown up of local species of plant called Uttis
2	Simpani Landslide	Simpani, Baruwa	12 yrs ago	Damaged the farming land	Damaged the animal shelter	Done nothing yet	Partially stable
	Dalit tole landslide	Tallo baruwa	15 yrs ago	Damaged 2 HH and farming land	Damaged 2 HH	Plantation by Kapine Forest Committee	Now stable
	Tenzet landslide	Baruwa	2077 shrawan	Damaged farming land and 24 HH at risk	-	Done nothing yet	Active during rainy season
	Bolgaun Basti, Dalit Basti	Bolgaun	5/18/2076	Damaged the farming land	-	Gabion wall by the help of RM	
	Dale landslide	Dale, Baruwa	4/2/2080	Community at risk (28-28 HH)	Relocated 2 HH, remaining on process	Done nothing yet	Stable
	Toshiba	Baruwa	3/1/2078	Damaged the farming land	-	On process of gabion wall by the help of provincial government	Stable

	Sunchaur landslide	Sunchaur, Baruwa	3/1/2078	Damaged the 2 HH and farming land	Relocated 2 HH	Done nothing yet	Stable
3	Thulo Bhotang Landslide	Thulo Bhotang	2073 shrawan	Community at risk (30 HH)	-	Gabion wall	Stable
	Yarsa Maneghyang landslide (Road induced)	Maneghyang tole	2077 mansoon	Community and highway at risk	5 HH at high risk	Done nothing yet	Active during monsoon.
	Larke landslide	Larke, Bhotang	2072 monsoon	Damaged 12 HH and farming land	Relocated 12 HH	Done nothing yet	Active during monsoon
4	Dhadkhark landslide	Dhap and Kot border	2078 Ashad	Damaged the farm of large cardamom and farming land	-	Done nothing yet	Active during mansoon
Ward No	**Name of Landslide**	**Location & Name**	**Date on which the landslide Triggered**	**Damaged Caused**	**No. HH Damaged/ Relocated**	**Mitigation Measures adopted**	**Still Active**
5	Chepare khola landslide	Chepare khola, Gunsa	2039	Damaged 3 HH and farming land	Damaged 3 HH	Gabion wall	Stable
7	Thumke lower region landslide	Ward no. 6,Thangpaldap	After earthquake	Damaged 4 HH, land slipping	Damaged 4 HH	Gabion wall by CSRC	Now stable
	Siyale landslide	Ward no. 6, Siyale	-	Damaged 2 HH and farming land	Damaged 2 HH	Gabion wall	Still active
	Mude landslide	Ward no. 6, Tar	Long time ago	7-8 HH at risk	-	Bioengineering by ARSHOW	Still active
	Ghatera Tole	Ward no. 6, Tallo Tar	After 2072	Community and farming land at risk	-	Gabion wall	Now stable due to naturally grown up of local species plant called uttis.
	Mudelewa Landslide	Bhotenamlang	2074/075, Ashad/Shrawan	Damaged of farming land (20-22	-	Done nothing yet.	Active during rainy

				Ropani)			season
1	Ratamate landslide	Bhotenamlang	4/19/2077	Damaged house and farming land with crops (20-22 Ropani)	Damaged 1 HH	Done nothing yet.	Still active
	Kafle landslide	Kafle basti, Bhotenamlang	Long time ago	Damaged 2 HH and land (30-35 Ropani)	Damaged 2 HH	Done nothing yet.	Now stable
	Newar tole landslide (Pokosomkhola)	Newar tole (near Bhotenamlang secondary school), Bhotenamlang	Long time ago	Damaged 1 house and land	Damaged 1 HH	Gabion wall	Still active
	Danuwar tole landslide	Danuwar tole, Bhotenamlang	2073 Ashad	Damaged land	-	Gabion wall	Still active
8	Uttis ghari landslide	Khaldekhola, Lagarche	2077 Shrawan	Damaged highway Community and farming land at risk	-	Done nothing yet	Still active
	Ange Pahiro (Khaldekhola mathi)	Khaldekhola, Lagarche	2074 Ashad	Khalde khola Community and farming land at risk	-	Gabion wall	Still active
	Tipeni landslide	Tipenin bazzar, (Khaldekhola & Kharsebaluw)	4/30/2077	Damaged 4 HH	Relocated 4 HH	Machinery wall (Partially)	Still active
	Sole landslide	Sole, Lagarche	Lone time ago	Sole community at risk (3 HH needs to be relocate)	Relocated 1 HH (land provided by the chairperson)	Gabion wall	Still active
Ward No	**Name of Landslide**	**Location & Name**	**Date on which the landslide Triggered**	**Damaged Caused**	**No. HH Damaged/ Relocated**	**Mitigation Measures adopted**	**Still Active**

	Sunkhani Pahiro	Sunkhani (B.K Tole), Lagarche	After earthquake	Damaged 1 HH	Relocated 1 HH	Gabion wall by CSRC with collaboration with ward	Still active

Similarly, the landslide inventory of Helambu was prepared in consultation to the ward chairman and local community (Table 5-4). Together 47 landslides have been identified in Helambu. Most of the landslides as reported are active during monsoon season.

Table 5-4. Summary of landslide inventory of Helambu Rural Municipality.

Ward No.	Name of Landslide	Location Name, and Ward No	Date of landslide Triggered	Causes of Landslide	No. HH Damaged/Relocated		Mitigation Measures adopted	Status of Landslide
					House	Other		
1	Melamchi Ghyang Landslide मेलची घ्याङ प�हरो	Melamchi Ghange	2078	flood 2078 BS.	3	Land and Forest	No	Flood effected and yearly down by Melamchi River
	Tashi Ghang Landslide	Tashigang	2072	Earthquake	7	Land and Forest	No	Land movement, 1 meter down per year.
	Sarkathali Landslide सकर् थली प�हरो	Sarkhathali	2072, 2079	Earthquake 2072 BS. and flood 2078 BS.	35	Land and Forest	No	Flood effected and yearly down by Melamchi River
	Doring Landslide दोर�ङ पह�रो	Doring	2072, 2080	Earthquake 2072 BS. and flood 2078 BS.	17	Land and Forest	No	Flood effected and yearly down by Melamchi River
	Ambathan Landslide अम्बाथान प�हरो	Ambathang	2072, 2081	Earthquake 2072 BS. and flood 2078 BS. Melamchi water project dam and tunnel effect the land for the landslide.	10	Land and Forest	No	Now Plants and grass grown
	Ringur (Timbu) Landslide	Timbu	2072, 2082	Earthquake 2072 BS. and flood	65	Land and	No	Land movement, 1 meter down

	�रङगुर (ितम्बु) प�हरो			2078 BS.		Forest		per year.
	Halde/ Cheurikharka Landslide िचउर�खकर् प�हरो	Cheurikharka	2072, 2083	Earthquake 2072 BS. and flood 2078 BS.	22	Land and Forest	No	Effect by land and raining, community will tansfer another place.
2	Ganeshe Tamang Dhodeni	Tamang Dhodeni	2072	Earthquake 2072 and road construction	25	Land and Forest	Gabin constructio n	Land movement, 2/3 meter down per year.
	Churetar Ganeshdi	Churetar Ganeshe	1997, 2072,	Flood 2078	15	Land	No	Risk on monsoon

Ward No.	Name of Landslide	Location Name, and Ward No	Date of landslide Triggered	Causes of Landslide	No. HH Damaged/Relocated		Mitigation Measures adopted	Status of Landslide
					House	Other		
	Kiul Bazar Now Palika area	Kuel Palika	1972	Heavy rainfall on Monsoon	3	Land and Forest	No	Stop by natural cause, Plant growth, People farming and living
	Jyamire Basti	Jyamere Kuel	2043	Landslide from Deurali, okherini	15	Land and Forest	Natural plant growth	Stop by natural cause, Plant growth, People farming and living
	Ganesi Bagar Dhugane dada	Dhugane dada	2050	landslide from Tamag bhirkharka	25	Land and Forest	Gabin constructio n	Risk on monsoon
	Kachuwa/ Archale Vir Gairibeshi Landslide	Gairibeshi, Archale	2045, 2073, 2078	Earthquake, Flood etc.	25 Water meal 4	Land and Forest	No	Risk on monsoon
3	Palchok Sera	Kartike Mod and Chalese Basti	2078 Bhadra	Heavy raining and flow road on nessary water.	Cowsheed 1 two Water meal	90 ropani	No	Risk on monsoon

	Bharati Breauti/Fedi Rumto Landslide	Bharati Berauto/Fedirumt o	2078	Flood 2078	3	20 Ropani	No	Flow river
	Ishing	Ishing Palchok	2074	After earthquake 2072	30	Forest and land	little gabin, plant growth etc.	Risk on monsoon
	Odare basti Landslide	Odare	2072	After earthquake 2072	30	Forest and land	No	Land Moving,
4	Gyalthum Dalit Tool	Gyalthum Dalit tol	2049, 2072	After earthquake 2072	30	Land anf farming	No	Now Plants and grass growths
	Ukhubari Tallo Tol and Majhi Tar	Majhitar	2062, 2072	Road construction and earthquake 2072	15	Land anf farming	No	Now Plants and grass growths, Risk on Monsoon
	Lapsi Pakha	Lapsi Dada			40	Land anf farming	No	Risk on monsoon
	Haridada	Haridada	2072	Natural caught	24	Land anf farming	No	Risk on monsoon
	Ukhubari Chaur and Jugepani pahiro	Jugepani	2078 flood	weak gographical condition िसम रहेको	8	Land anf farming	No	Risk on monsoon
	Thapa Gau Pahiro	Thapa Gau	2072	Earthquake 2072	5	Forest and land	No	Risk on monsoon
	Gangetar Pahiro	Gangetar	2072	Earthquake and road construction	5	Land and Forest	No	Risk on monsoon
	Gorikhola Pahiro	Gorikhola	2072	weak gographical condition िसम रहेको	7	Land and Forest	No	Risk on monsoon

Ward No.	**Name of Landslide**	**Location Name, and Ward No**	**Date of landslide Triggered**	**Causes of Landslide**	**No. HH Damaged/Relocated**		**Mitigation Measures adopted**	**Status of Landslide**
					House	**Other**		
	Bolde Pahiro	Bolde and Sabeche	2077 bhadra	Monsoon and construction road	65	Houe land and forest		Risk on monsoon

5	Kalleri Pahiro	Kalleri	2076 Shwan	Monsoon and construction road	100			Risk on monsoon
	Gyalthum Surung Pahiro	Gyalthum Surung	2079 Bhadra	Monsoon and construction road	0	Land and Forest		Risk on monsoon
	Sirese Pahiro	Sirese	2080 Bhadra	Monsoon and construction road	50	Land and Forest		Risk on monsoon
	Urleni Pahiro	Urleni	2079	Monsoon and construction road	35	Land and Forest	No	High risk for the settlement
6	Kharkadada Pahiro	Kharkadada	2073	Earthquake 2072	16	Land forest and house	No	Risk on monsoon
	Thapatar Pahiro	Thapatar	2078	Flood 2078	20	Farm, land and house	No	Risk on monsoon
	Nayabasti Pahiro	Nayabasti	2078	Flood 2078	30	Farm, land and house	No	Risk on monsoon
	Dhapsung Pahiro	Dhapsung	2072	Nonsoon and weak soil	66	House land and foreste	No	Risk on monsoon
	Lama Tol school Pahiro	Lamatol Ichok	2073	Earthquake 2072	30	Land foreste	No	
	Nalunkharka Pahiro	Nalunkharka	2076	Earthquake 2072 and road construction	30	land house and farm	No	Risk on monsoon
	Sunar tool Pahiro	Sunar Tol	2078	Road construction and water drawin	20	commun ity, land and foreste	No	Risk on monsoon
7	Chanaute Kodele Pahiro	Kodale	2078	Flood 2078	4	land	No	Risk on monsoon
	Tallo Pating and Mathello Pating Pahiro	Pating	2077	Earthquake 2072 and road construction	65	Land forest	No	Risk on monsoon
	Pipal Dada	Pipaldada	2072	Earthquake	40	Land	No	Risk on

	Pahiro			2072		Foreste		monsoon
	Tallo Majuwa Pahiro	Tallo Majuwa	2072	Earthquake 2072 and road construction	10	Land Foreste	No	Risk on monsoon

The list of the landslides shown in the table above indicated the largely missing date on which the landslides were triggered, which is important for developing rainfall threshold.

5.4 Rainfall and Landslide Early Warning System

Rainfall and landslide early warning systems (LEWS) are vital in mountainous regions like Helambu and Panchpokhari-Thangpal Rural Municipalities. These systems rely on rainfall data collected through meteorological stations and remote sensing technology. When heavy rainfall is detected, alerts are issued to warn communities about potential landslides. In these areas, where landslides can have devastating consequences, early warning systems play a critical role in saving lives and minimizing property damage. Community preparedness, evacuation plans, and responsive authorities are key components of effective landslide early warning systems, ensuring that residents can take timely action to stay safe during rainfall-triggered landslide events.

The LEWS requires comprehensive data sets of historical landslides, and rainfall, which is limitedly maintained. The LEWS is the region is less known and yet to be developed.

Study reveals that there is no functional landslide early warning system established in Helambu and Panchpokahri Rural Municipalities. However, there are some evidences of rainfall threshold for landslides developed such as Dahal and Hasegawa (2008), Guo et al. (2022), and UNDP (2017). Among them Dahal and Hasegawa (2008) is the representative rainfall threshold for the country as a whole while other two were suggested for catchment scale.

5.5 Landslide Hazards and Risks

Landslide hazards and risks are geological phenomena that occur when masses of rock, soil, or debris move downhill due to various triggers, such as heavy rainfall, earthquakes, or human activities. These events pose significant dangers, including loss of life, damage to infrastructure, and environmental disruption. Vulnerable regions, especially mountainous areas, face a higher risk. Mitigation measures involve monitoring, early warning systems, and land-use planning to minimize the potential impact of landslides and protect communities from these natural disasters. Public awareness and preparedness play a crucial role in reducing the risks associated with landslides.

Reviewing of the past studies depicted that a few efforts have been made towards developing landslide hazard model of Sindhupalchok such as MoIAL (2023). They carried out Multi-hazard and Vulnerability assessment of Sindhupalchok District that also includes landslides and other climate induced and geological hazards of Helambu and Panchpokhari Rural Municipalities. They have found that the district comprises about 40.8% of geographical area is under the high to very high susceptible to landsliding. Most of the studies were carried out after the April 2015 Gorkha Earthquake followed by Melamchi Disaster of 2021. However, no specific studies on LEWS and LSM of Helambu and Panchpokhari Municipalities were found.

5.5.1 Panchpokhari-Thangpal Rural Municipality

The eight wards of Panchpokhari-Thangpal Rural Municipality were visited and the data related to developing the landslide early warning system were extracted using the KII and FGD interviews. The summary of the KII is shown in the following table (Table 5-3) while wards level situation is discussed in the following section.

Table 5-5. Summary of KII of Panchpokhari-Thangpal Rural Municipality.

Ward No	Ward Name	Landslide prone areas	Demography	Budget in disaster management	Protection works done now
1	Baskharka	1. Bakte Bari (5 HH+ lands) 2. Tauli khet 3. Jantare tole (3 HH) 4. Misenpa landslide (due to road induced) 5. Barje tole (150 HH) 6. Khatri tole (10-12 HH) 7. Dahi khani 8. Aaru danda/Devi danda landslide 9. Simkhet landslide near health post (road induced) 10. Tenzing (2-3 HH) 11. Chempehop Bazar (10-15 household,road induced)		10-15 lakhs	Gabion wall in Bakte bari-7 lakhs, Barje tole (Gabion wall, Jau grass, Dale bamboo), 1 lakh allocated in the ward for plants
2	Baruwa	1. Simpani (36 HH) 2. Dalit tole (13 HH). ; landslide stopped now, 3. Tenzet (35 HH)-Gabion, plantation done, 4. Bolgau, Dalit basti (7 HH), 5. Dale (26 HH), have to be shifted, 6. Toshiba (11 HH), 7. Sunchaur (27HH), 8. Yangri tole (60 HH)	Tamang: 90%, Sherpas, Brahmin/Chhetri		
3	Votang	No active landslide now; Landslide in Gyalsim was stabilized.		1 crore in whole rural municipality	
4	Thangpalkot	1. Dhadkharka 2. Dhap and kots border 3. Near thapatole (Agricultural land); Element at risk: Devithan Mandir	Tamang, Hylmo, Newar, Brahmin		
5	Gunsa	1. Chyu chyu danda: Cracks, 2. Chepare Khola (80-90 HH total in that area); 17 died in landslide in 2039 B.S, 3. Kumbeshhwori adaharvut Ma. Vi (150 students) under risks	96% Tamang, 2.5% Dalit, Newar		Gabion walls, Plantations

6	Thangpaldhaap	1. Thumke lower regions-4 HH shifted, 6 HH to be shifted 2. Siyale jyoti tole-(5-7) HH, 3. Mude- 6 HH to be shifted 4. Ghatera tole-11 HH	Giri, Puri, Jyoti, Magar

Ward No	Ward Name	Landslide prone areas	Demography	Budget in disaster management	Protection works done now
7	Bhotenamlang	1. Newar tole (1-2 feet land settlement for which gabions of 40/45 lakhs walls used); 2. Kafle pahiro- 2 HH+ Bal sudhar school in danger (40-45 students) 3. Danuwar basti- Bhotenamlang Ma Vi-700+ students- Gabion walls used; 4. Ratmate danda-2 HH + agricultural lands 5. Mudilewa Landslide(30-35 ropani of land effected);			
8	Langarche	1. Near utis ghari tipine (Highway induced, 18-20 HH); 2. Aange (18-20 HH, road induced near Panchakanya Adharvut Mavi, Gabion walls used; 3. Landslide in Tipine previously ward 6: 33 HH recommended for relocation (Bamboo, Amriso planted in this); 4. Sole landslide: slipping type, Creeping (Gabion walls used)	Chhetri, Brahman, Tamang, Newar		

The KII indicated that all the wards of the municipality have some degree of landslide risk, yet it has not been prioritized in terms of risk reduction measures.

Ward 1, Baskharka:

In Ward 1, Baskharka, demographic data is not specified. CSRC conducted risk area mapping, with disaster information being disseminated through SMS, the Ward Facebook page, and messages from employees. The ward disaster management committee only holds ad-hoc meetings; there are no regular meetings scheduled. There are three community development committees within the ward. Disaster response equipment is limited to one box, a TV screen, and tents, with no clear inventory system despite a disaster management budget of 10-15 lakhs. A financial organization named Garibi Niwaran Tatha Krishi Sahakari assists in the financial distribution of seeds and fruits. The ward has not specified the number of disaster-prone areas. Protection works have been carried out in various areas with associated costs. Fifteen community buildings are mentioned, and the report does not provide data on the number of people with disabilities.

Ward 2, Baruwa

In Ward 2, Baruwa, the demographics consist of 90% Tamang, along with Sherpas, Brahmin, and Chhetri. Disaster information is shared through SMS, and there is a ward-wise disaster management committee in place. Notably, there are no community development committees in this ward. The paragraph indicates a lack of disaster response equipment, and the disaster management budget details are not provided. Two financial organizations, Ama Yangri and

Mahila sahakari, are mentioned, aiding in financial matters. There are several disaster-prone areas, including Simpani with 36 households and Dalit Tole with 13 households, among others, with various protection works completed, such as gabion installation and plantation. The community buildings include 14 Gumbas, over 20 Manes, and 9 registered committees. Regarding individuals with disabilities, the ward has 5 in category Ka, 12 in Kha, 4 in Ga, and 2 in Gha.

Ward 3, Bhotang

In Ward 3, Bhotang, the demographic details are not specified. Disaster information is communicated through SMS, the ward's Facebook page, and employees. There's no detailed information on the ward disaster management committee or community development committees. Disaster response equipment includes five kits with stretchers and lights. The entire rural municipality has a disaster management budget of 1 crore. Two financial organizations, Serchu Barli and Reactive, are involved in financial distribution. Specific disaster-prone areas have not been detailed. There is no information on protection works or community organizations. Eleven community buildings are registered, and there is a mention of people with disabilities, with 4 in category Ka and 25 in Kha.

Ward 4, Thangpalkot:

In Ward 4, Thangpalkot, the demographics consist of Tamang, Hylmo, Newar, and Brahmin. There is no information provided on previous data collection efforts, and disaster information is disseminated through radio and SMS. Specifics regarding the ward disaster management committee are not given. There is one community development committee. Disaster response equipment includes stretchers, but there are no other equipments related to disaster management. The budget for disaster management is not mentioned. There is no information on a financial organization assisting in financial distribution. One disaster-prone area is identified as Manekharka health posts. Protection works have been conducted at several sites, including Dhadkharka and the border of Dhap and Kots, with a specific note on the Devithan Mandir being at risk. Details about community organizations and NGOs delineating safe areas are not provided. There are 8 community buildings, and the number of people with disabilities includes 8 in category Ka and 16 in category Kha.

Ward 5, Gunsa

In Ward 5, Gunsa, the population is predominantly 96% Tamang, with 2.5% Dalit and some Newar. CRSC and ARSO Nepal, specializing in geology, have previously collected data. Disaster information is uniquely disseminated by shouting from a place known as Mamyugba stone. There are no details provided about the ward disaster management committee or community development committees. No disaster response equipment is reported, and the disaster management budget is not specified. The birthing center is noted as a disaster-prone area. Protective works have been conducted in areas with geological risks, such as Chyu Chyu Danda and Chepare Khola, where a significant landslide occurred in 2039 B.S. There are concerns for Kumbeshhwori Adaharvut Ma. Vi, which has 150 students at risk. Gabion walls and plantations are mentioned as community organization initiatives, but no specific NGOs delineating safe areas are listed. The ward has 4 community buildings, in addition to 2 manes. The number of people with disabilities includes 5 in category Ka, 9 in category Kha, and 4 in category Ga.

Ward 6, Taar:

In Ward 6, Taar, the demographics are Giri, Puri, Jyoti, Magar. Disaster mapping has been conducted, and disaster information is disseminated through sirens, especially for floods along the Indrawati Khola. There are no specifics provided about the ward disaster management committee. The ward has community development committees, but the exact number is not specified. Disaster response equipment includes tents, though the disaster management budget details are not mentioned. No financial organization is noted for assisting in financial distribution. Disaster-prone areas include health posts, health units, and a birthing center. Protective works have been conducted in various areas such as Thumke lower regions, where households have been shifted, Siyale Jyoti Tole, Mude, and Ghatera Tole, affecting numerous households. There are no details on community organizations or NGOs delineating safe areas. There are four community buildings, two completed and two partially complete. The number of people with disabilities is 6 in category Ka and 29 in category Kha.

Ward 7, Bhotenamlang:

In Ward 7, Bhotenamlang, the demographic information is not provided. There are no details available on data collection, the dissemination of disaster information, or the ward disaster management committee's activities. There is no mention of the number of community development committees. Disaster response equipment includes shovels and blankets, although there is no specified budget for disaster management. The status of financial organizations assisting in distribution is not mentioned. Identified disaster-prone areas include health posts that are 80% completed and currently using a JICA building; the health sector is considered backward. Protection works have been conducted in several areas: Newar Tole has had land settlements for which gabion walls costing 40/45 lakhs were used; Kafle Pahiro poses a danger to 2 households and Bal Sudhar School with around 40-45 students; Danuwar Basti and Bhotenamlang Ma Vi with over 700 students are protected by gabion walls; Ratmate Danda affects 2 households and agricultural lands; and the Mudilewa Landslide has impacted 30-35 ropani of land. There is no information on community organizations or NGOs delineating safe areas. The number of community buildings and the details of people with disabilities in various categories are not specified.

Ward 8, Langarche:

In Ward 8, Langarche, the demographics include Chhetri, Brahman, Tamang, and Newar populations. Disaster information dissemination is done by ama, mahila samuha, and the disaster samiti. A local disaster management committee is to be established, and there are no community development committees mentioned. Disaster response equipment decisions are made by the LDMC, but the budget details are not provided. The financial organization and specific disaster-prone areas are not mentioned. Protection works include addressing highway-induced landslides affecting households, road-induced landslides near a school, and a recommended relocation due to a landslide. There are six completed community buildings and two under construction. The number of people with disabilities includes 13 in category Ka and 19 in category Kha.

5.5.2 Summary HH Survey and Landslides

The large data sets and information obtained from the HH survey was summarized in terms of understanding of landslide causes, knowledge about NbS and losses in terms of monitory value (Table 5-6).

Table 5-6. Summary of HH surveyed, causes of landslides, knowlsge about NbS and losses in terms of monitory values.

Ward No.	Actual HH (CBS 2021)	Surveyed HH					Money Loss (NPR)
		Total Sample HH	Disability Person	NbS (Knowledge)	HH Affected by LS	Reasons of landslide	
1	652	34	24	34	0	Road Construction, Deforestation	-
2	556	24	5	24	6	Road Construction, Deforestation	2,180,000
3	824	125	57	120	6	Road Construction, Deforestation	436,222
4	760	114	25	114	2	Road Construction, Deforestation, Earthquake	5,015,000
5	575	64	10	59	1	Deforestation	12,000,000
6	924	35	1	35	11	Road Construction, Deforestation	5,100,000
7	982	118	16	118	3	Deforestation, Fire	805,000
8	641	33	18	33	9	Road Construction	195,000
Total	**5914**	**547**	**156**	**537**	**38**		**25,731,222**

5.5.3 Helambhu Rural Municipality

Similar to the Panchpokhari-Thangpal Municipality, the KII indicated that the Helambu municipality is also contains some degree of landslide risks. The following table (Table 5-4) presents the KII results of all the wards of the municipality.

Table 5-7. Summary KII of Helambu Rural Municipality.

Ward No.	Name of Ward	Landslide prone areas	Demography	Budget in disaster management	Protection works done now
1	Helambu	1. Sarkathali-(30-35 Household) 2. Doring- Creeping debris mass- 15 HH 3. Aambathong- 8 HHs-moderately risky 4. Timbu- 55 HHs- Landslide in 2072 B.S. 5. Halde-35 HHs- Resettlement from lower part to upper part 6. Churikharka-22 HHs-Resettlement in the area	Sunar, Tamang		
2	Kiul	1. Churetar Ganeshdi 2.(Kiul Bagar, Jyamire Basti, Ganesi Bagar)-Stopped due to plantation	Tamang	50 lakhs in development (which is used in disaster if needed)	
Ward No.	Name of Ward	Landslide prone areas	Demography	Budget in disaster management	Protection works done now
3	Palchowk	1. Gairibeshi, 2. Toriswora, 3. Fedi Romto 4. Serabeshi 5. Amilopani	Tamang, Hyolmo, Kami, Damai, Saraki, Chhetri, Brahmin, Newar	No	
4	Gyalthum	1. Ward no. 3, due to blockage of khola, 2. Sugarcane planted areas in Tallo basti and Majhitar, 3. Dalit Basti-30 HH 4. Maramchi (Thapatar)			
5	Chhajogang	1. Bolendo Purano-Monsoon and creeping+road induced land in 2080 2. Kalleri Pahiro- Due to the natural cause and road construction	Mostly tamang		
6	Ichowk	1. Dhapsum- Cracks are seen-66 HH in the area 2. Nalungkharka-30 HH, 3. Kharkedanda-16 HH (Necessary to shift the community in the area also debris) 4. Sunar basti tole (agricultural lands affected, Cracks after the canal construction)			Uttis was planted in Namtole, Ichu Mavi in past but now stopped
7	Mahakal	1. Chanuate-43 HH, 2. Kodal Basti 3. Tallo Majuwa 4. Pipal danda 5. Tallo Pathing	Sherpa, Tamang, and Newar		

The risk of landslide hazard has been identified in the municipality, however, the risk reduction measures are limited.

Ward 1:

Helambu is populated by Sunar and Tamang communities. A siren is used for early warning about disasters. The ward has a 15-member disaster management committee and a 14-member community development committee. Recovery tools provided by CDECF are available for immediate disaster response. Health facilities include a health post. Notable disaster-prone areas include Sarkathali with 30-35 households, Doring with creeping debris mass affecting 15 households, Aambathong with 8 moderately risky households, Timbu with 55 households affected by a landslide in 2072 B.S., Halde with 35 resettled households, and Churikharka with 22 resettled households. Drinking water is available.

Ward 2:

Kiul, primarily inhabited by Tamang people, uses sirens to warn about floods. There are no materials available for immediate disaster response. A budget of 50 lakhs for development, which can be utilized in disaster situations if needed, has been allocated. Churetar Ganeshdi and plantation areas such as Kiul Bagar, Jyamire Basti, and Ganesi Bagar are identified as disaster-prone. The Nature-Based Solutions (NBS) concept has not yet been implemented. The Ward Disaster Management Committee (WDMC) is operational, and NGOs/INGOs like CDECF and Just Nepal are active in the area.

Ward 3:

Palchowk in ward no 3 comprises five major settlements (ref. Table 5-4). The KII reported that the ward has no active landslide; however, there was a few landslides before.

Ward 4:

Gyalthum receives disaster alerts via SMS from DHM and sirens from LDMC. The ward has a health post with basic facilities and several educational institutions including community schools and a private school. Disaster-prone areas include Ward no. 3 due to khola blockage, sugarcane planted areas in Tallo Basti and Majhitar, Dalit Basti with 30 households, and Maramchi (Thapatar). Aama Samuha is an active organization, and the community has buildings including gumbas and manes. NBS concepts have not been adopted, but the WDMC is active, and there were previously four Female Community Health Volunteers (FCHVs).

Ward 5:

Chhajogang has a predominant Tamang population. There are 5-6 members in the community development committee but no materials for immediate disaster response. Sajha Krishi Sahakari is a cooperative in the ward. Health facilities include Mahakal Health Centre and a birthing centre. Educational facilities cover various levels up to class 10. Disaster-prone areas include Bolendo Purano and Kalleri Puchhar, affected by monsoon and creeping plus road-induced landslides. The WDMC is present, and irrigation facilities are lacking. The agriculture sector faces challenges from animal terror.

Ward 6:

Ichowk disseminates disaster information through phones. The community development committee has three members. There are two cooperatives, Kafe Sahakari and Annapurna Agricultural Sahakari. Health services are provided by a health unit. Disaster-prone areas include Dhapsum with visible cracks affecting 66 households, Nalungkharka with 30 households, Kharkedanda with 16 households requiring community shifting due to debris, and Sunar Basti Tole affected by cracks after canal construction. Planting of Uttis trees has ceased. Youth clubs and Aama Samuha are registered organizations, and Just Nepal provides training. The community has 13 buildings, including gumbas under construction and 15 manes. The NBS concept is implemented with crops such as Amriso and Sito on roads. Major crops are potatoes, rice, tea plants, apples, and coffee. The agriculture sector is affected by animals like deer and monkeys.

Ward 7:

Mahakal, inhabited by Sherpa, Tamang, and Newar communities, uses sirens for disaster alerts. The ward has an 18-member disaster management committee and community groups including Ama Samuha and Mahila Samuha. Emergency kits have been distributed, but no materials are currently available. There are two cooperatives, Nava Jivan Sana Kishan Sahakari and Mahakaleswori. Health services are offered by Ichwok Health Centre, and there are four schools. Disaster-prone areas include Chanuate with 43 households, Kodal Basti, Tallo Majuwa, Pipal Danda, Tallo Pathing, and Mathillo Pathing. Disaster registration is done through applications at wards. There are 8 registered community buildings, and the number of disabled individuals is noted. Drinking water is available, and major crops include millet and rice. Irrigation assistance has been provided by Helvatas, and agriculture is challenged by reduced rice production due to climate change.

5.5.4 Summary of HH Survey and Landslides

The large data sets and information obtained from the HH survey was summarized for the in terms of understanding of landslide causes, knowledge about NbS and losses in terms of monitory value (Table 5-7).

Table 5-8. Summary of HH Surveyed, knowledge about NbS, Causes of landslides and losses in terms of monitory value.

Ward No.	Actual HH (CBS 2021)	Surveyed HH				Reasons of landslide	Loss (monitory terms, NPR)
		Total Sample HH	Disability	NbS (Knowledge, HH)	HH Affected by LS		
1	709	119	18	119 (16.7%)	4	Road Construction, Deforestation, Earthquake	-
2	782	27	2	22 (2.8%)	17	Road Construction, Deforestation, Heavy Rainfall	17,340,000.00
3	537	74	15	74 (13.7%)	5	Road Construction, Deforestation	1,650,000.00
4	549	77	17	74 (13.5%)	2	Road Construction, Deforestation	2,000.00
5	610	98	21	98 (16%)	7	Deforestation	5,100,000.00
6	762	111	12	110 (14.4%)	0	Deforestation	-
7	741	116	13	116 (15.6%)	7	Road Construction, Deforestation	23,590,000.00
Total	**4690**	**622**	**98**	**613 (13.1%)**	**42**		**47,682,000.00**

The estimated losses caused by landslides in Helambu municipality according to the local community is about 47.68 Million Rupees, affected households were about 42.

5.5.5 Disable Population

The recent CBS data reveals that about 3.1% and 2.1% of the population respectively

Panchpokhari-Thangpal and Helambu municipality has some kind of disabilities. Altogether, 16 different types disabilities have been identified among which physical disabilities is highest followed by low vision (Table 5-5).

The municipality also reported that they have verified the CBS data and issued the identity card for all the disables.

Table 5-9. List of disability and number of disable perosons in the municipality.

Type of Disability	Panchpokhari-Thangpal			Helambu		
	Total	Male	Female	Total	Male	Female
Physical	218	118	100	151	91	60
Low Vision	112	58	54	49	31	18
Blind	41	16	25	19	9	10
Deaf	39	22	17	39	23	16
Psycho-Social disability	31	16	15	8	7	1
Hard of hearing	46	22	24	36	19	17
Deaf and blind	18	13	5	6	4	2
Speech impairment	32	15	17	9	7	2
Intellectual disability	14	3	11	3	2	1
Hemophilia	5	2	3	4	3	1
Autism	2		2	3	1	2
Multiple disability	93	60	33	34	20	14

During the FGD and HH survey, an effort was made to reach out the families with the disabilities.

5.6 Community Perception on Landslide Hazard

Landslides are common and frequently occurring hazards in the mountain terrain in general. Landslide have caused significant impacts in the lives and livelihoods particularly in the mid-hill region of Nepal. Field observation and community consultation through FGD and HH survey indicated that the people in the two municipalities Helambu and Panchpokhari-Thangpal in Sindupalchok have considerable knowledge about landslides.

The survey covers about 13% (622HH) and 10% (547HH) HHs respectively in Helambu and Panchpokhari-Thangpal municipality. The survey explains their perception about the landslides;

- About, 71% of 1,169 respondents perceive landslides as a significant threat, impacting their daily activities, damaging croplands and infrastructures especially the access road;
- The community realized that the frequency of the landslides has increased due to increased amount of rainstorms and unplanned construction of rural roads;
- After the Melamchi Disaster of 2021 the community people have realized that geological hazards can triggers anytime and any places;
- About 61% respondents in Helambu and about 52% in Panchpokhari-Thangpal Municipality have realized that landslides are more frequent where human activity is

intense/unplanned threating the settlements and houses;

- About 81% of 622 respondents in Helambu and 72% of 547 respondents in Panchpokhari-Tahngpal perceive that in monsoon season much of the roads are inaccessible due to the roadside slope failure;
- All most of the respondents in the two municipality reported that the landslide frequency have increased over the recent past damaged crop lands and physical environment;

5.7 Landslide Protection Measures

Landslide protection measures encompass a range of strategies aimed at mitigating the risks associated with landslides. These strategies involve engineering and non-engineering approaches to safeguard communities and infrastructure. Key measures include slope stabilization through retaining walls and reinforced vegetation, early warning systems to provide timely alerts, and land-use planning to avoid vulnerable areas. Public awareness and education are also integral components of landslide protection efforts, empowering communities to respond effectively to potential threats.

5.7.1 Landslide Protection Conventional Measures

Conventional landslide protection measures typically involve engineering solutions. These include constructing retaining structures like retaining walls and embankments to stabilize slopes and prevent landslides. Drainage systems are implemented to manage excess water that can trigger slides. Additionally, geotechnical investigations and monitoring systems are used to assess slope stability and provide early warnings. While effective, conventional measures can be costly and may have limited sustainability in the long term.

The FGD, KII and HH survey illustrates that majority of the respondents (72% of Helambu and 66% of Panchpokhari-Thangpal) believes that the structural measures are the means for slope protection. They have practiced installation of gabion and stone masonry retaining wall to protect their cropland, access road among others.

5.7.2 Landslide Protection Nature-based Solutions

Nature-based Solutions (NbS) for landslide protection embrace the use of natural processes and ecosystems to reduce landslide risks. Afforestation and reforestation programs help reinforce slopes by enhancing root systems that stabilize soil. Wetland restoration and soil conservation efforts also contribute to reducing erosion and landslide susceptibility. These approaches emphasize the sustainable management of natural resources and can complement conventional methods, offering cost-effective and environmentally friendly alternatives for mitigating landslide hazards. In the context of Helambu and Panchpokhari-Thangpal Rural Municipalities NbS play a crucial role in mitigating landslide risks. These mountainous regions are susceptible to landslides due to heavy rainfall and complex topography. Nature-based solutions involve afforestation and reforestation efforts to strengthen slopes through robust root systems, reducing soil erosion and landslide susceptibility.

Additionally, NbS also found to be effective for wetland restoration and soil conservation initiatives help maintain ecosystem health and resilience. By incorporating these environmentally friendly approaches alongside conventional measures, these RMs can enhance their landslide protection strategies while promoting sustainable land management and ecological well-being.

This study through field observation, community consultation and HH survey reveals that the NbS measures is less known at community level. The community people think that the technique is less effective in slope protection.

5.8 Perception of Locals on Landslide Protection Measures

Local communities in regions prone to landslides, such as Helambu and Panchpokhari-Thangpal Rural Municipalities, often recognize the importance of landslide protection measures. They appreciate the efforts taken by authorities to implement engineering solutions like retaining walls. However, challenges may arise due to the disruption caused by construction and the need for community participation in preparedness efforts. Local perceptions play a significant role in the success of these measures, emphasizing the importance of effective communication and community engagement.

5.9 Perceptions on NbS and Landslide Protection

Local governments and communities often view nature-based solutions (NbS) positively in the context of landslide protection. NbS strategies, such as afforestation and wetland restoration, are seen as environmentally friendly approaches that enhance landscape resilience. However, there may be concerns about the time it takes for NbS to yield results, and ongoing maintenance is essential. Public awareness and support are crucial for the successful implementation of NbS, aligning with the broader goals of environmental conservation and sustainable development.

5.9.1 Local Government

Local governments in Helambu and Panchpokhari-Thangpal RMs play a central role in landslide protection. They are responsible for implementing protection measures, early warning systems, and land-use planning. These authorities face challenges related to funding, coordination with higher levels of government, and community engagement. Effective governance and transparent communication with the local community are critical for successful landslide risk reduction.

However, the two local government have shown successful cases of landslide protection with the adoption of NbS such as in Ward No. 7 of Thangpal-Panchpokhari Municipality. They have demonstrated the use of Amriso, Utish and other plant species to stabilize the unstable slopes. Similarly, in Ichok of Helambu Ward No. 6 demonstration of roadside slope protection was carried out through planting Amriso and Sito, both are locally available plant. They have also used simple civil engineering structures such as dry stone wall and check dams.

The HH survey followed by the KII indicated that the local government have known the benefits of NbS and it is more commonly known as soil bioengineering. The survey assessed the perception of local government on the use of NbS depicted the following:

- About 75% of the local government representative in Helambu and 70% in Panchpokhari-Thangpal municipality expressed that the soil bioengineering (or the NbS) is useful and cost effective measures for slope protection;

- 80% of the local government in Helambu municipality stated that the NbS measures are simple, does not requires high technology. The measures can be implemented through mobilizing local community with the short training and demonstration;
- About 70% local representative in Panchpokhari-Thangpal Municipality noted that the NbS measures not only stabilized the slopes but also provided additional benefits such as fodders, fuel wood, and create job opportunities at local level;

- About 55% respondents of local government representative believes that the NbS (soil bioengineering) measures contributes to improve the degraded ecosystem and land that eventually improves the crop production thereby improves food security;

5.9.2 Local Community

The local community's perception of landslide protection measures is shaped by their lived experiences and the perceived benefits of these initiatives. They may appreciate the efforts made by local governments and other stakeholders in safeguarding their homes and livelihoods. However, challenges can arise in terms of community involvement, especially in construction projects that disrupt daily life. Effective communication and community engagement are essential to address these concerns and ensure that locals actively participate in landslide preparedness and mitigation efforts.

In contrast to the knowledge of the local government on the use of the NbS measures, local community are less confident on the use of the NbS to stabilized the unstable slopes. They think that the NbS (or the soil bioengineering) is less effective in protecting the slopes. They have their mind-set towards the structural measures such as gabion and stone/concrete retaining wall are the effective measures for slope protection.

Out of 622 HH surveyed in Helambu Municipality, about 42% (~261 HH) shows their interest on the use of NbS for slope and river bank protection. While in Panchpokhari-Thangplan the figure slightly higher with about 46% (~252 HH). The community perception toward NbS in the two municipality can be summarised as below;

- Majority of the respondents' response was that the NbS is less effective (~58% in Helambu and 54% in Panchpokhari-Thangpal) for slope protection. They think that the plant need longer time to grow and stabilize the slopes;
- About 85% respondents in Helambu and 80% in Panchpokhari-Thangpal municipality think that the NbS means only plant species;
- Majority of the respondents (over 85% in both municipality) were not aware about the multiple co-benefits of the NbS such as fodders, fuel woods, local job that the NbS measures can create;
- About 25% respondents (in both municipality) were owe that the NbS (or soil bioengineering) measures helps to improve the degraded ecosystems and water resources;
- About 15% (in both municipality) think that the NbS measures is time consuming and

involves costly activities;

5.10 Anthropogenic Actions Triggering Landslide Risks

Human activities can trigger landslide risks in these regions. Deforestation, improper land use, road construction, and mining can destabilize slopes and increase vulnerability to landslides. The perception of locals and authorities regarding these anthropogenic actions varies. Some may prioritize economic activities, while others advocate for responsible land management practices. Balancing development with environmental sustainability is a complex challenge, requiring collaborative efforts between communities, local governments, and relevant stakeholders to mitigate landslide risks.

Among the anthropogenic activity, rural road constriction is massive in both the municipality leading to frequent slope failure. The local reported that the non-engineered road construction is massively damaging crop land and road obstruction is frequent during monsoon season. Besides, excessive erosion, and river bank under cutting is also common in many places.

5.11 Opportunities and Challenges of Nature-based Solutions

Nature-based solutions (NbS) are actions inspired by, supported by or copied from nature that aim to help societies address a variety of environmental, social and economic challenges in sustainable ways (Faivre et al., 2017). Most NbS do not have a single objective, but aim to bring multiple co-benefits. The concept emerged in the 2000s to promote nature as a source of solutions to challenges associated with climate change. It has been supported and broadened by the International Union for the Conservation of Nature (IUCN) and later by the European Commission.

NbS present promising opportunities for landslide mitigation in these mountainous areas. Afforestation, reforestation, and wetland restoration offer sustainable options for stabilizing slopes and reducing landslide risks. However, challenges include the time required for these solutions to yield results and the need for continuous maintenance. Funding and community participation are also critical factors influencing the success of NbS. Nevertheless, these approaches align with environmental conservation goals and can contribute to long-term resilience.

5.11.1 Opportunity

Unlike conventional solutions, which tend to aim for a single objective, NbS can deliver multiple benefits. In turn, these benefits can ultimately increase societal resilience, in particular against the backdrop of climate change. For instance, the restoration of wetlands can contribute to increased carbon storage and flood protection, and the restoration of forest ecosystems can contribute to higher carbon storage and reduced risks of landslides and avalanches. In urban settings, NbS can contribute to the regeneration of previously neglected areas, protect the slopes and improve the degraded land and forest areas. The measures can contribute to reducing and/or avoiding costs of soil erosion and improves crop production. Besides, NbS can contribute to create job and promote green economy. Finally, NbS may create a new narrative associating biodiversity and ecosystem services on the one hand, and innovation for jobs and growth on the other, which could contribute to initiating transitions towards sustainability.

5.11.2 Challenges

There are knowledge gaps regarding the long-term effectiveness of NbS for climate change mitigation and adaptation, as well as regarding their impacts on the natural and social environment. The long-term impact and relationship to the social and societal environment is still to be assessed in the context of Nepal Himalayas. While the design of NbS measures and their implementation procedural are not very much clear at local level. In a number of instances, NbS can give rise to difficult trade-offs.

A number of challenges relate to the implementation of successful NbS, particularly in weak and poor socio-economic areas and the places where conventional measures are being known since long. A few barriers to NbS such as the fear of unknowns among the residents and local government decision and policy-makers; lack of long-term planning, implementation and maintenance processes associated with NbS; the non-alignment of NbS projects and the traditional structure of local government, and the tendency of increasing built-up areas, even when populations decline. On the one hand, decisions about acceptable levels of human intervention may be required in some cases, for instance in relation with geoengineering. On the other hand, NbS need to build on strong biodiversity and ecosystems, and cannot be a substitute for them. Finally, financing of NbS can be a challenge in the context of local government as they are more relaying on conventional development and structural measures in slope protection.

5.12 Landslide Early Warning System

Landslide early warning systems (LEWS) are vital to reduce the risk to the human lives particularly in the landslide prone mid-hill region of Nepal such as Helambu and Panchpokhari-Thangpal Rural municipality. LEWS if developed provide timely alerts to communities, allowing them to take precautionary measures when landslides are imminent. These systems rely on rainfall and soil monitoring, which offer valuable data for predicting landslide events. The effectiveness of early warning systems depends on factors like technology, community responsiveness, and communication channels. Public awareness and drills are essential components in ensuring that locals understand and heed these warnings.

The LEWS is limitedly known in Nepal in general and in particular in the two municipalities considered in this study. LEWS relays on the historical data of landslides, there casual and triggering factors, type of landslide among others. Historical landslide database is limitedly maintained in Nepal and so in the two municipalities has hampered in landslide related studies, developing landslide susceptibility map and LEWS.

More recently, the National Disaster Risk Reduction Authority (NDRRMA) has made effort to establish the database of the hazards and disaster events that also includes landslides. The local government and community people are very important to develop reliable landslide database. Until now, the municipality have not initiated maintaining the landslide database scientifically.

As discussed earlier section there is no LEWS established in the two rural municipalities (i. e. Helambu and Panchpokhari-Thangpal). However, pilot research on LEWS have been made in Neelakantha Municipality in Dhading and Bhimeshower Municipality in Dolakha under the support of TAYAR Nepal project of USAID. They have also development Standard Operating

Procedures (SOP) of LEWS. These LEWS as saying are developed for the geographical area (i. e. for the municipality level). Similarly, research is undergoing for a specific landslide site under the leadership of Water Resource Research Centre (WRRDC) of the Government of Nepal.

5.13 Indigenous Technology and Knowledge

Traditionally landslide mitigation in the rural municipalities were 1) traces management, diversion of the natural surface runoff away from the settlements, 3) dry stone wall (protection wall), stone rip-rap and 4) construction of drystone bank protection, 5) bamboo plantation. The local reported that techniques were now not in practices and the community largely developed on the Gabion Wall and stone masonry.

It can be said that the traditional techniques are mostly like Nature-based Solutions (NbS) which is now overlooking and not in practices. Among the several techniques, diversion of surface runoff away from the settlement is important to protect the settlement. The techniques are not in practices and are been modified either due to the construction of access road or other infrastructures. Similarly, there was practices of tail and terrace maintenance in the past that help to stabilized the slope. However, these activities are significantly reduced.

5.14 Landslide Susceptibility Assessment

Landslide susceptibility mapping (LSM) is a geospatial technique used to assess areas at risk of landslides. It involves collecting geological, topographical, and environmental data, often using Geographic Information System (GIS) tools and remote sensing. Statistical and machine learning methods are employed to create susceptibility models. These models generate maps categorizing regions by landslide vulnerability. The process of landslide susceptibility mapping typically begins with data collection, including geological data, rainfall records, topographical surveys, and land cover information. GIS tools and remote sensing technology play a crucial role in integrating and analysing these datasets.

In the preparation of a landslide susceptibility map (LSM), a suite of geographic and environmental factors is analyzed for their potential to influence slope stability. The slope of the terrain is crucial; steeper gradients are inherently more susceptible to landslides. Aspect determines the direction a slope faces and affects its exposure to solar radiation and precipitation, both of which play a role in slope integrity. Proximity to roads and streams is also factored in, as these can alter water drainage patterns and contribute to slope weakening or failure. Stream density further augments this analysis by highlighting areas where water flow is concentrated, potentially affecting soil saturation levels. Land use and land cover (LULC) data are integrated to assess human impact and natural vegetation cover, which can either mitigate or exacerbate landslide risk. Vegetation health, gauged by the Normalized Difference Vegetation Index (NDVI), offers insights into root strength and soil cohesion, which are vital for slope stability. The plan and profile curvatures, derived from the terrain model, indicate the shape of the landscape which influences water accumulation and soil movement. Soil texture is pivotal as it dictates moisture retention and permeability. The Topographic Wetness Index (TWI) and geological factors are used to assess areas of potential water accumulation and the underlying material strength, respectively. These factors are weighted based on their influence and integrated using GIS techniques to produce a landslide susceptibility map that delineates the varying degrees of landslide risk across the landscape. This map is invaluable for identifying high-risk zones, informing land-use planning decisions, and prioritizing areas for detailed investigation or remedial measures.

The LSM of the two municipality was then developed in GIS with the identified landslide pre-disposing factors such as slope, aspect, landuse, soil and geology, terrain wetness index, distance to roads, distance to drainage, rainfall, Normalized Difference Vegetation Index (NDVI) and drainage density (Figure 5-3 and Figure 5-4).

1. **Slope**: The slope map was prepared by calculating the angle of inclination from the DEM. Slope is a critical factor as steeper slopes are more prone to failing. The slope values were classified into ranges (e.g., gentle, moderate, steep) to aid in risk assessment.

2. **Aspect**: Aspect denotes the compass direction that a slope faces, affecting microclimate conditions on the slope. It was derived from the DEM and categorized typically into eight cardinal directions, each possibly having different exposure to elements like sun and wind.
3. **Distance to Road**: The proximity of land to nearby roads can influence landslide risk due to potential changes in water drainage patterns and slope alterations. The GIS measured the distance from each point on the map to the nearest road and classified the data into intervals, indicating varying levels of risk due to human activities.
4. **Distance to Stream**: Similar to the distance to roads, this factor measures the proximity to water bodies that could undermine slope stability. GIS tools calculated the distance from each grid cell to the nearest stream, and the results were categorized to reflect different susceptibility levels.
5. **Terrain Roughness Index (TRI)**: TRI helps in characterizing the terrain by quantifying its roughness. This information is valuable for understanding the landscape and identifying areas with complex topography. Rough terrain is often associated with increased susceptibility to landslides. Areas with high TRI values may have steeper slopes, rugged terrain, and other factors that contribute to landslide risk.
6. **Land Use Land Cover (LULC)**: Using classified satellite imagery, the LULC map was created to reflect different land uses, such as forests, urban areas, agriculture, etc. Each land use type influences water runoff and soil retention differently, affecting landslide vulnerability.
7. **Normalized Difference Vegetation Index (NDVI)**: NDVI, derived from satellite imagery, indicates vegetation health. It was calculated using the red and near-infrared bands of light, with the resultant values classified to show areas of dense vegetation which might contribute to slope stability.
8. **Plan Curvature**: Plan curvature, representing the curvature of the land surface in a horizontal plane, was calculated from the DEM. It affects surface water flow and sedimentation, with different curvatures suggesting varying runoff patterns and thus influencing landslide susceptibility.
9. **Topographic Wetness Index (TWI)**: TWI was computed from the DEM to represent how water accumulates across the landscape. It combines local slope and upstream area, indicating potential areas of water accumulation and saturation that could lead to landslides.

10. **Geology**: The geological map, often sourced from geological surveys, details various rock and soil formations, with each type digitized in GIS. These formations are significant due to the differing mechanical properties that affect slope stability.

11. **Profile Curvature**: This represents the curvature of the slope in the direction of steepest descent, affecting the flow velocity of water. Derived from the DEM, it was used to predict how water might accelerate erosion or deposition, influencing landslide risk.

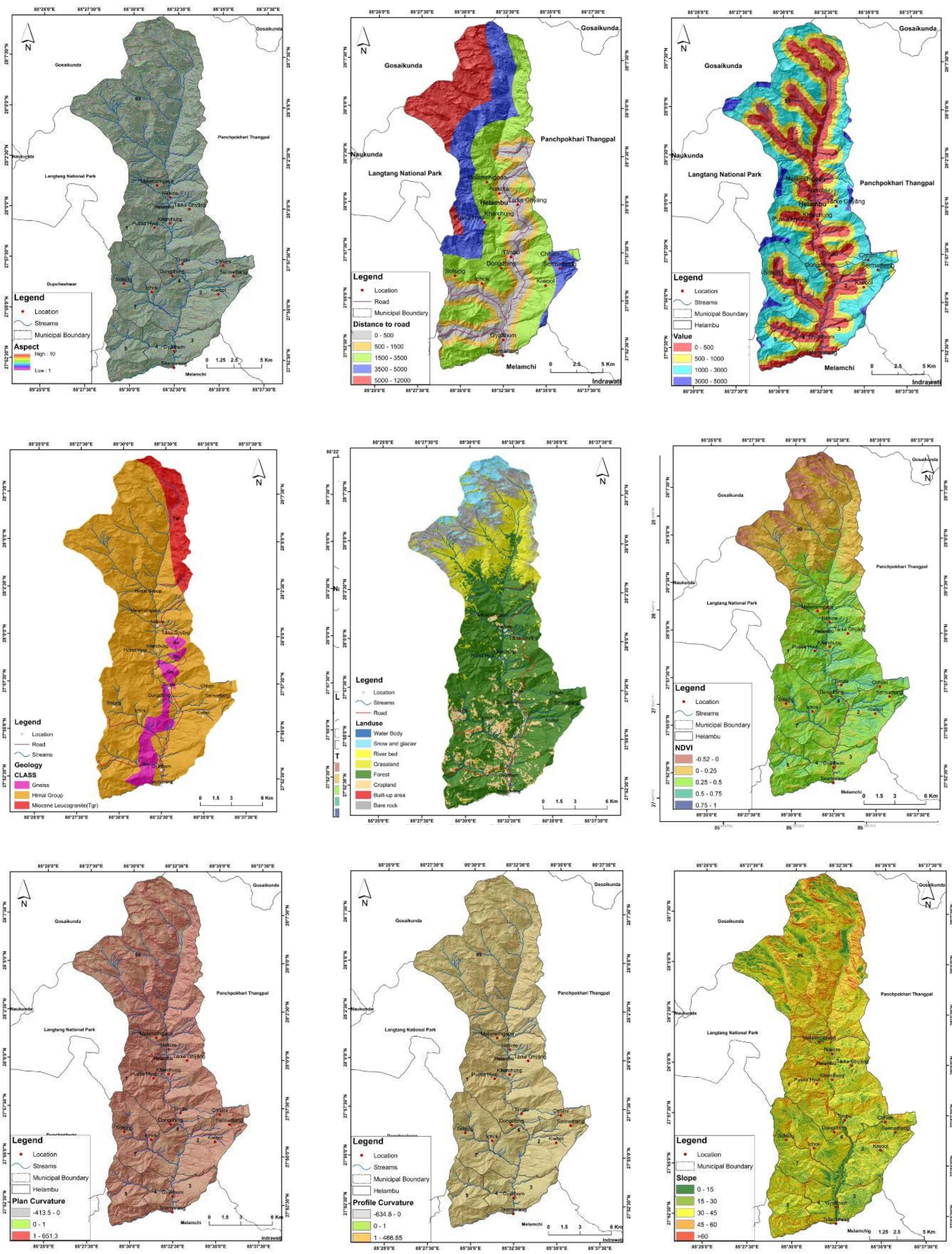
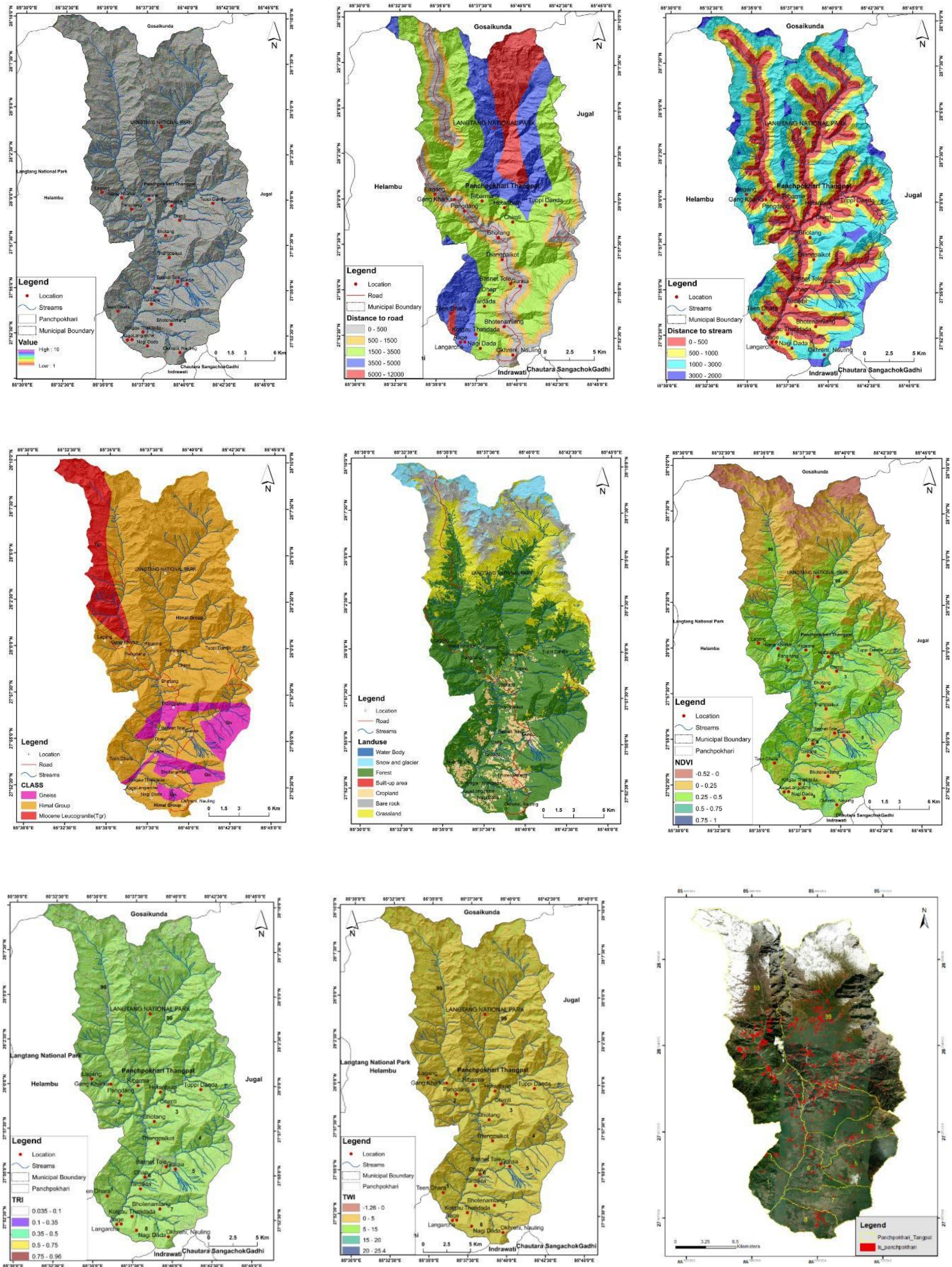


Figure 5-3. Landslide conditioning factors of Helambu Rural Municipality (A- Aspect, B-Distance to Road, C-Distance to drainage, D-Geology, E-Landuse, F-NDVI, G-Plan Curvature, H-Profile Curvature, I-Slope, J-Terrain Roughness Index and K-Terrain Wetness Index, L-LS Inventory.


Legend
Location
Streams
Panchpokhari
Municipal Boundary
Value
High : 10
Low : 1
Road
Distance to road
0 - 500
500 - 1500
1500 - 3500
3500 - 5000
5000 - 12000
Distance to stream
0 - 500
500 - 1000
1000 - 3000
3000 - 2000
CLASS
Gneiss
Himal Group
Miocene Leucogranite(Tgr)
Landuse
Water Body
Snow and glacier
Forest
Built-up area
Cropland
Bare rock
Grassland
NDVI
-0.52 - 0
0 - 0.25
0.25 - 0.5
0.5 - 0.75
0.75 - 1
TRI
0.035 - 0.1
0.1 - 0.35
0.35 - 0.5
0.5 - 0.75
0.75 - 0.96
TWI
-1.26 - 0
0 - 5
5 - 15
15 - 20
20 - 25.4
Gosaikunda
Jugal
Helambu
Langtang National Park
LANGTANG NATIONAL PARK
Panchpokhari Thangpal
Indrawati
Chautara SangachokGadhi
Panchpokhari_Tangpal
ls_panchpokhari

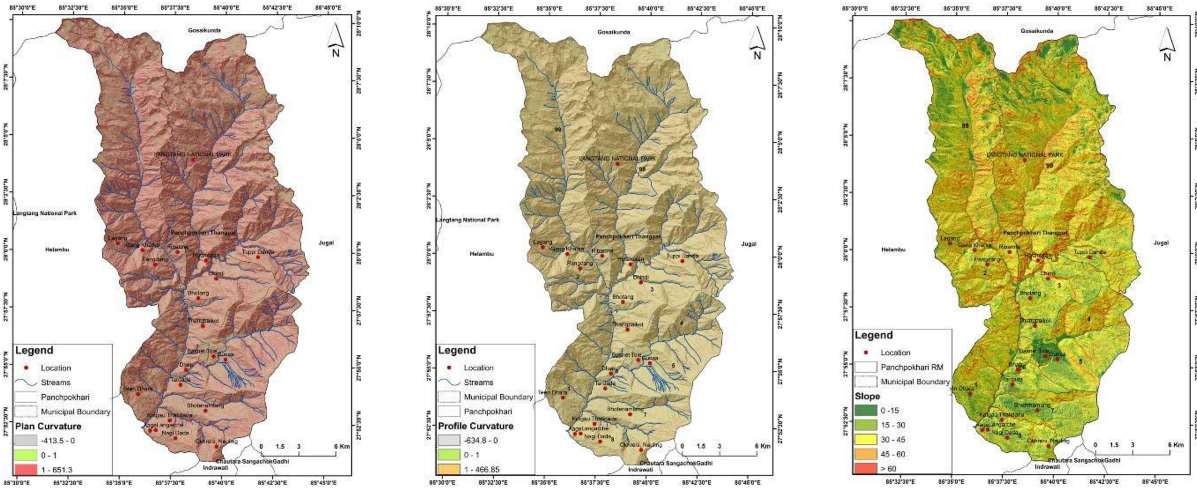


Figure 5-4. Landslide conditioning factors of Panchpokhari-Thangpal Rural Municipality (A- Aspect, B-Distance to Road, C-Distance to drainage, D-Geology, E-Landuse, F-NDVI, G-Plan Curvature, H-Profile Curvature, I-Slope, J-Terrain Roughness Index and K-Terrain Wetness Index, L-LS Inventory.

The LSM was developed implementing Frequency Ratio (FR) model in GIS environment depicted the following map (**Figure 5-5** A). The classified LSM illustrates different classes of landscape stability as shown in the following Table 5-10. In Helambu and Panchpokhari-Thangpal Rural Municipalities, with their steep terrain and heavy rainfall, this mapping informs that the slope failure is more pronounce in the upper reaches in the Langtang National Park. However, there are unstable places in the lower reaches where settlements are located such as Ward No 1, 2, 5 and 6 of Helambu and Ward No. 2, 3, 4, 5, 7 and 8 in Panchpokhari-Thangpal Municipality. The LSM model indicated that about 29% of Helambu and 31% of Panchpokhari is high to very highly susceptible to slope failure. Considerable area (~25.5%) is moderately susceptible in both municipalities. The moderately stable landscape is always critical as it could turn unstable if the rainstorm is above normal.

An effort was made to assess the model quality with the adoption of ROC and AUC. The measurements indicated that the predictive capacity of the model is about 80% and success rate is about 81% (**Figure 5-5** B).

Table 5-10. Landscape classes according to susceptibility.

Classification	Helambu		Panchpokhari-Thangpal	
	Area (km^2)	**%**	**Area (km^2)**	**%**
Very Low	33.3	19.8%	35.4	19.0%
Low	73.0	43.3%	81.5	43.7%
Moderate	29.5	17.5%	30.7	16.5%

High	25.7	15.3%	29.6	15.9%
Very High	6.9	4.1%	9.2	5.0%
Total	**168.5**	**100%**	**186.4**	**100%**

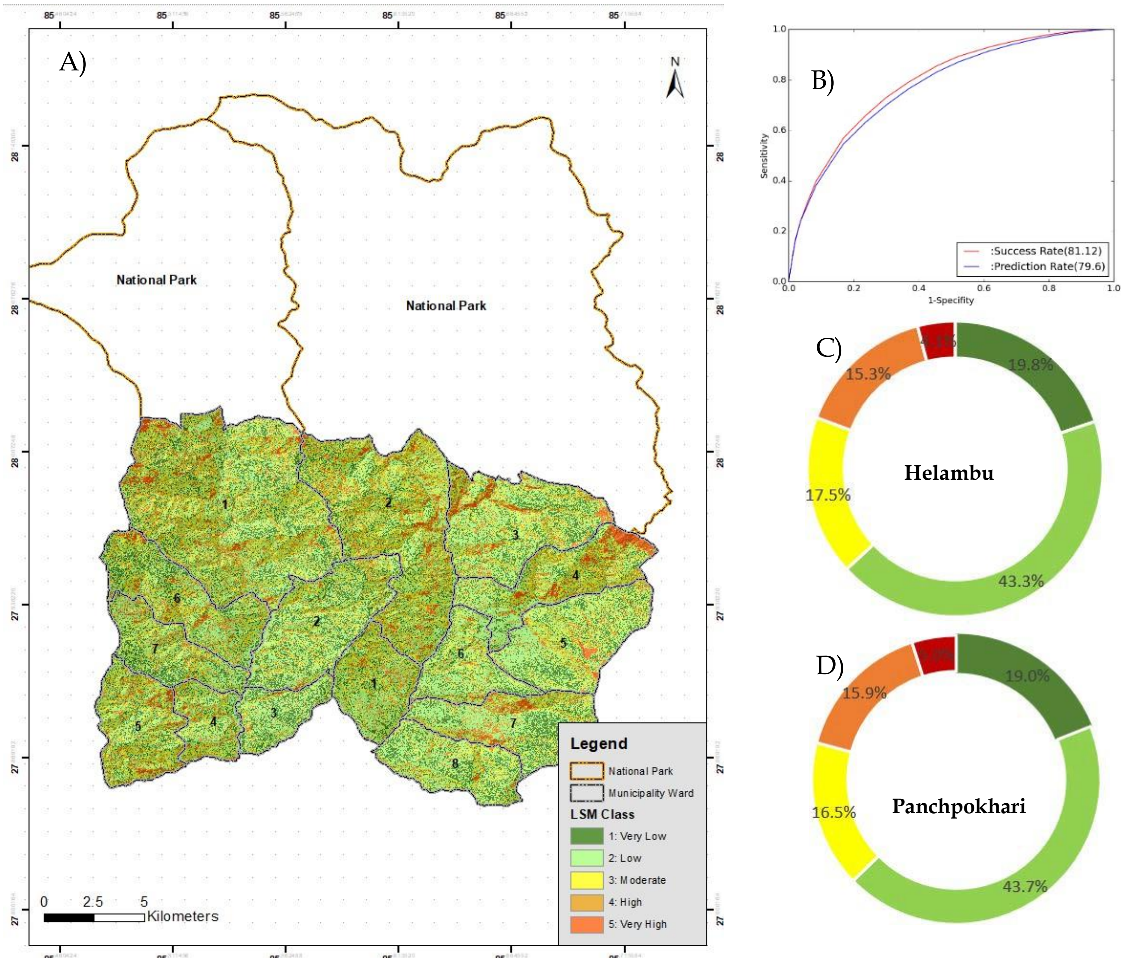


Figure 5-5. LSM map of Panchpokhari-Thangpal and Helambu RM; A-LSM, B-Accuracy assessment, C & D- Area under different classes of LSM.

The LSM was then classified for each ward of the municipalities (Table 5-11 and Table 5-12). The classification illustrates Ward No. 5, followed by Ward No. 1, 6, and 4 of Helambu and Ward No. 4 followed by Ward No, 2, 3 and 7 of Panchpokhari-Thangpal municipality were observed to be the most susceptible for landslides.

Table 5-11. Ward Level landslide susceptible area of Helambu.

Class	Area %						
	Ward 1	Ward 2	Ward 3	Ward 4	Ward 5	Ward 6	Ward 7
Very Low	17.75	25.85	32.38	15.39	13.66	19.03	21.81
Low	40.38	45.54	48.58	47.96	41.05	44.38	47.80
Moderate	19.45	15.01	8.77	17.77	21.44	17.41	14.02
High	17.18	11.73	8.52	15.30	18.65	14.97	13.22
Very high	5.23	1.87	1.76	3.58	5.20	4.20	3.16

Table 5-12. Ward Level landslide susceptible area of Panchpokhari-Thangpal.

Class	Area %							
	Ward 1	Ward 2	Ward 3	Ward 4	Ward 5	Ward 6	Ward 7	Ward 8
Very Low	15.96	13.73	20.78	14.46	23.04	21.78	23.46	25.06
Low	47.52	39.13	42.75	40.20	46.00	50.82	44.69	48.68
Class	**Area %**							
	Ward 1	**Ward 2**	**Ward 3**	**Ward 4**	**Ward 5**	**Ward 6**	**Ward 7**	**Ward 8**
Moderate	18.20	22.51	14.38	17.60	14.05	12.20	11.75	13.31
High	16.08	20.03	15.70	17.45	13.14	12.38	15.10	10.59
Very high	2.25	4.61	6.39	10.30	3.77	2.83	5.00	2.35

LSM is crucial for assessing and mitigating landslide risks in the municipalities. These maps inform that the local government should consider developmental activities and create awareness at community level for better land-use planning and disaster preparedness. Proper landuse planning will support reducing the vulnerability of communities to landslide hazards. In addition, by identifying high-risk zones, it enables targeted mitigation measures and enhances community preparedness through landuse planning, awareness and education and early warning systems.

5.15 Elements at Risks

Elements at risk in the context of landslides refer to the infrastructure, assets, and human activities that are potentially susceptible to damage or disruption in the event of a landslide. Identifying elements at risk is a crucial step in landslide risk assessment and management. The susceptibility of these elements depends on factors such as the type and magnitude of the landslide, local topography, soil conditions, and human activities.

Houses and Buildings: Residential and commercial structures located on or at the base of slopes are at risk of damage during a landslide. The vulnerability of buildings depends on factors such as construction type, foundation design, and the intensity of the landslide.

Infrastructure: Roads, bridges, tunnels, and other transportation infrastructure situated in landslide-prone areas are susceptible to damage or blockage. Landslides can disrupt transportation networks, causing significant economic and social impacts.

Utilities: Utility networks, including water supply systems, sewer lines, and electrical grids, can be affected by landslides. Disruption to these systems can lead to service outages, affecting communities and businesses.

Critical Facilities: Facilities such as schools, hospitals, and emergency services located in landslide-prone zones are at risk. Landslides can compromise access to these critical services, impacting community resilience during and after an event.

Crops and Agriculture: Agricultural areas on or near slopes may be affected by landslides, leading to soil erosion, loss of crops, and damage to infrastructure like irrigation systems. This can impact local economies and food production.

Cultural and Heritage Sites: Historical sites and cultural heritage can be at risk from landslides. These sites often have structures that are sensitive to ground movement and can be irreversibly damaged in landslide events.

Mining Operations: Areas with mining activities, especially those involving excavation on slopes, are at risk of landslides. Landslides can disrupt mining operations, leading to economic losses and potential environmental impacts.

Recreational Areas: Parks, campgrounds, and recreational areas located in landslide-prone regions may be impacted. Landslides can pose a threat to the safety of visitors and damage recreational facilities.

Ecosystems: Natural ecosystems, including flora and fauna, can be affected by landslides. Changes in terrain and soil conditions can disrupt habitats and have ecological consequences.

Human Lives: The most critical element at risk is human life. Residential areas and communities located in landslide-prone zones face the risk of injury or loss of life during landslide events.

This study considered two main elements: 1) buildings blocks/houses and 2) access road. Separate layers of building blocks were extracted from OSM and overlaid on top of LSM to assess their location state.

5.15.1 Households and Settlements

The building-block layer of the two municipality was prepared and extracted their sate of locations. The OSM depicted that about 15,704 building-blocks (building like structures) were found in Helambu and 15,582 in Panchpokhari-Thangpal municipality. The building-blocks includes Cow-Sheds, Schools, Health-posts, including the households (Figure 5-6).

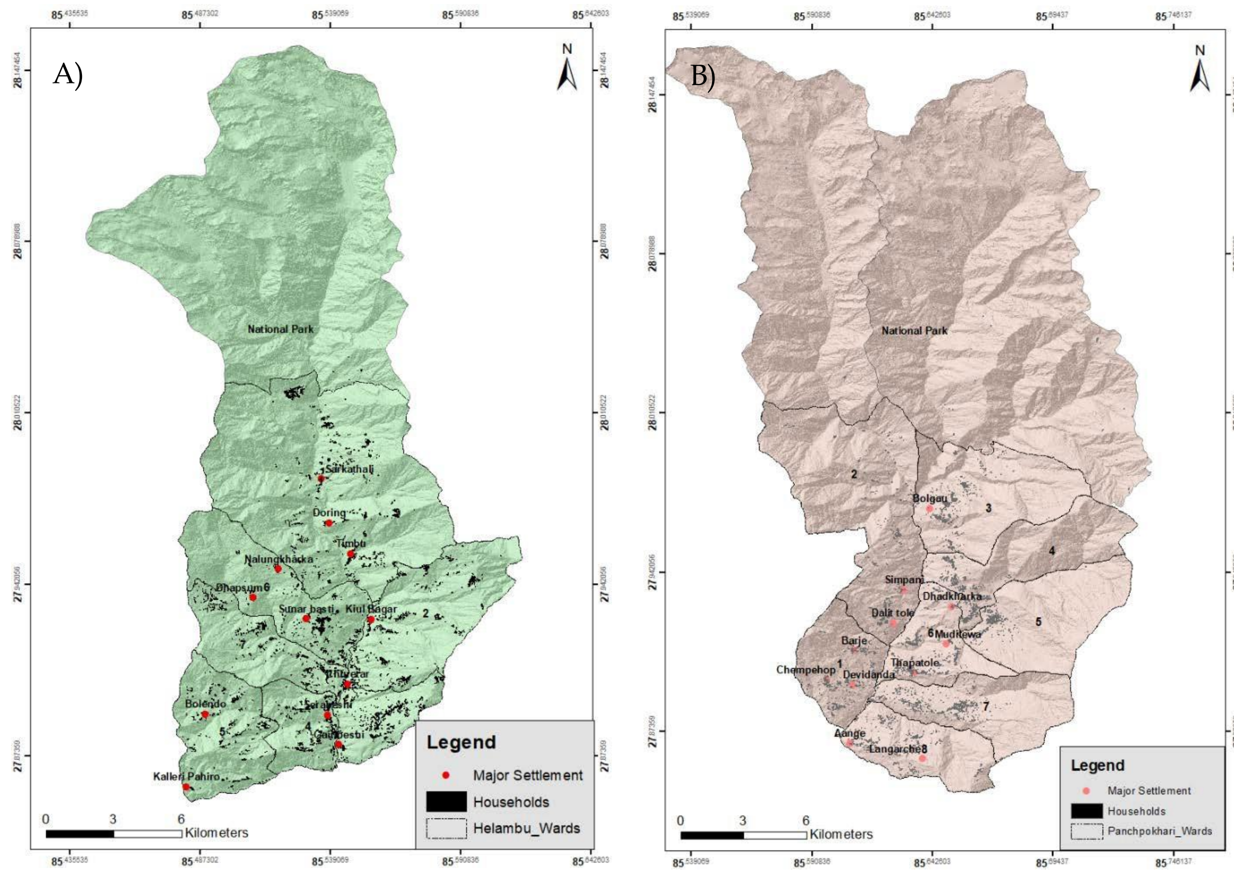


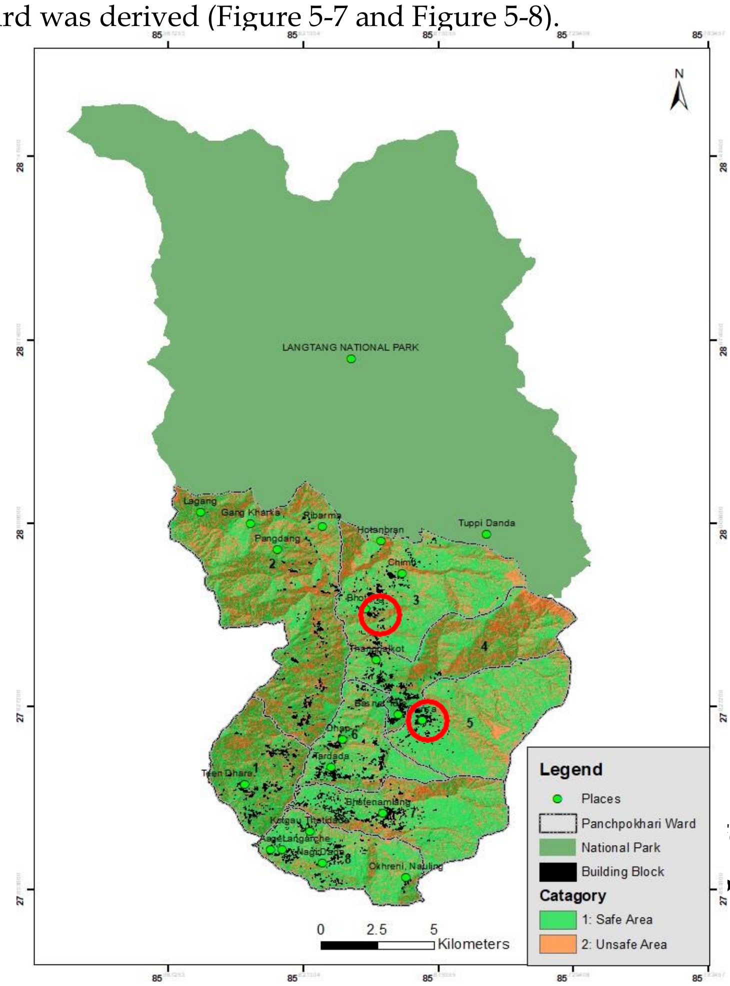
Figure 5-6. Building Blocks and Settlement maps, A) Helambu and B) Panchpokhari-Thangpal Rural Municipality.

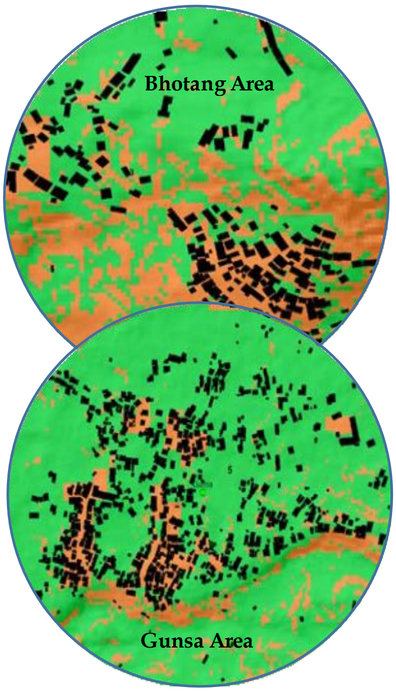
An effort was made to assess the safe landscape of the two municipality in terms of slope stability. The LSM and slope map was used to assess the safer area. The LSM and slope maps were normalized (0-1 scale) and over-lay operation was implemented in GIS with equal weight. The depicted map was than classified as safe and unsafe landscape (safe landscape = 0-0.35 and unsafe >0.35). The classification depicted the following results (Table 5-13).

Table 5-13. Safe and Unsafe landscape of the two rural municipality.

Municipality	Type of Landscape	
	Safe	Unsafe
Helambu	63.13%	36.87%
Panchpokhari-Thangpal	62.68%	37.32%

The safe and unsafe landscape area was further assessed for each wards of the municipality. Considering the ward as a single polygon (8 Polygons in Panchpokhari-Thangpal and 7 Polygons in Helambu) and over lay operation was performed and safe and unsafe landscape area for each ward was derived (Figure 5-7 and Figure 5-8).





e area in terms of slope stability in
ality.

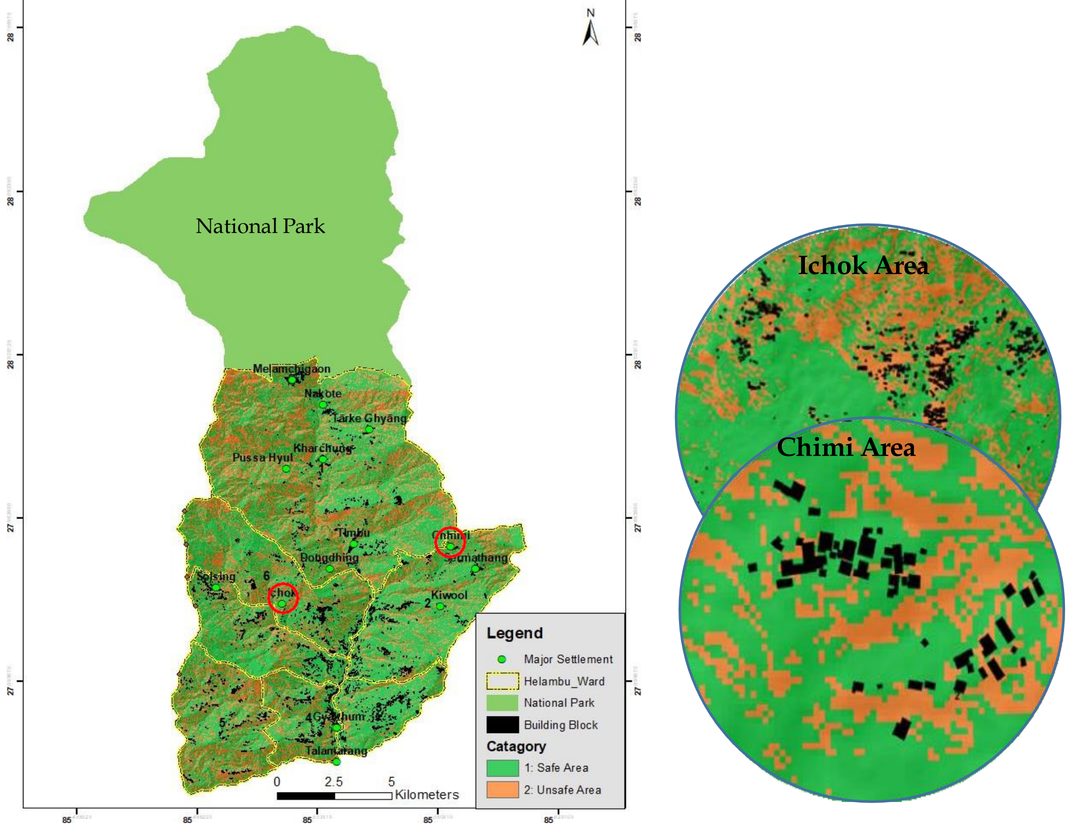


Figure 5-8. Example of HH/Building like structures and Safe Area in terms of slope stability in Helambu Rural Municipality.

Much of the building blocks are located in safer place (~11,333 in Helambu and 10,882 in Panchpokhari-Thangpal) as indicated in the model. However, there are buildings located in unsafe landscape. The analysis indicated that about 4,371 and 4,720 buildings blocks respectively in Helambu and Panchpokhari-Thangpal municipality are located in unsafe landscape. Considerable building blocks are located in moderately susceptible landscape (Table 5-9).

Table 5-14. Buildings/HHs or Building like structures susceptibility in the municipality.

Municipality	Type of Landscape	
	Safe Area % (HH)	**Unsafe Area % (HH)**
Helambu	63.13 (11,333)	36.86 (4371)
Panchpokhari-Thangpal	62.67 (10862)	37.32 (4720)

5.15.2 Access Roads

The road layers of the two municipality was prepared from the Google earth images (Figure 5-9) and the layer then overlaid on top of the LSM and extracted the road state in terms of the slope stability.

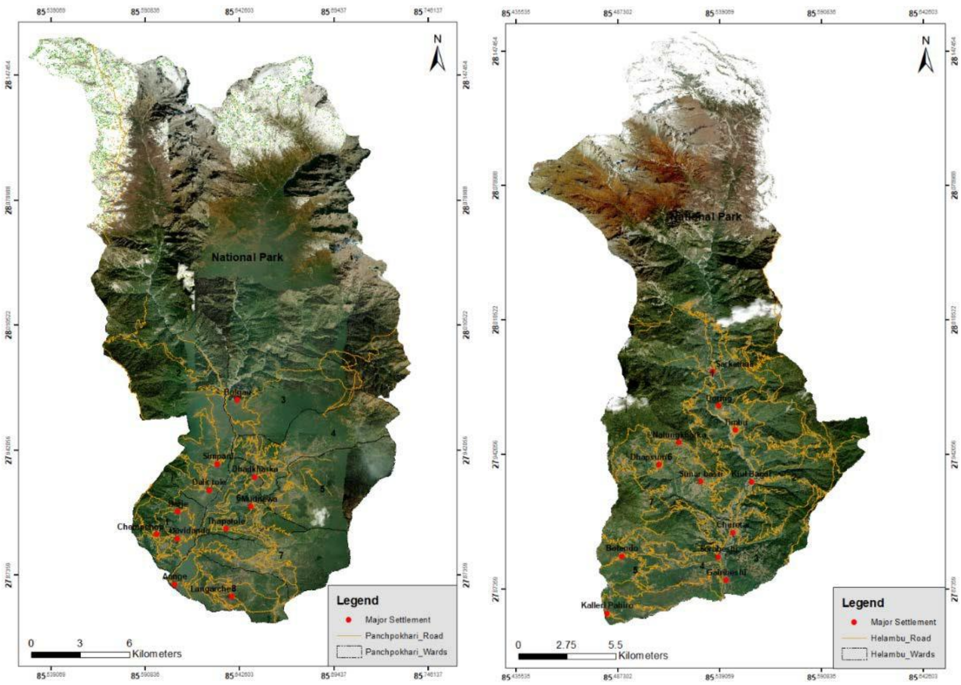


Figure 5-9. Road Network, A-Panchpokhari and B-Helambu Rural Municipality.

The estimated road length in Helambu is about 429 km and 387 km in Panchpokhari-Thangpal municipality. Out of which about 15 km in Helambu and 25 km in Panchpokhari-Thangpal is running through highly susceptible terrain followed by moderately stable terrain (74 km in Helmabu and 68 km in Panchpokhari-Thangpal). Considerable road length under moderately stable terrain which is critical that can easily turn unstable in case of monsoon rain in above normal (Table 5-10 and Figure 5-10).

Table 5-15. Road length passaging through different susceptible areas.

Road Susceptibility	**Road Length (km)**	
	Helambu	**Panchpokhari-Thangpal**
Low	339	294
Moderate	74	68
High	15	25
Total	**429**	**387**

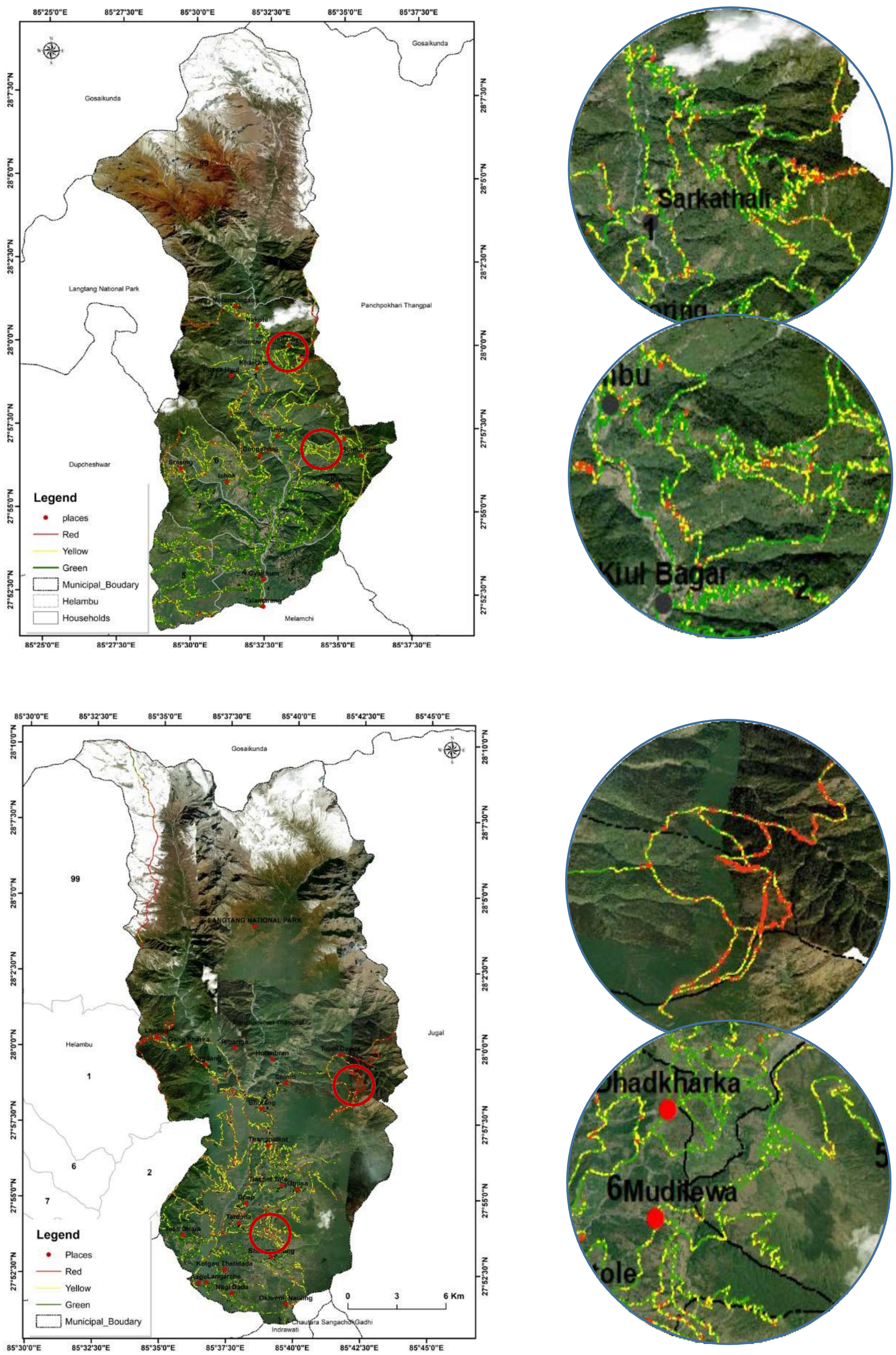


Figure 5-10. Susceptible roads alignment (note the red line indicated the high susceptible road alignment).

Section 6. Concluding Remarks

6.1 Conclusions

The picturesque landscapes of Helambu and Panchpokhari in Sindhupalchok, while captivating in their natural beauty, face the looming threat of landslides due to their moderate to highly susceptible terrain. These regions experience occasional rainstorms, which, combined with the underlying geology, human activities and soil, poses a significant challenge for assessing and mitigating landslide risks.

Rainfall in the area is characterized by its non-uniform distribution, and it stands out as one of the primary triggers for landslides. The variability in rainfall patterns heightens the vulnerability of the landscape, as even moderate rain events can lead to soil saturation and increased landslide potential.

Compounding this risk is human activity, notably unplanned rural road development, which has a considerable impact on slope stability. The absence of proper planning and construction practices exacerbates the susceptibility of the terrain to landslides, putting both the natural environment and human settlements at risk.

Recent assessments have indicated that a considerable area within the two municipalities is already marked as unstable, with a significant portion categorized as moderately stable. The moderately stable landscape is critical and poised to turn unstable under above-normal monsoon rainfall conditions. This adds a layer of urgency to the situation, as the upcoming monsoon seasons could bring heightened risks to the region.

While major settlements are currently located in stable landscape, caution is warranted. Moderate stability areas, although not classified as high-risk zones, have the potential to trigger landslides that could inflict damage on settlements, roads, and other critical infrastructure such as schools, health-care centres, water supply schemes among others. The need for comprehensive risk assessment, early warning systems, and sustainable land-use planning is evident to safeguard the communities inhabiting these vulnerable landscapes from the impending threat of landslides. Proactive measures are essential to minimize the impact of both natural factors like rainfall and anthropogenic activities on the stability of the region.

The table below presents the summery of the baseline study:

Table 6-1. Summary of baseline study.

Goal / Outcome / Output	Indicator	Baselined Figure

Reduced risk of landslide hazards to minimize loss of lives and damage of properties in Nepal	Number of human casualties reduced due to landslide in Helambu-Panchpokhari area (within 10 years' time period)	1 in Helambu and 23 missing (Memachi disaster); this was caused by the 2021 flood-debris flow of Melamchi River; No records were found in Panchpokhari-Thangpal
	Loss of properties due to landslide (NRP) in Helambu-Panchapokhari area	47.68 Million in Helambu; 25.73 Million in Panchpokhari-Thangpal
Goal / Outcome / Output	**Indicator**	**Baselined Figure**
Function of land slide EWS in Helambu-Panchpokhari area	# of people benefited by the project	No LEWS in these Municipalities they have Flood EWS
Developed a LEWS system and response mechanism in Helambu-Panchpokhari area	Strengthened impact-based forecasting system of LEWS in the target area.	**Helambu** – LEOC established, but they have developed disaster risk mitigation and management directives which is however salient on LEWS operation and installation; **Panchpokhari** – They are in process of establishing LEOC and CDMCs at ward Level, similarly they have developed situation analysis report of the municipality and has developed strategies.
	Rainfall threshold developed for landslide and debris flow	No
	Enhanced the capacity of community and local government for landslide risk reduction and tailored risk communication approach	No specific plan and procedural has developed

	Integrated LEWS (using citizen-science) into policy at all levels.	No
Identified and prepared a mapping of landslide risk	# of rainfall threshold for landslide constructed.	Identified 3 rainfall threshold developed, one is for the country level, the other two are for a catchment scale proposed for Rasuwa and Sindukhola
	Develop Early Action Protocol for landslides and debris flow	No
	# of landslide hazard and exposure mapping developed.	Landslide Susceptibility Model of the two municipality developed
	Establish weather stations	5 weather stations are installed in the surrounding of the two municipality,
	Developed landslide and debris flow threshold for project area	NA
	Develop risk polygon and disseminate SMS alerts	
Developed capacity on LEWS of communities	# of local government staff and community people trained on LEWS	No such training have been reported
Goal / Outcome / Output	**Indicator**	**Baselined Figure**
and local government	Establish LEOC/DEOC	Helambu- LEOC yet to be established; Panchpokhari-LEOC is established; DEOC at District level established
	# of small scale nature based solution established for DRR	NbS was adopted around the Melamchi Water Supply Scheme Intake area. There are no planned applications of NbS in both the Municipalities. Naturally grown plant species have established some of the landslides.
Generated evidence for LEWS	number of evidence on landslide forecasting	A few pilot research on LEWs have been observed in other part of the country but not in the two

policy advocacy	prepared	municipalities!

The important requirement of the LEWS to establish requires the policy of the local government, which is yet to be developed. Similarly, the high variation in rainfall due to effect of micro-climate in the region requires further research.

6.2 Recommendations

Addressing the landslide issues and problems in the Helambu and Panchpokhari Rural Municipalities requires a holistic and integrated approach that combines both structural (e. g. NbS) and non-structural (LEWS, education and awareness) measures. Here are some recommendations:

Refinement of LSM with the improved landslide database: Establish a comprehensive landslide hazard mapping system using advanced remote sensing and GIS technologies. Develop a historical landslide database to understand the patterns and triggers of past events, aiding in better prediction and mitigation efforts.

Early Warning Systems: Implement early warning systems that utilize meteorological data to provide timely alerts about potential landslide-triggering rainfall events. Establish a communication network to disseminate warnings to the local communities, enabling prompt evacuation and reducing the risk of casualties.

Land-Use Planning and Zoning: Enforce strict land-use planning and zoning regulations to restrict construction in high-risk landslide areas. Promote sustainable land-use practices and ensure adherence to building codes and standards to enhance the resilience of structures to landslide impacts.

Infrastructure Development and Maintenance: Prioritize and invest in the development of resilient infrastructure, especially in critical areas such as roads, bridges, and utilities. Regularly inspect and maintain existing infrastructure to ensure its stability and minimize the risk of landslides.

Community Awareness and Capacity Building: Conduct community awareness programs to educate residents about the risks of landslides and the necessary safety measures. Provide training for local communities on emergency response and evacuation procedures.

Vegetation Management: Implement afforestation and reforestation projects to stabilize slopes and reduce soil erosion. Promote sustainable agricultural practices that prevent deforestation and soil degradation.

Monitoring and Early Detection Systems: Install monitoring systems, such as inclinometers and ground sensors, in landslide-prone areas to detect early signs of slope instability. Conduct regular monitoring and maintenance of these systems to ensure their effectiveness.

Regulation of Human Activities: Regulate and plan rural road development to minimize the impact on slope stability. Implement measures to control and mitigate the adverse effects of unplanned construction and deforestation.

Research and Technical Capacity Building: Support research initiatives to further understand the geological and hydrological factors contributing to landslides in the region. Build technical capacity at the local level for effective landslide risk assessment and management.

Collaboration and Stakeholder Engagement: Foster collaboration among government agencies, local communities, non-governmental organizations, and researchers to address landslide challenges collectively. Engage stakeholders in decision-making processes to ensure that solutions are contextually relevant and sustainable.

By combining these recommendations into a comprehensive landslide risk management strategy, the Helambu and Panchpokhari Rural Municipality can work towards building resilience, reducing vulnerability, and safeguarding the well-being of their communities in the face of landslide threats.

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Annexes

85.409392 85.460424 85.511456 85.562488 85.613520 85.664552

28.145304 28.145304

National Park

28.076276 28.076276

28.007248 28.007248

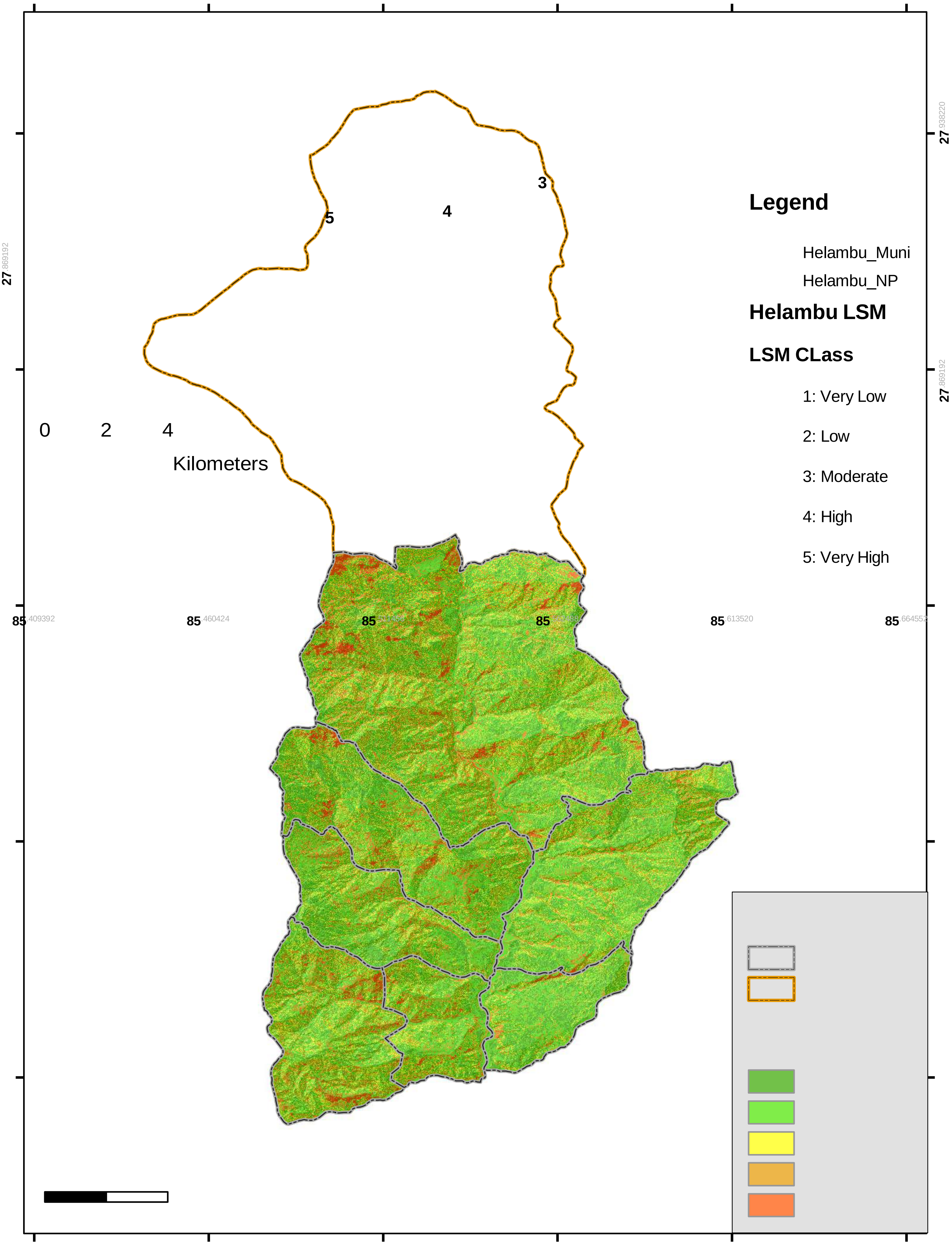
1

27.938220

6

7

2


Legend
Helambu_Muni
Helambu_NP
Helambu LSM
LSM CLass
1: Very Low
2: Low
3: Moderate
4: High
5: Very High
0 2 4
Kilometers
3
4
5
85.409392
85.460424
85.613520
27.938220
27.869192

85.511456 85.562488 85.613520 85.664552 85.715584 85.766616

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28.076276

National Park

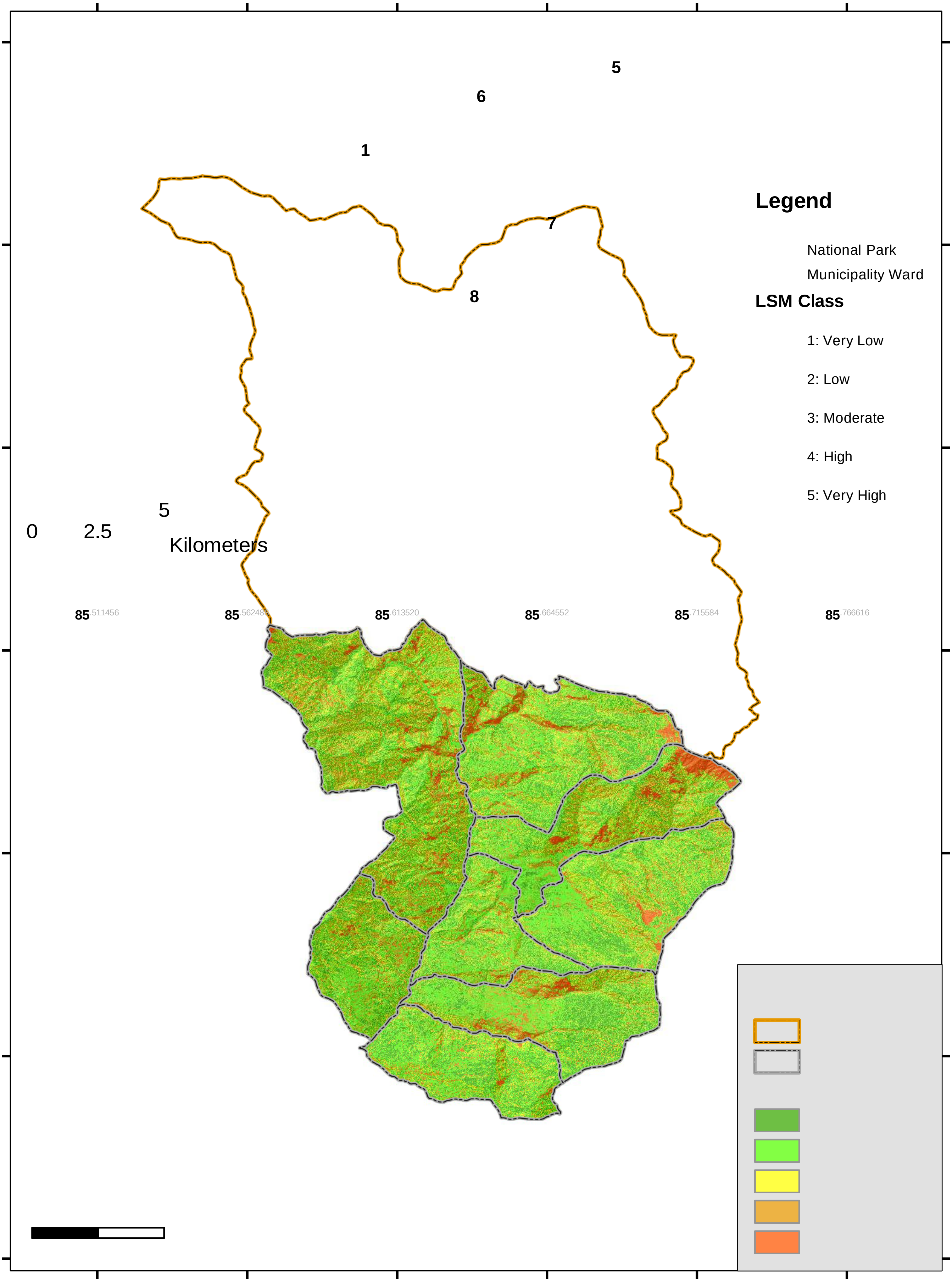
28.007248

2

3

4

27.938220


Legend
National Park
Municipality Ward
LSM Class
1: Very Low
2: Low
3: Moderate
4: High
5: Very High
0
2.5
5
Kilometers
1
5
6
7
8
85.511456
85.562488
85.613520
85.664552
85.715584
85.766616
27.869192
27.800164

85.438925 85.486220 85.533515 85.580810 85.628105

28.156575

28.092350

National Park

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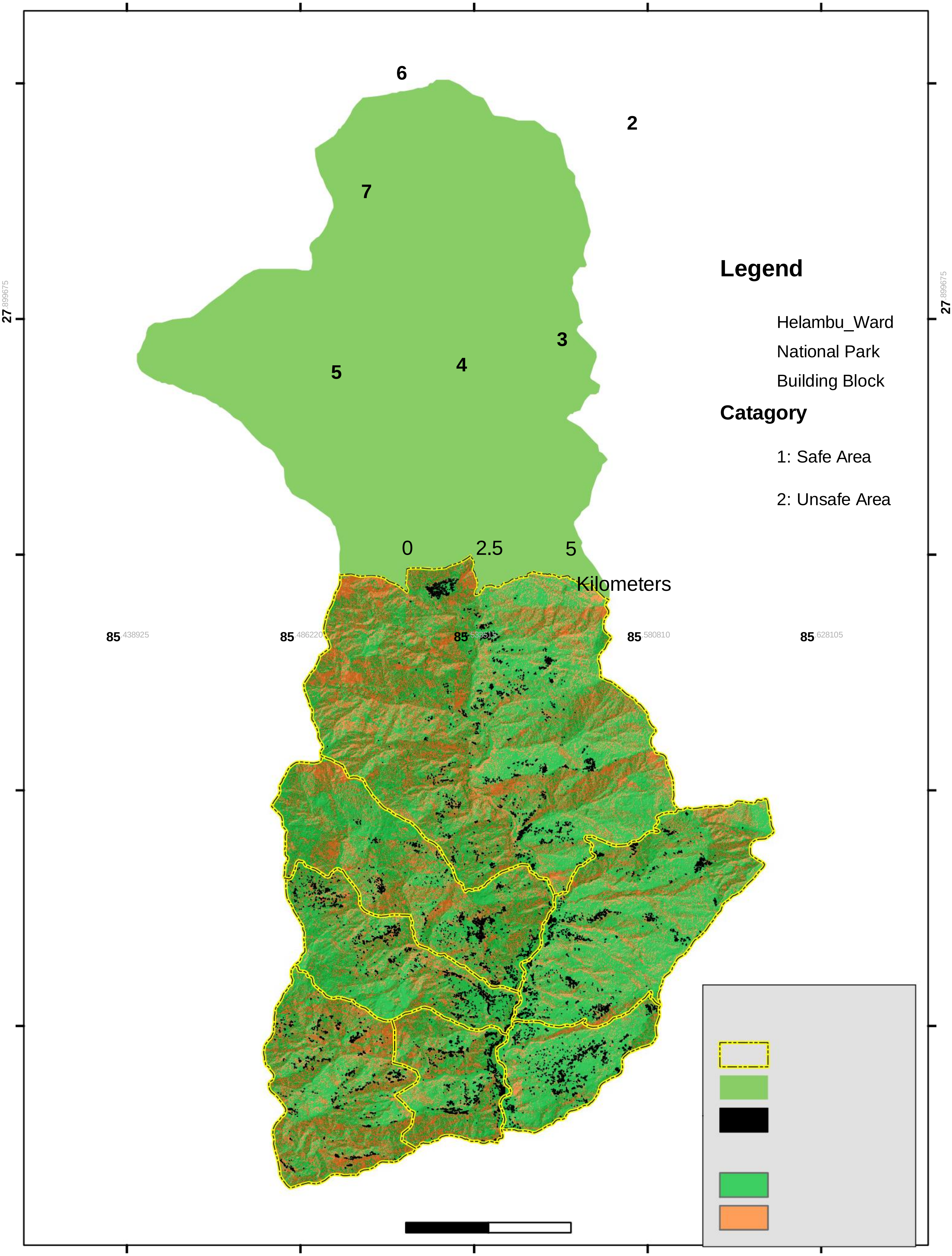
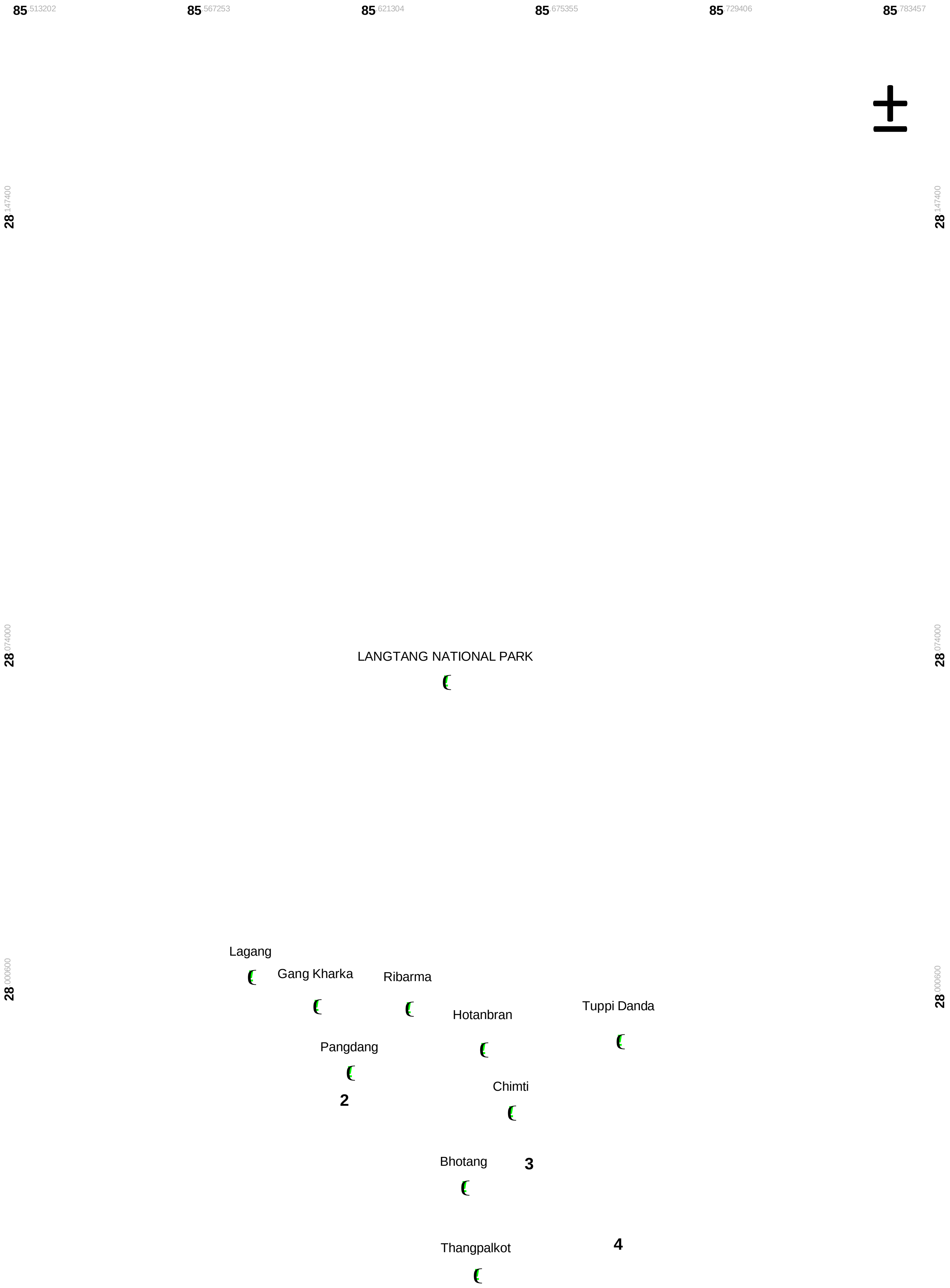
1

27.963900



6
2
7
3
5
4
0
2.5
5
Kilometers
Legend
Helambu_Ward
National Park
Building Block
Catagory
1: Safe Area
2: Unsafe Area
27 899675
27 899675
85 438925
85 486220
85 580810
85 628105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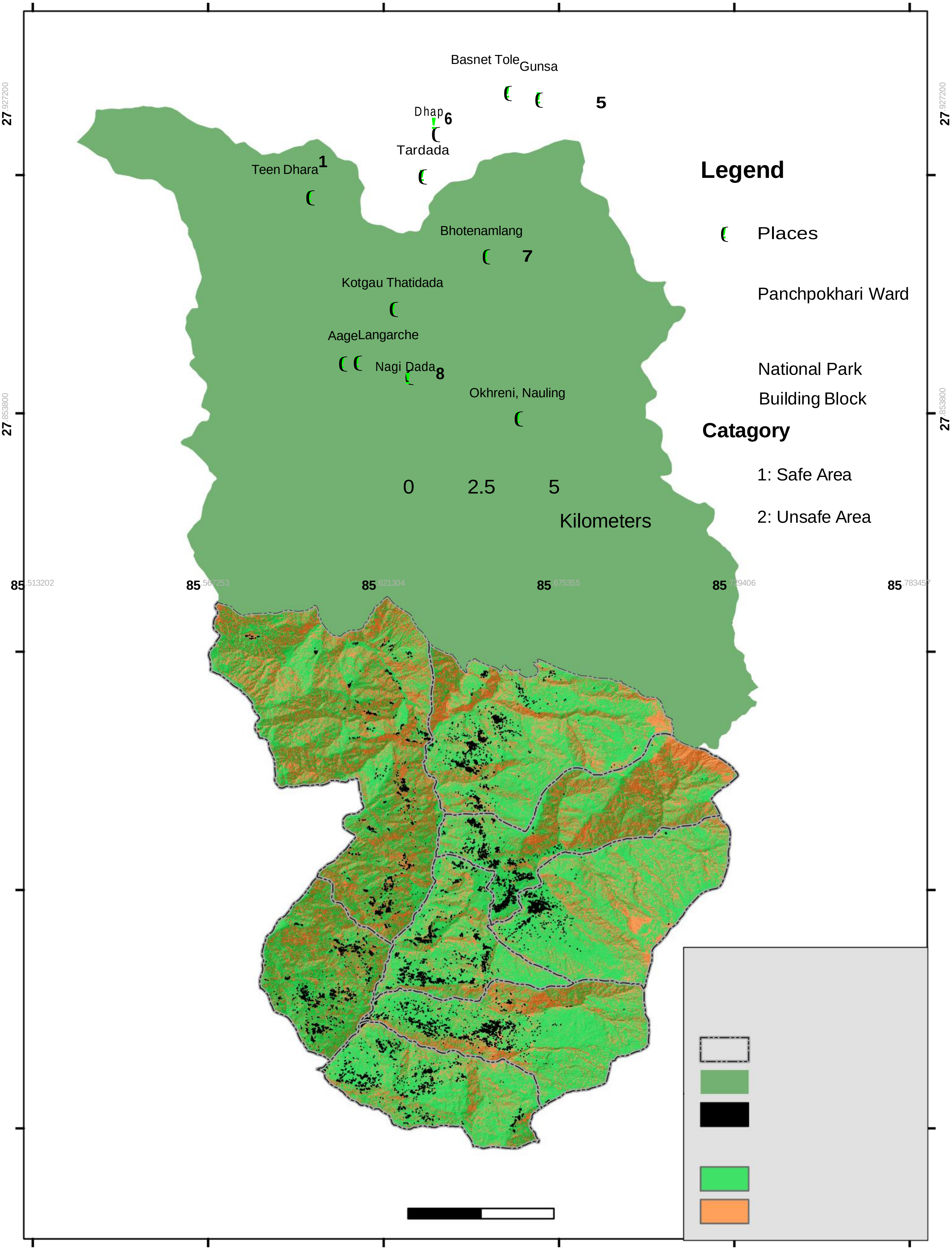
LANGTANG NATIONAL PARK
Lagang
Gang Kharka
Ribarma
Hotanbran
Tuppi Danda
Pangdang
2
Chimti
Bhotang
3
Thangpalkot
4



Basnet Tole
Gunsa
5
Dhap
6
Tardada
Teen Dhara
1
Bhotenamlang
7
Kotgau Thatidada
AageLangarche
Nagi Dada
8
Okhreni, Nauling
0
2.5
5
Kilometers
Legend
Places
Panchpokhari Ward
National Park
Building Block
Catagory
1: Safe Area
2: Unsafe Area
27 927200
27 853800
85 513202
85 567253
85 621304
85 675355
85 729406
85 783457