DEVELOPING THRESHOLDS FOR LANDSLIDES TRIGGERED BY RAINFALL IN SINDHUPALCHOK REGION

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Rainfall station at Manekharka, Panchpokhari © Practical Action/Prakash Chandra Timilsena

Acknowledgement

We are proud to publish this first ever report on "**Rainfall induced landslide thresholds in the Helambu-Panchpokhari region of Sindhupalchok"** and **facilitate the incorporation of these thresholds into the forecasting system of the Department of Hydrology and Meteorology (DHM).**

This report is an effort to minimize human casualties through the establishment and effective operation of the Landslide Early Warning System in Panchpokhari Thangpal and Helambu Rural Municipalities. Practical Action sincerely acknowledges the invaluable technical support provided by the **National Disaster Risk Reduction and Management Authority (NDRRMA), the Department of Hydrology and Meteorology (DHM) and the Department of Mines and Geology (DMG)**. Technical inputs and guidance from these institutions have played an instrumental role in standardizing this research and ownership. Additionally, we are grateful to DHM for providing technical support in the installation of rainfall station and for providing historical rainfall data for the analysis of rainfall threshold.

I am grateful to Panchpokhari Thangpal Rural Municipality and Helambu Rural Municipality for the constructive inputs for finalization of individual rainfall threshold, their ownership and their commitment towards rolling out rainfall threshold. I also appreciate the valuable time and participation of Ward Disaster Management Committees (WDMCs), ward chairpersons, Community Disaster Management Committees (CDMCs), and community members, throughout the data and information collection process.

I would like to express sincere gratitude to the Geotech Solutions International Private Limited, its research team and the lead expert, Prof. Dr. Ranjan Kumar Dahal for successful completion of this study. Their dedication, expertise, and commitment supported us in the realization of our research objectives.

Practical Action experts, especially Dr. Dharam Raj Uprety, and the project team Bina Khadka, and Pabina Khadka have actively engaged in rainfall threshold development, localization of the landslide risk knowledge at respective local and provincial governments and dissemination at national level. Our local partner, Community Development and Environment Conservation Forum (CDECF) Nepal, played a crucial role in coordinating with the local stakeholders, establishing rainfall threshold, sharing their knowledge and providing feedback on this report. Their commitment towards localizing the rainfall threshold is truly an exemplary work. Lastly, I extend my heartfelt thanks to all who played a part in this endeavor.

Pooja Sharma

Country Director, Practical Action in Nepal

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1. Introduction

Landslides are frequent occurrence in the mountains of Nepal. In monsoon season of 2023, Nepal's Disaster Risk Reduction Portal reported 494 landslides across the county leading 49 death 9 missing 62 injury and sever effect on 1969 family with loss of NRS 60 million.

Helambu-Panchpokhari region of Sindhupalchok, Nepal, is prone to rainfall-induced landslides due to its steep topography, unstable geological formations, and heavy monsoon rainfall. Landslides in this area pose serious threats to human lives, infrastructure, and the environment. To address these concerns, accurate and reliable rainfall-induced landslide thresholds must be developed and integrated into the Department of Hydrology and Meteorology's (DHM) forecasting system.

The purpose of this study is to identify rainfall thresholds for landslides in the Helambu rural municipality and Panchpokhari Thangpal rural municipality region by evaluating historical rainfall and landslides data. We can improve the DHM's early warning capabilities by determining the crucial rainfall intensity and duration that cause landslides. Integrating these limits into the DHM's forecasting system will allow for the prompt and effective transmission of landslide warnings, decreasing the impact of such disasters on local communities.

The broader goal of this project is to reduce risk of landslide hazards to minimize loss of lives and damage of properties in Nepal. The end investment outcome is functionality of landslide EWS in Helambu-Panchpokhari area. The intermediate outcome of this project is to develop a Landslide Early Warning System (LEWS) and response mechanism in Helambu-Panchpokhari area. There are four outputs of the project which are: a) identify and prepare a landslide risk map, b) develop risk measures and information mechanism, c) develop capacity on LEWS of communities and local government, d) generate evidence for LEWS policy advocacy. To achieve the aforementioned results, Practical Action carried out the comprehensive scientific modeling of landslide, debris flow and flood in Indrawati River watershed and Melamchi watershed, prepared susceptibility and vulnerability maps to aid the development of LEWS and understand the capacity of local government and communities to implement LEWS in the region.

The research has included a thorough examination of the current literature on rainfall-induced landslides, field surveys which collected data on previous landslide events, and statistical analysis to identify the rainfall thresholds. The work will also discuss the technique for adding these levels into the DHM's forecasting system, as well as make recommendations for enhancing the region's overall landslide early warning system.

1.1. Background

1.2. Study area

1.2.1. Location and accessibility

The area is located in the Sindhupalchok district of Nepal which is approximately 80 kilometers northeast of Kathmandu. This area is characterized by its rugged topography and high-altitude landscapes. Accessibility is primarily through trekking routes and road trails, with the nearest road access point being Melamchi. There are trails and roads connecting different parts of the region from Melamchi. However, accessibility can be problematic because of the remote area and difficult terrain, particularly during the monsoon season when landslides are more common. The location map of the area is given in the Figure 1.

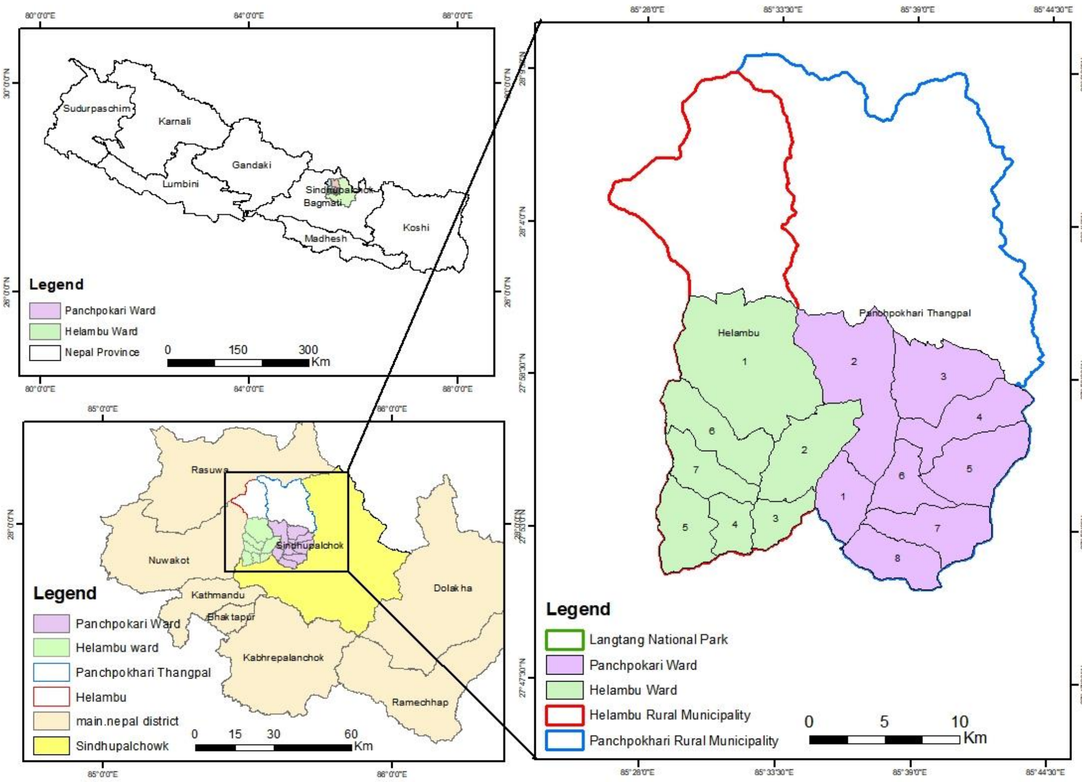

Figure 1: Location map of the research area

1.2.2. Socio-economy

The Helambu and Panchpokhari Thangpal areas have diverse socio-economic status mostly based on agriculture, trout farming, animal husbandry and tourism. Number of populations in this area faces challenges like limited healthcare access, blocked roads in monsoon, and uneven literacy rates.

In Panchpokhari Thangpal area, the population is 20,997, with a sex ratio of 102.22 males per 100 females. The population density is 112 people per square kilometer, and there are 5,914 households. The literacy rate is 57.7%, with a higher percentage of literate males (63.1%) compared to females (52.1%). Similarly, in Helambu rural municipality the area has a population of 17,497 with a balanced sex ratio of 100.75 males per 100 females. The population density is 61 people per square kilometer, distributed across 4,690 households. The literacy rate stands at 63.5%, with a higher literacy rate among males (69.3%) compared to females (57.8%) (National Population and Census 2021).

1.2.3. Climate and Vegetation

The area has an altitude between 1,500 and 4,100 meters above sea level, which contributes to its moderate climate. The region receives a significant amount of rainfall during the monsoon season (June to September), which leads to vibrant flowers and lush greenery. The average rainfall for Panchpokhari Thangpal Rural Municipality during monsoon is 3338 mm whereas for Helambu Rural Municipality, it is 3646.75 mm during monsoon. Winter (December to February) brings colder temperatures and snowfall, particularly in Panchpokhari, while autumn (October to November) offers clear skies and pleasant weather, making it perfect for trekking. Spring (March to May) is marked by vibrant rhododendron blossoms. This area has a variety of vegetation types, ranging from alpine meadows with wildflowers at higher elevations to subtropical forests with oak, pine, and rhododendron trees at lower elevations.

1.2.4. Geology

The area has a diverse geological landscape. Situated in-between the central Himalayas, it encompasses various rock formations, fault lines, and tectonic features. The geology of the area lies in the Higher Himalayan Zone. Regionally, this area consists of Higher Himalaya crystalline rocks such as gneisses, quartzites and marbles with dominance of migmatite and granite gneisses. The rocks around the study area are weathered to fresh metamorphic.

Figure 2, the geological map of Central Nepal shows that the selected municipality is primarily composed of Himal Group and Midland Group rocks which are primarily composed of garnet-biotite gneisses, kyanite biotite gneisses, garnetiferous mica schists, augen gneisses, micaceous quartzites, and thin bands of marbles.

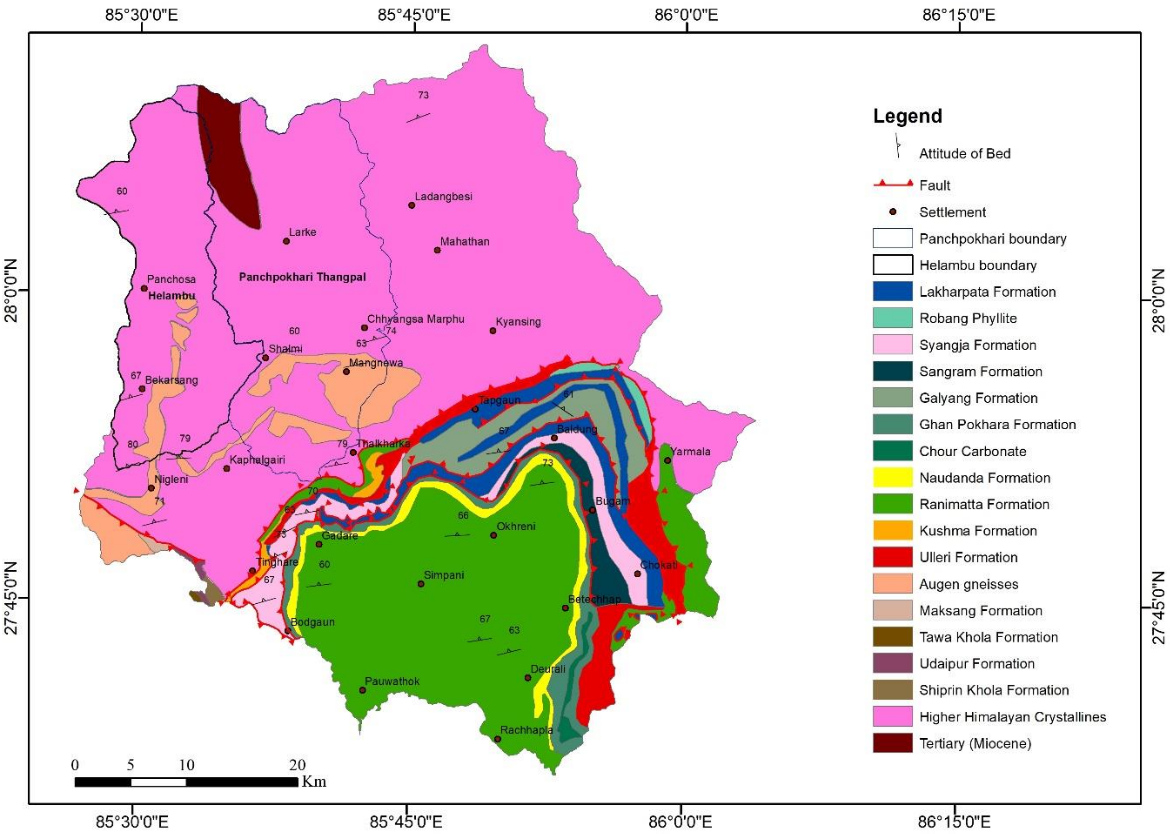

Figure 2: Geological map of the central Nepal including location of study area (after Geological map of central Nepal 1:250,000, DMG)

1.3. Objectives

The main objective of this study is to develop rainfall-induced landslide threshold covering the geography of two local governments (Helambu and Panchpokhari) of Sindhupalchok district and integrate the developed and validated threshold in the DHM impact-based forecasting system. The specific objectives are:

- To create a historical landslide inventory and to validate past major landslides using rainfall records.
- To investigate the correlation between geology, soil characteristics and rainfall patterns to establish landslide thresholds.
- To determine rainfall intensity and duration-based thresholds for landslide initiation, normalizing them for comparison.
- To analyze present outcomes in the context of regional and global thresholds, considering pre- and post-2015 Gorkha earthquake conditions.

- To develop landslide risk maps on the basis of vulnerability and exposure data, along with recommendations for adaptation and mitigation.
- To share findings through a national-level workshop.

1.4. Scope of work

The main scope of this work is to develop rainfall threshold for landslide in Helambu Rural Municipality and Panchpokhari Thangpal Rural Municipality. The work is grouped into the following tasks:

- Develop rainfall-threshold for landslides in the study area in consensus with government authorities mainly with DHM, the Department of Mine and Geology (DoMG) and NDRRMA.
- Test rainfall induced landslide threshold in the monsoon 2024 working closely with DHM.
- Identify wards/ communities that are at recurring risk of landslides and population impacted by landslides of two local governments.
- Identify most vulnerable settlements through a detailed exposure and vulnerability study.
- Understand communities' and local government's ability to communicate the LEWS generated from DHM with clear and concise roles and responsibilities.

2. Methodology

The overall methodology of the research is given below in Figure 3.

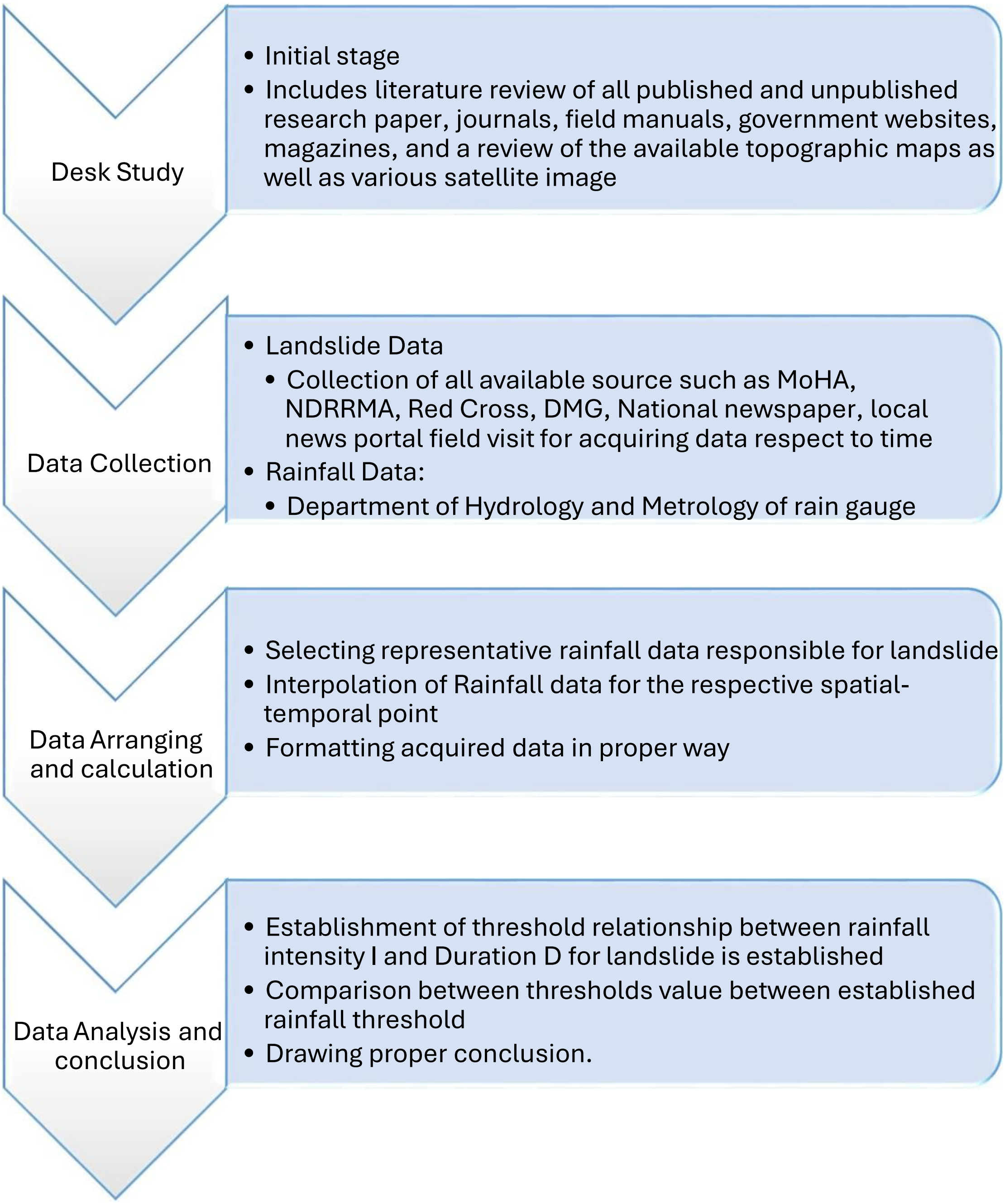

Figure 3: Methodological framework of the research in various phases

2.1. Desk study

First, a literature review and collection of available data, especially for rainfall and landslides, were conducted. During the review, research articles, peer-reviewed journals, published and unpublished reports were reviewed. Various datasets for landslide inventory, such as the BIPAD portal of National Disaster Risk Reduction and Management Authority (NDRRMA), base report of the project, data collected by local level police officer, etc. were reviewed. For rainfall data, the nearest rainfall or weather station of DHM and ICIMOD data around the selected municipalities/rural municipalities were listed and collected. Topographic/DEM data from the Department of Survey were collected. Additionally, geological and engineering geological information was consulted from the Department of Mines and Geology (DMG).

2.2. Data collection

2.2.1. Primary data collection

It involves documenting past landslide events through field observations and interviews with local residents. Landslide occurrence date and visualization of landslide that has been set up during the inventory was crucial for the finding along with new landslide. Field study was conducted for 7 days to ensure the accuracy and comprehensiveness of the information gathered. Visiting all area was possible during field visit, asking old people and victims for the date of occurrence of the landslide. The data collected from the field is shown in Annex 1.

2.2.2. Secondary data collection

It involves reviewing existing data from meteorological departments or weather databases. It also involves analyzing satellite imagery and aerial photographs to identify changes in land cover and topography. Similarly, maps and past research were studied to gain a better understanding of the area's geological and slope characteristics. The secondary data is tried to check in field verification and the genuine source is considered as the positive data for the research. The secondary data collected is shown in Annex 2.

2.3. Landslide inventory

Landslide inventory is one of the most important data sources for threshold calculations. Many landslide inventory data for the selected area are available, after Gorkha Earthquake in 2015. Practical Action's local partners in selected communities have collected landslide information, providing us with the most accurate data available. The initial phase of the data collection includes creating a landslide inventory using Google Earth. This remote sensing technique enabled the identification and mapping of landslide occurrences in the research area. Following the creation of the inventory, field visits were performed to confirm the landslides caused by rainfall. During these field visits, the details of the landslides were rechecked by observations on the ground. The inventory map prepared in different phase is shown in Annex 3.

2.3.1. Selection of landslide for threshold

Determining the precise spatial-temporal distribution of landslides in Nepal is challenging due to the absence of a reliable governing body responsible for collecting accurate data. To address this issue, a comprehensive dataset was compiled from various reputable sources to enhance the accuracy of the landslide catalogue. This dataset incorporates information from field visit, government publications (like the NDRRP 2023), newspaper articles, scientific journals, NGO reports, and social media platforms such as YouTube, Facebook, and Twitter, along with personal inquiries. Some photographs that represent the work in field for collecting the landslide spatiotemporal data with its time distribution is shown in Annex 4.

2.4 Rainfall data

In Nepal, the Department of Hydrology and Meteorology (DHM) is the authorized authority for providing rainfall data. To obtain this data, the nearest rainfall station to the study area is first selected, and the data is then requested from DHM, considering the timing of the landslide occurrence. Historical rainfall records for specific weather stations within the study area were purchased from DHM, covering the relevant time period. This enabled an analysis of rainfall patterns and their correlation with landslide occurrences. Selection of rainfall station is shown in Table 1.

Table 1: Station selected for rainfall data

Name	Index no	District	Lon	Lat	Elv
Thamachit	1054	Rasuwa	85.30183889	28.18352222	1770
Dhunche	1055	Rasuwa	85.3076915	28.1053174	2005
Nuwakot	1004	Nuwakot	85.1648105	27.9151267	966
Tarkeyghyang	-	Sindupalchok	85°33'11"	27°59'57"	
Tarke Ghyang	1058	Sindupalchok	85.554444	27.9981054	2596
Dhunge	101602	Sindupalchok	85.5056545	27.9493782	2500
Sarmathang	1016	Sindupalchok	85.59513611	27.94456111	2574
Dhap	1025	Sindupalchok	85.633379	27.9124519	1284
Dhap(tarnamlang)	1078	Sindupalchok	85.6328963	27.901559	1362
Duwachaur	1017	Sindupalchok	85.56695	27.8583681	1483

Name	Index no	District	Lon	Lat	Elv
Bahunipati	1018	Sindupalchok	85.57264583	27.79248889	774
Nawalpur	1008	Sindupalchok	85.6241	27.81306111	1653
Gumthang	1006	Sindupalchok	85.8589011	27.8576885	1846
Chautara	1009	Sindupalchok	85.7313911	27.7543909	1552
Melamchi ghyang	100699	Sindupalchok	28.010525	*85.31 2606*	2548
Bolde	100696	Sindupalchok	27.560434	*85. 39 0723*	1832
Bhotang	101601	Sindupalchok	27.965573	85.6468599	1872
Manekharka	100698	Sindupalchok	27.861388	85.671345	1745
Gobre	100695	Sindupalchok	27.861388	85.671345	2420
Banskharka	100697	Sindupalchok	27.894152	85.598294	1660

Data from DHM was obtained from the above-mentioned station. Rainfall data from station Nuwakot from Nuwakot district, Dhunche, from Rasuwa district Baunepati, Nawalpur, Duwachaur, Sarmathang, Thamachit, Chautara, Tarke Ghyang, Dhap(tar-namlang) from Sindhupalchok district was obtained for daily frequency and Gum-thang AWS and Nuwakot station have its hourly rainfall data from 2022 only.

2.5 Report preparation

After collecting rainfall data and landslide data, the threshold equation is calculated by treating rainfall data with respect to landslide time using equation given by Shakya (2002), and ArcGis for interpolation of the data. Then boot strapping technique is used to expand the data range from the collected data. After finalization of threshold and landslide susceptibility map, the report is written in a good format.

3. Landslide susceptibility

The landslide hazard zonation of the research area is determined using ArcGIS. It is a remote sensing and geographic information system software that combines images, vectors, and thematic data into a single, powerful package. The method used is Information value (Info Val) bivariate method.

3.1. Thematic Map

The causative factors included in the landslide hazard mapping of study area are slope, aspect, curvature, relief, distance to river, distance to road, distance to fault, land use and sediment transport index (STI). The landslides for analysis of landslide hazard, historical landslide of 1990 to 2023 were taken as inventory and recent position and landslides of 2024 were used for the validation purpose.

3.1.1. Aspect map

The aspect map shows the direction and steepness of the slope for a terrain. The steeper slopes are brighter in color. Mainly aspect of slope comprises nine group. The aspect differentiated in this study are flat, North, North-East, East, South-East, South, South-West, West and North-West. The aspect map of the area is shown in Figure 20.

3.1.2. Curvature map

Curvature map represents the rate of change of slope and is the second derivative of elevation. The slope comprises three class of curvature. It shows the convexity or concavity of the slope surface (Figure 4). The curvature of slope of the area is classified to convex, planar and concave as shown in Figure 21 where A represents the Convex, B represents the concave, and C represents the planar curvature.

3.1.3. Relief Map

Relief map shows the landscape terrain and elevation using the shape and height of the slope usually by the means of its contour. As the inventory of landslide, the occurrence of landslide is taken for classification of relief. The classified relief map has 5 classes as <2000 m, 2000-2500 m, 2500-3000 m, 3000-4000 m and >4000 m. The relief map of the area is shown in Figure 22.

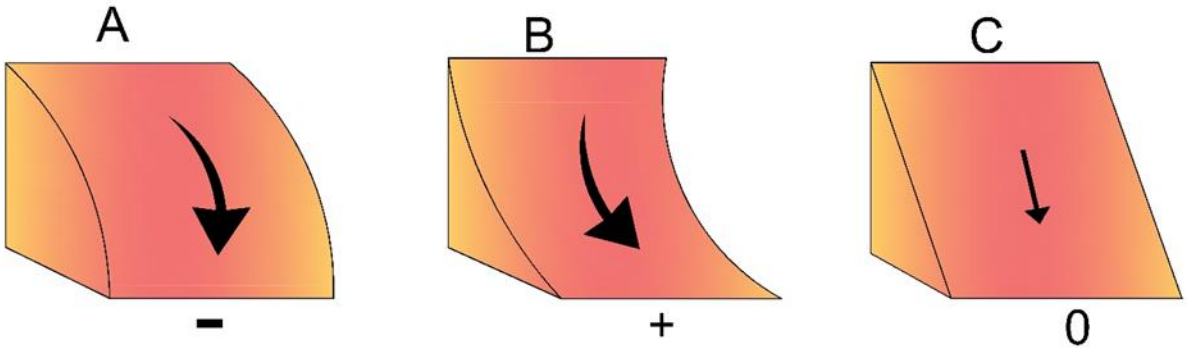

Figure 4: Schematic representation of the curvature of slope

3.1.4. Distance to River

The distance to river map is classified into five classes as <100 m, 100-200 m, 200-350 m, 350-450 m and >450 m as shown in Figure 23. As distribution of the pixel data of river distance, the thematic map has classified by equal distribution of data.

3.1.5. Distance to Road

The distance to road map is classified into five classes as <1100 m, 1100-2500 m, 2500-4500 m, >6400 m as shown in Figure 24. Equal distribution of data has been used to classify the thematic map's pixel data on river distance.

3.1.6 Landuse Map

The land use or landcover map of the area include Forest, Bare land, Rocky terrain, Built Up area, Snow cover rocky terrain, Glacier, Water bodies and Crop land as shown in Figure 25. Equal distribution of data has been used to classify the thematic map's pixel data on river distance.

3.1.7 Slope Map

A slope map is a topographic map which shows the changes in elevation in detail. The slope within the area varies from 0 to 60° degrees which was classified into different categories as <15°, 15-30°, 30-45°, 45-60°and 60-88° as shown in Figure 26. Equal distribution of data has been used to classify the thematic map based on the slope of the pixel data. The pixel data on river distance in the themed map has been categorized using an equal distribution of data.

3.1.8 Sediment Transport Index

Sediment transport index map helps to understand about the process of erosion and deposition distance to which sediment can be transported by the river or stream. Sediment transport index map relies on flow direction and flow accumulation map. The thematic map's classification of the sediment movement index factor's pixel data is based on an equal distribution of data. The pixel data on river distance in the themed map has been categorized using an equal distribution of data. The map is classified to five categories as <1.34, 1.34-2.36, 2.3 6-5.35, 5.35-6.35 and >6.35 m as shown in Figure 27.

3.1.9. Landslide Inventory Map

Landslide inventory map refers to the location, its distribution and characteristics of the past landslides. A total of 213 landslide of Panchpokhari Thangpal rural municipality and 755 of landslide of Helambu rural municipality were mapped using Google Earth Pro for inventory purposes between 1990 and 2023. The landslide inventory map of the area for analysis of landslide hazard map is shown in Annex 3.

3.1.10. Landslide susceptibility map

Landslide susceptibility mapping is a vital tool in assessing and managing landslide risks within a region. By categorizing areas into susceptibility zones ranging from very low to very high, the prepared maps provide a clear visual representation of where landslides are more likely to occur. The process integrates field data, remote sensing, and GIS analysis to evaluate factors such as slope steepness, soil composition, and geological formations. The map in Figure 13 illustrates how different zones are classified based on their risk levels, identified for their varying degrees of susceptibility. Such maps are crucial for informing land-use planning, infrastructure development, and disaster risk management, ensuring that high-risk areas are appropriately addressed to mitigate potential landslide hazards. The region is classified into five zones based on susceptibility Figure 28:

- Very Low Susceptible Zone (Green): This zone represents areas where the likelihood of landslides is minimal. These regions are often flat or gently sloping, with stable geological formations.

- Low Susceptible Zone (Light Green): These areas have a low risk of landslides, which might occur under specific conditions such as heavy rainfall or minor seismic activity.
- Moderate Susceptible Zone (Yellow): This zone has a moderate risk, indicating that landslides are more likely under certain triggers like intense rainfall or minor earthquakes.
- High Susceptible Zone (Orange): Areas in this zone have a significant risk of landslides, often due to steep slopes, unstable soils, and fractured rock formations.
- Very High Susceptible Zone (Red): This zone represents the highest risk areas where landslides are very likely to occur. These regions usually have steep slopes, loose or weathered materials, and are prone to frequent landslides.

The landslide susceptibility maps for Helambu and Panchpokhari Thangpal rural municipalities have been developed to identify areas prone to landslides in each ward. The map categorizes the susceptibility levels into low, moderate, high, and very high. The color-coded zones visually represent the degree of susceptibility where red color representing higher risk. Ward-1,4,5,6 of Helambu rural municipality and ward-1,2,4 of Panchpokhari rural municipality represent the high risks of susceptibility to landslide.

Landslide susceptibility map of Helambu

Ward 1

Ward-1 of Helambu Municipality is identified as a high risk zone for landslides, particulary in its northern and eastern sections around Bimbale, Tarkado, Nakotegaun, Tasithang, Yambalama etc. wherease areas like Tochhum, Tartong, Dapkharka, Nadang, Kyayung, Ghangyul exhibit a low risk of landslides (Figure 5). The steep slopes and proximity to river valleys make this area more susceptible to landslides especially during the heavy rainfall events.

Ward 2

Ward-2 of Helambu Municipality exhibit high risk of landslide in the eastern part around Gijet, Chiurikharka, Sermathang area wherease the southern part of area like

Thalo, Barsang, Nigale Bhanjyang, kiul, Bhote Dhodeni Nagidanda, Churetarphant exhibit a low risk of landslide (Figure 6). There is a low risk of landslide susceptibility in comparison to Ward-1.

Ward 3

Ward-3 of Helambu Municipality exhibits low risk of landslide in comparison to the Ward-1 and Ward-2. The ward-3 has high risk of landslide in its southern part around Palchokbesi and Beltar wherease in its central part around the area Pipal-chaur, Palchok Devithan, Kakani Bhanjyang, Pujarichok risk of landslide is very low (Figure 7).

Ward 4

Ward-4 of Helambu Municipality has high risk of landslide in comparison to Ward-2 and Ward-3. There is a high risk of landslide in the western and southern part around the area Thulo Manchet, Gyalthung Maltar whereas the risk of landslide is low in the central and eastern part around the area Gaitar, Maramchi, Sera, Gyal-thung etc (Figure 8).

Ward 5

Ward-5 of Helambu Municipality shows high risk of landslides in its northern and southern part around the area like Pakhe, Thaldanda, Bharati, Lapagaun, Kalleri, Uriyani and Kalleri Dihi whereas the ward has low risk of landslide in its central part around the area Pipse, Chitre, Kharbuje and Sirise (Figure 9).

Ward 6

Ward-6 of Helambu Municipality has high risk of landslides in almost all the area like Manegaira, Dhapchung, Dhuseni, Kharkadanda, Otero, Gohare etc (Figure 10).

Ward 7

Ward-7 of Helambu Municipality exhibit low risk of landslide in comparison to other wards. The risk of landslide is high in the areas like Sano Manchel, Nimadanda, Padling, Bekarsang, Sursing, Bolamche etc. whereas the risk of landslide is low in the area like Kutumsang, Singhyang, Pipaldanda, Mahangkal, Pokharidanda etc (Figure 11).

Landslide susceptibility map of Panchpokhari

Ward 1

Ward-1 of Panchpokhari Thangpal Rural Municipality exhibit a significant level of landslide susceptibility, particularly in its northern and eastern regions around Jatanthala, Pakughyang, Kagchet, Khanaltol wherease the area around Kamitol, Mandigaun, Dangaduba has low level of susceptibility (Figure 12). These are characterized by steep slopes, unstable geological formations, and proximity to water bodies, making them highly susceptible to landslides, especially during heavy rainfall events. While some areas in the central and southern parts of the ward have moderate to low susceptibility, the overall risk remains substantial.

Ward 2

Ward-2 of Panchpokhari Municipality exhibit high risk of landslide in the northern, southern and eastern part around Lagangghyang, Ribarma, Sunchaur, Dalegaun, Simpani, Granpang, Kerabari etc. and risk of landslide is low in the central and western part of the ward around Gankharka, Bangdang area (Figure 13).

Ward 3

Ward-3 of Panchpokhari Municipality shows high risk of susceptibility in the western part of Nepal around Makaimarang Wachelidanda, Gyalsung, Parangang, Chhepar etc. and risk of susceptibility is low in the central part around Kusumti, Yarsa, Mugugaug, Thulo Bhotang, Jalmarang etc (Figure 14).

Ward 4

Ward-4 of Panchpokhari Municipality exhibit high risk of landslide in the northern, eastern and central parts of the area around Chhyangsa Marphu whereas risk of landslide is low in the western part around Kotgaun, Nagighyang, Chilaune, Palghyang area (Figure 15).

Ward 5

Ward-5 of Panchpokhari Municipality shows high risk of landslide susceptibility around northern part of gunsakot. The steep slopes, unstable geological formations, and proximity to water bodies, make this area more susceptible to landslides.

Ward-6

Ward 6 of Panchpokhari Municipality exhibit high risk of landslide in the northern and southern part of the area around Siyanle, Taletule, Dhap, Amdunge and risk of landslide is low in the central part of the area around Barutol and Lekkharka.

Ward -7

Ward 7 of Panchpokhari Municipality exhibit high risk of landslide in the northern and southern part of the area around Kaphale and Tipeni area and risk of landslide is low in the central part around Kotnamlang and Bhote Namlang area.

Ward - 8

Ward 8 of Panchpokhari Municipality shows high risk of landslide in the eastern and southern part of area around Okhreni, Ghyang, Puranogaun, Sunkhani wherease the risk of landslide is low in the central and western part around Lapse, Ange, Nangedanda, Kotgaun area.

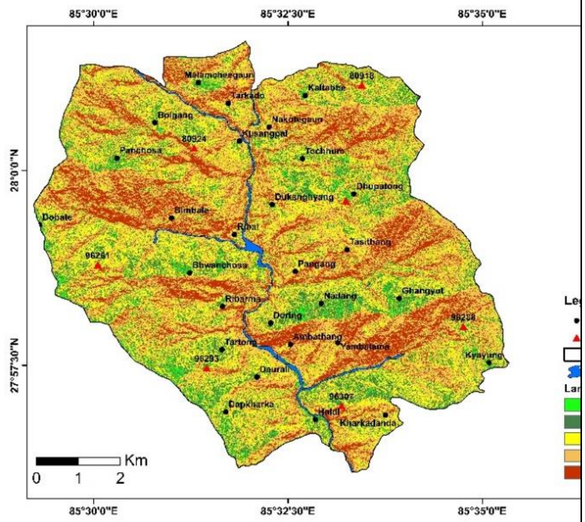

Figure 5: Landslide susceptibility of ward 1 of Helambu.

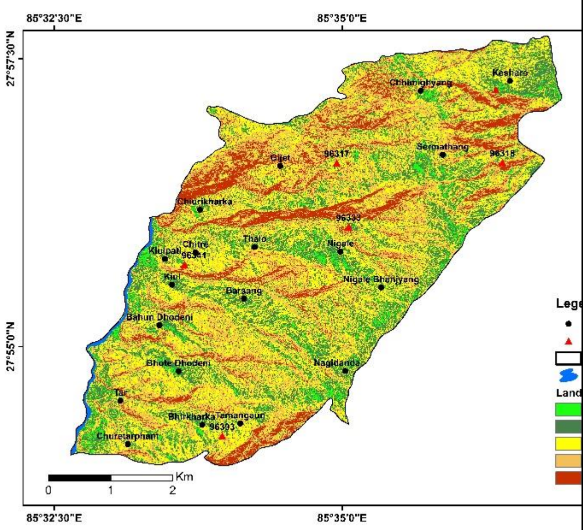

Figure 6: Landslide susceptibility of ward 2 of Helambu.

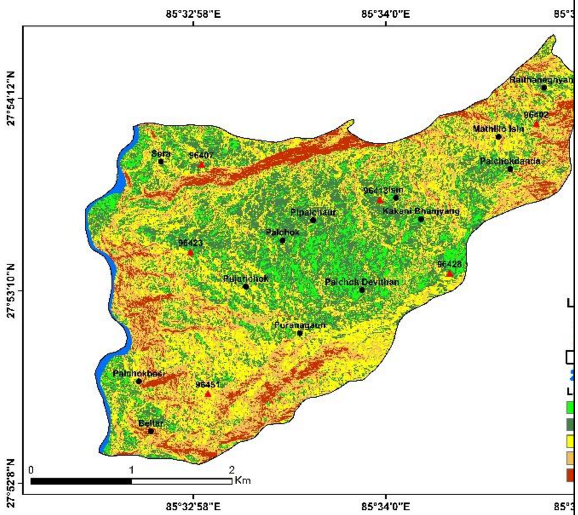

Figure 7: Landslide susceptibility of ward 3 of Helambu.

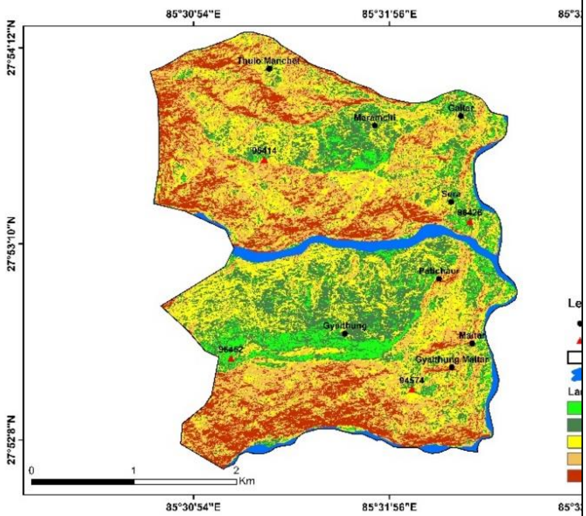

Figure 8: Landslide susceptibility of ward 4 of Helambu.

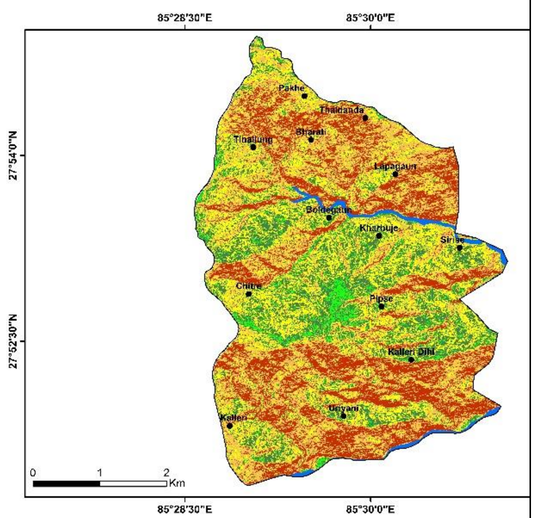

Figure 9: Landslide susceptibility of ward 5 of Helambu.

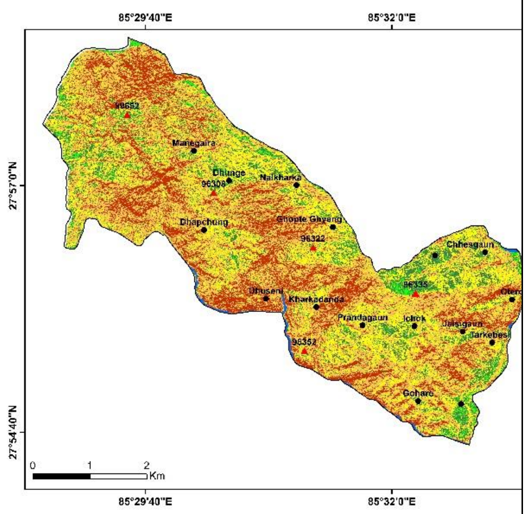

Figure 10: Landslide susceptibility of ward 6 of Helambu.

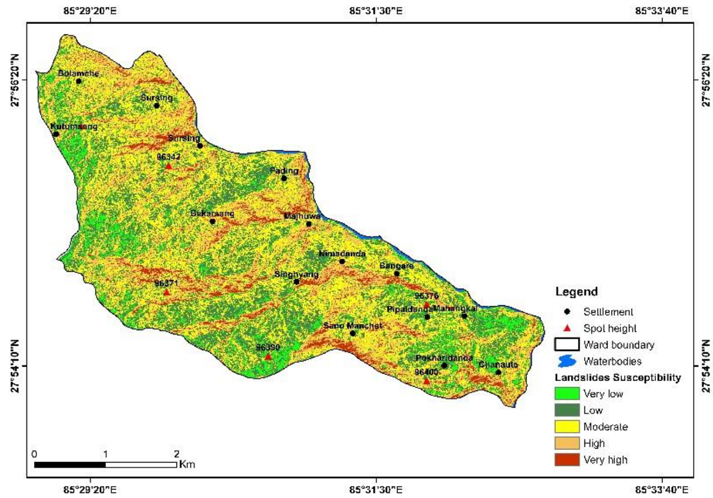

Figure 11: Landslide susceptibility of ward 7 of Helambu.

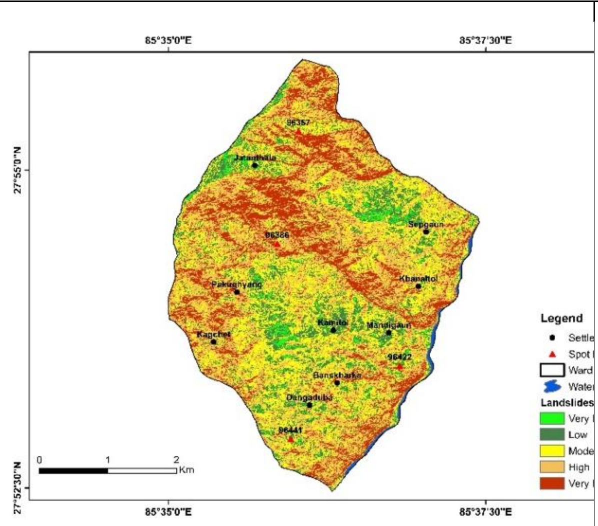

Figure 12: Landslide susceptibility map of ward 1 of Panchpokhari.

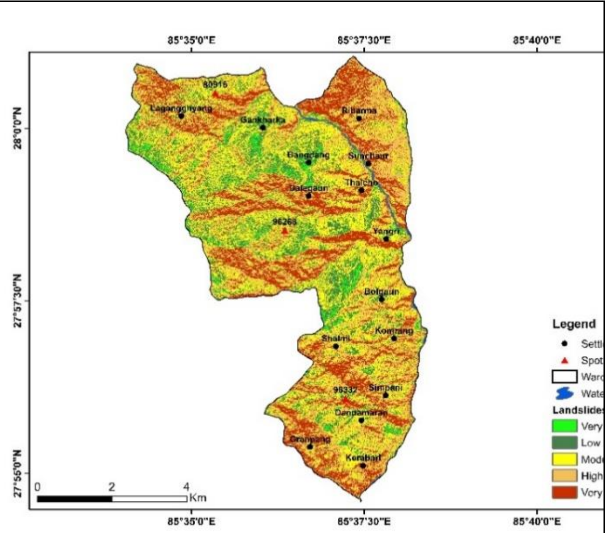

Figure 13: Landslide susceptibility map of ward 2 of Panchpokhari.

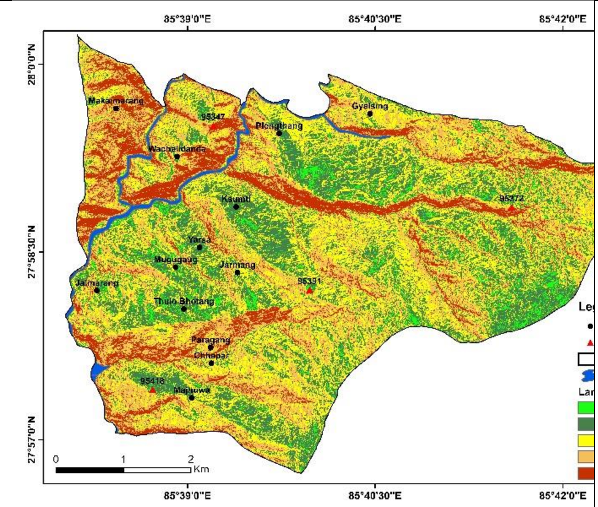

Figure 14: Landslide susceptibility map of ward 3 of Panchpokhari.

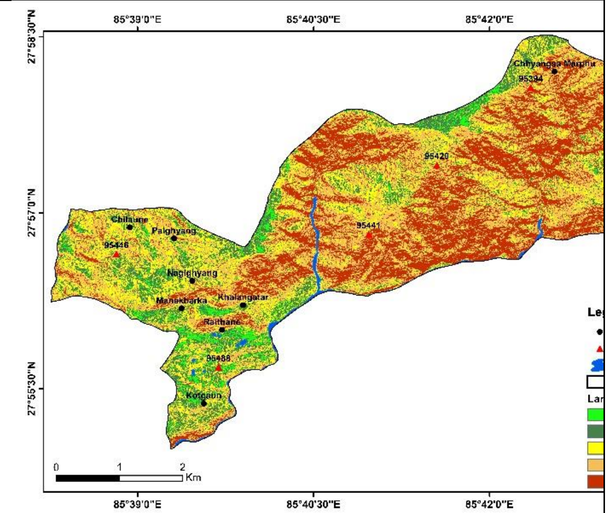

Figure 15: Landslide susceptibility map of ward 4 of Panchpokhari.

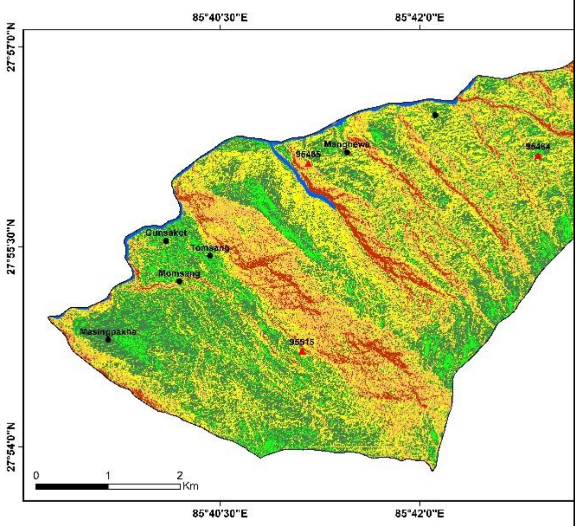

Figure 16: Landslide susceptibility map of ward 5 of Panchpokhari

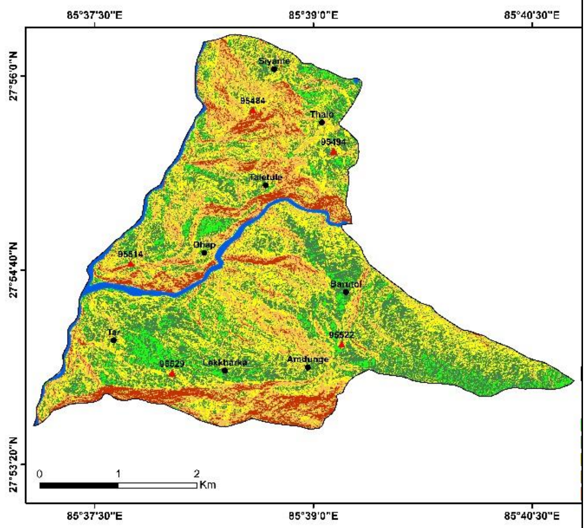

Figure 17: Landslide susceptibility map of ward 6 of Panchpokhari

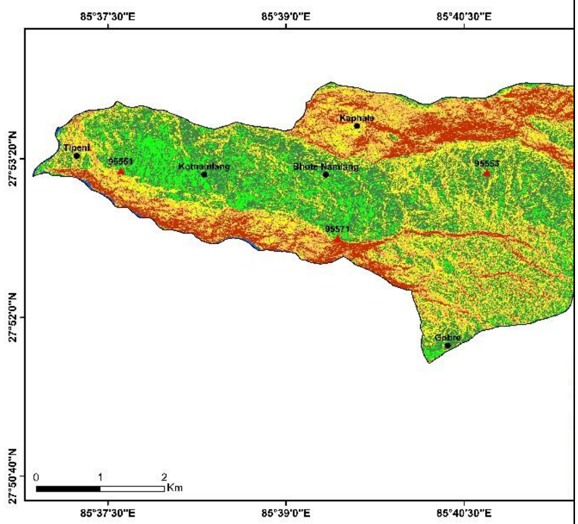

Figure 18: Landslide susceptibility map of ward 7 of Panchpokhari

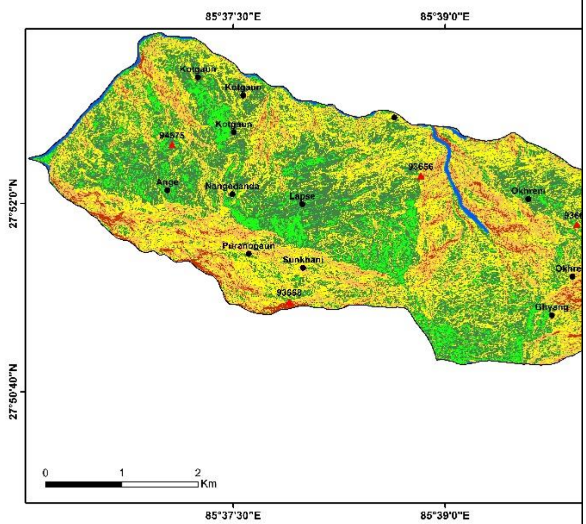

Figure 19: Landslide susceptibility map of ward 8 of Panchpokhari

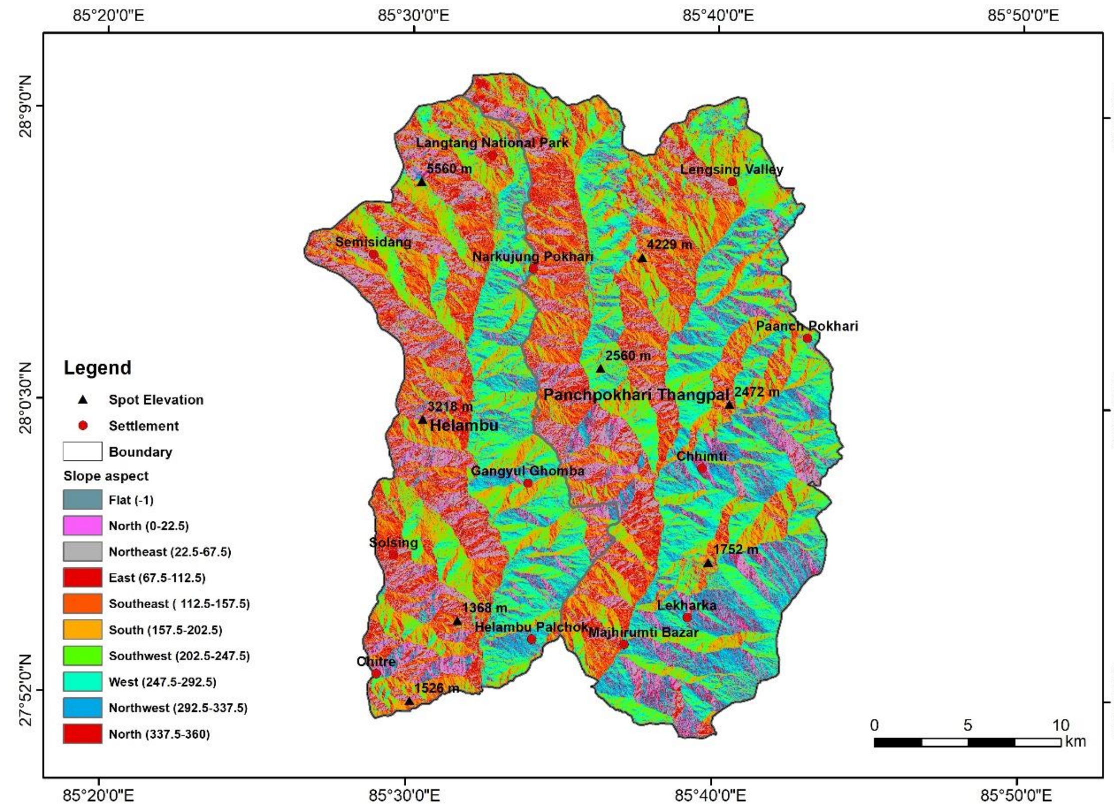

Figure 20: Aspect map of Helambu and Panchpokhari Thangpal Area.

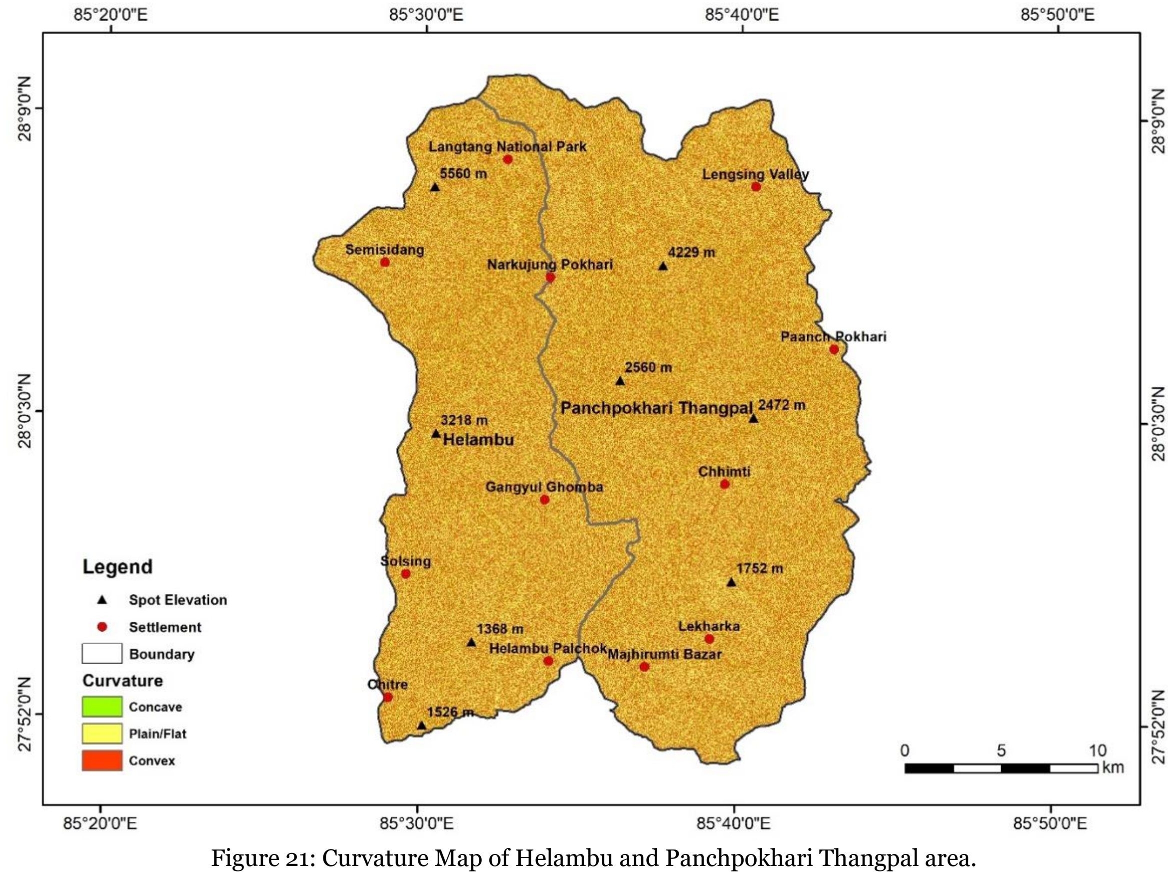

Figure 21: Curvature Map of Helambu and Panchpokhari Thangpal area.

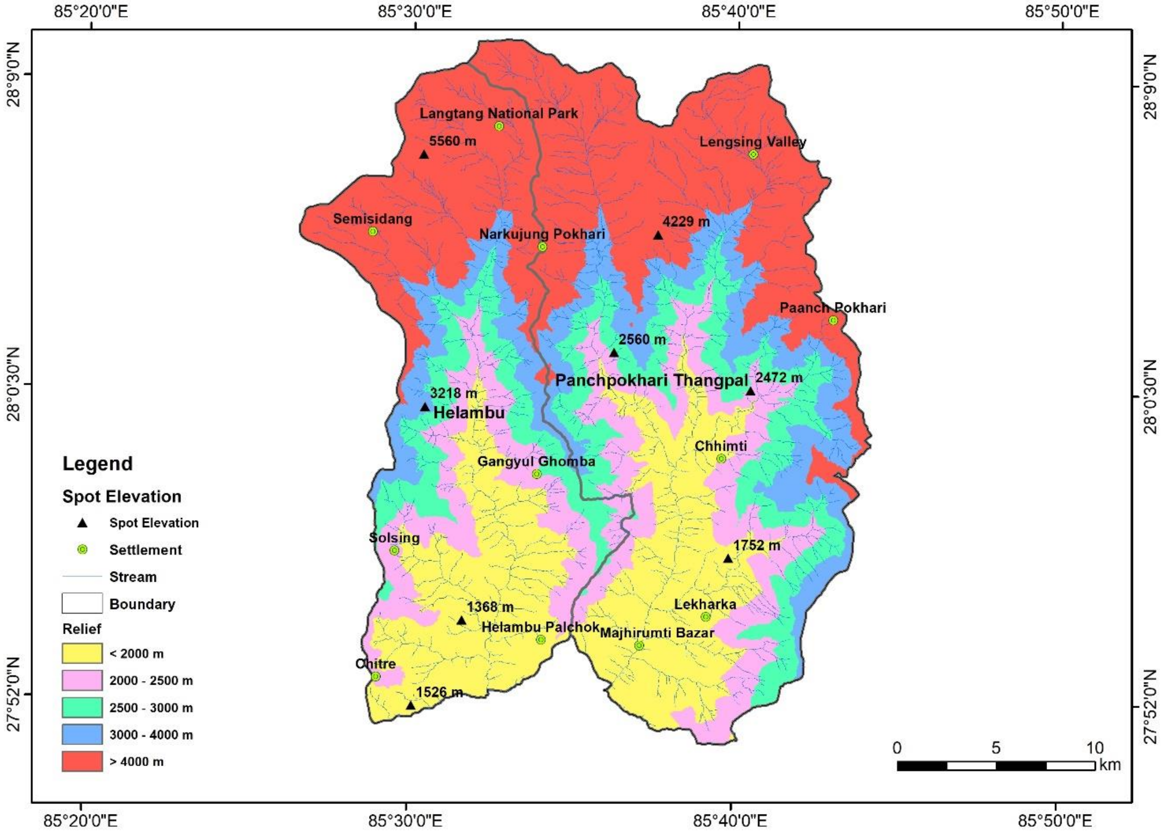

Figure 22: Relief Map of Helambu and Panchpokhari area.

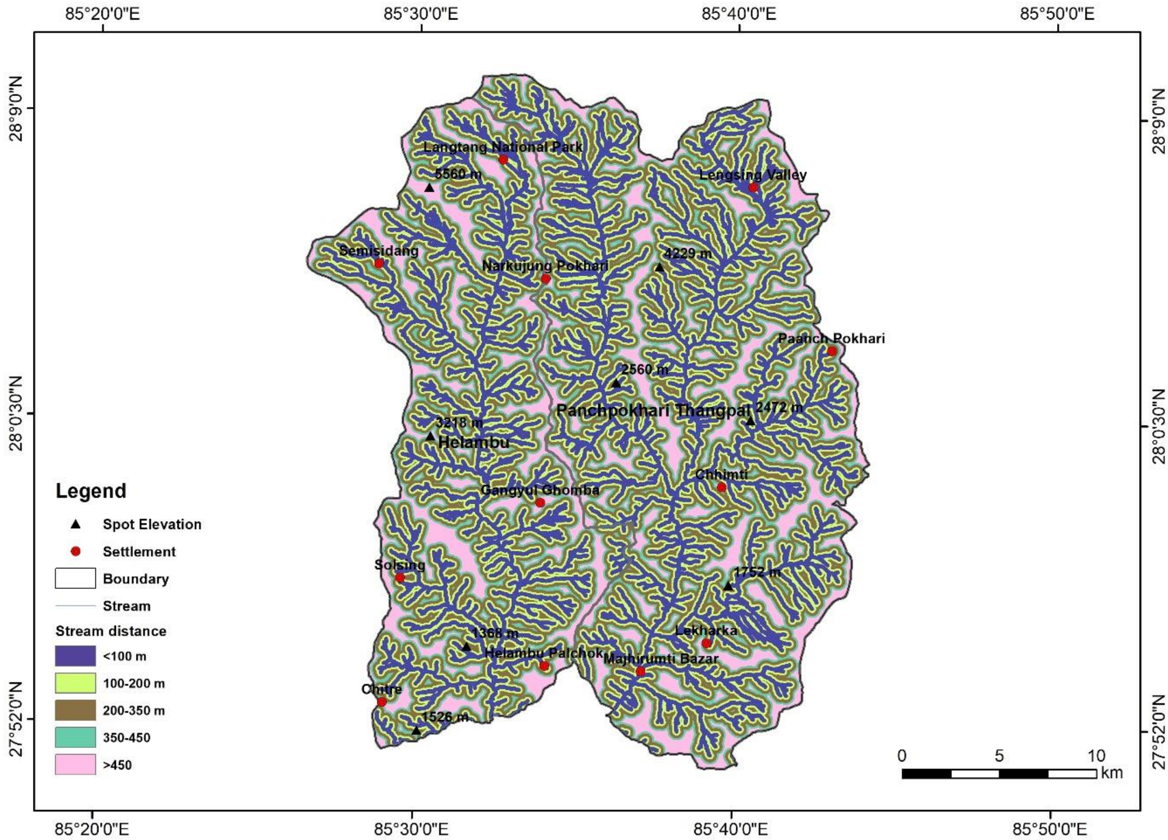

Figure 23: Distance to river Map of Helambu and Panchpokhari Thangpal area.

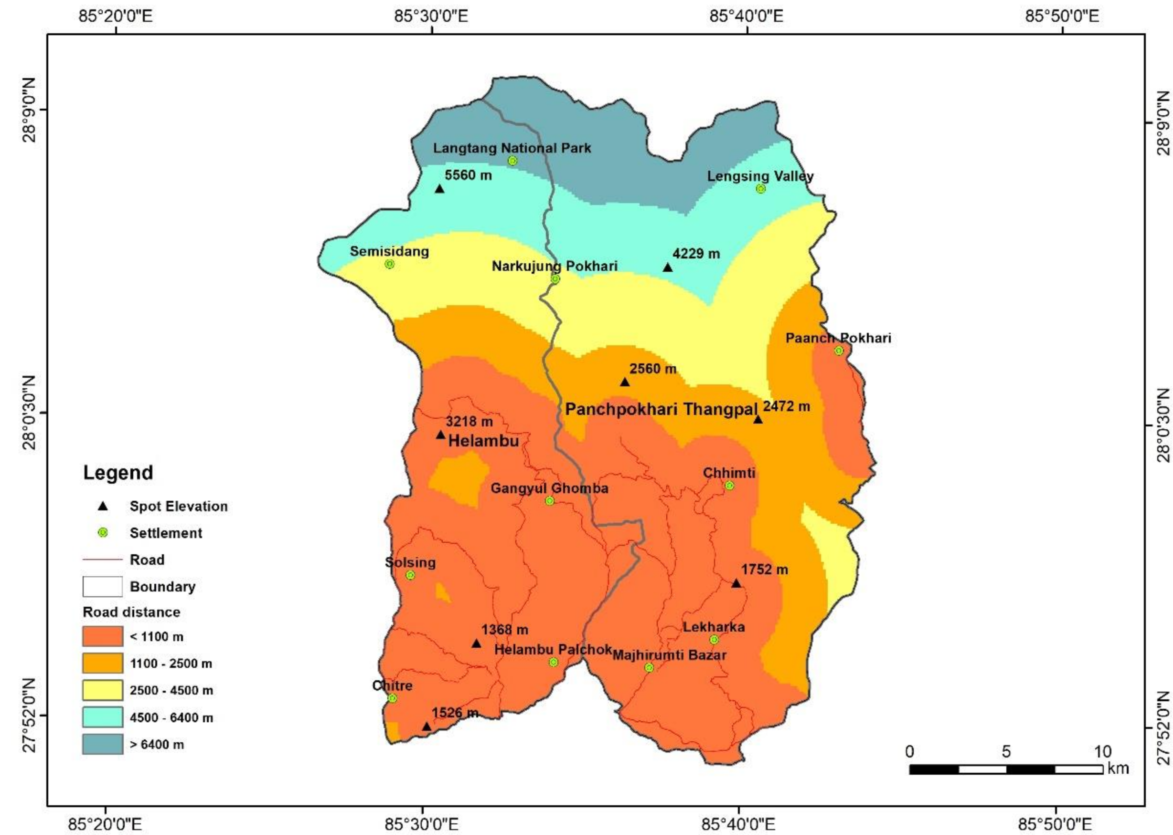

Figure 24: Distance to road Map of Helambu and Panchpokhari Thangpal area

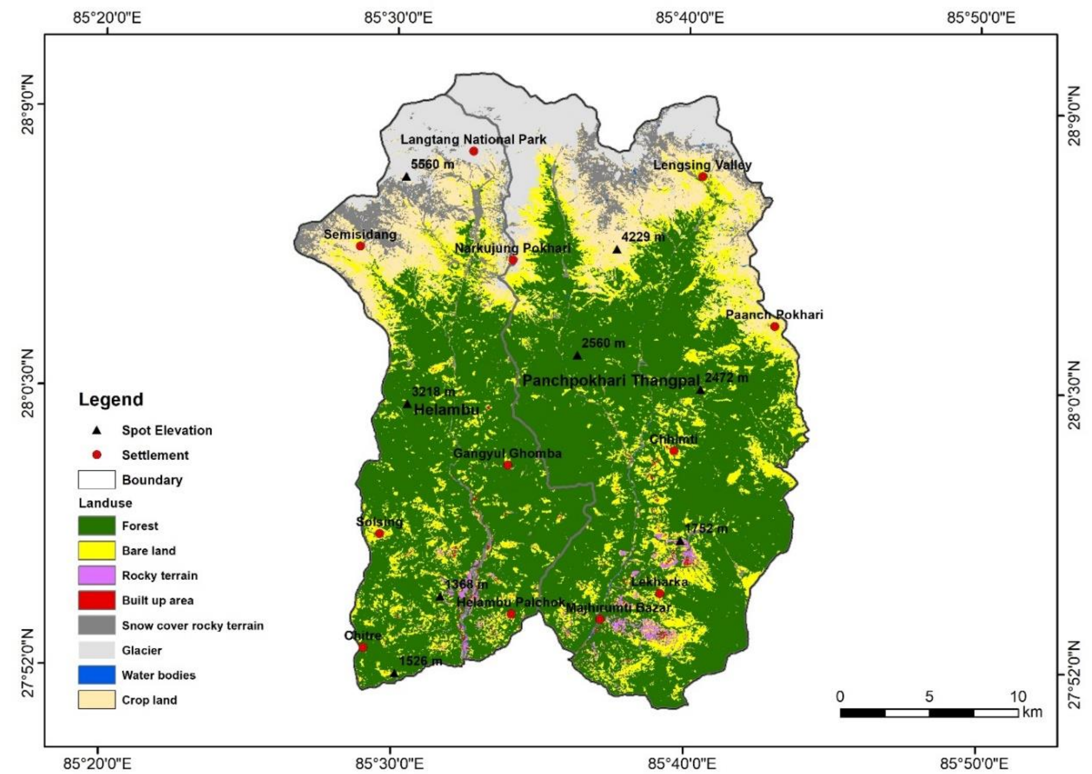

Figure 25: Landuse Map of Helambu and Panchpokhari Thangpal area.

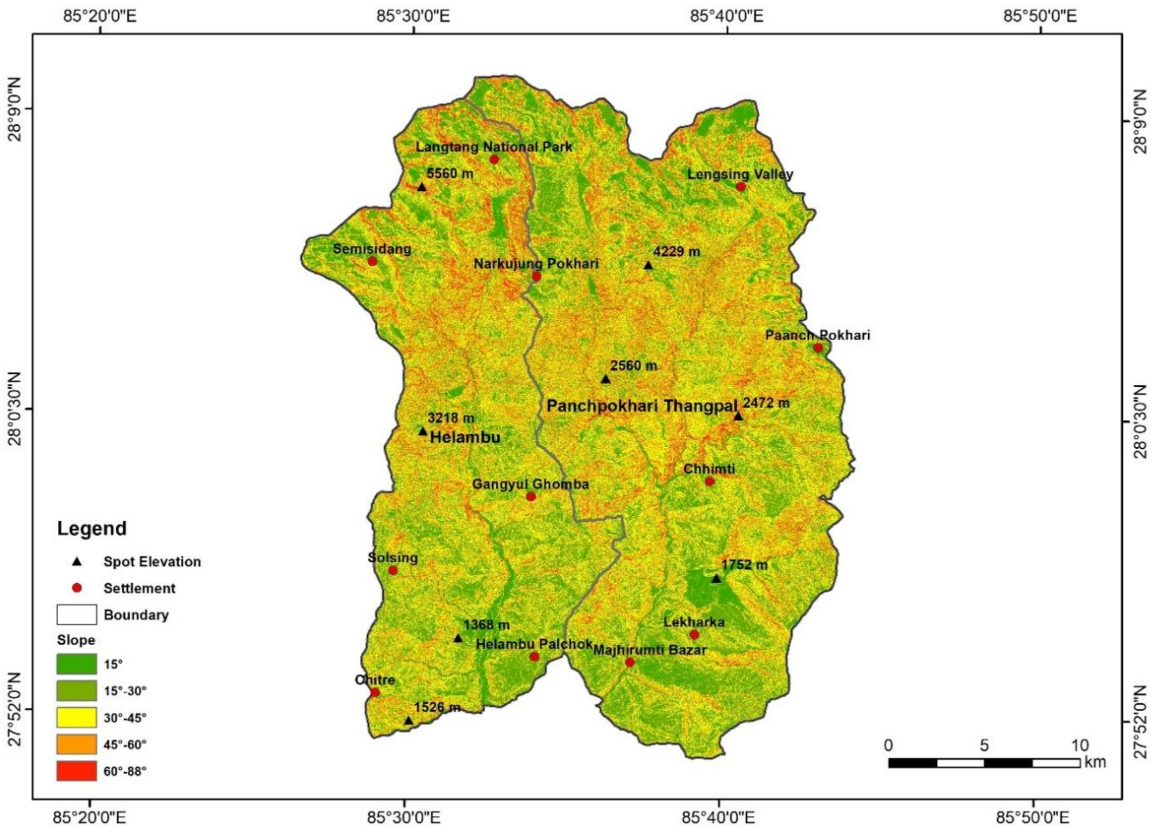

Figure 26: Slope Map of Helambu and Panchpokhari Thangpal area.

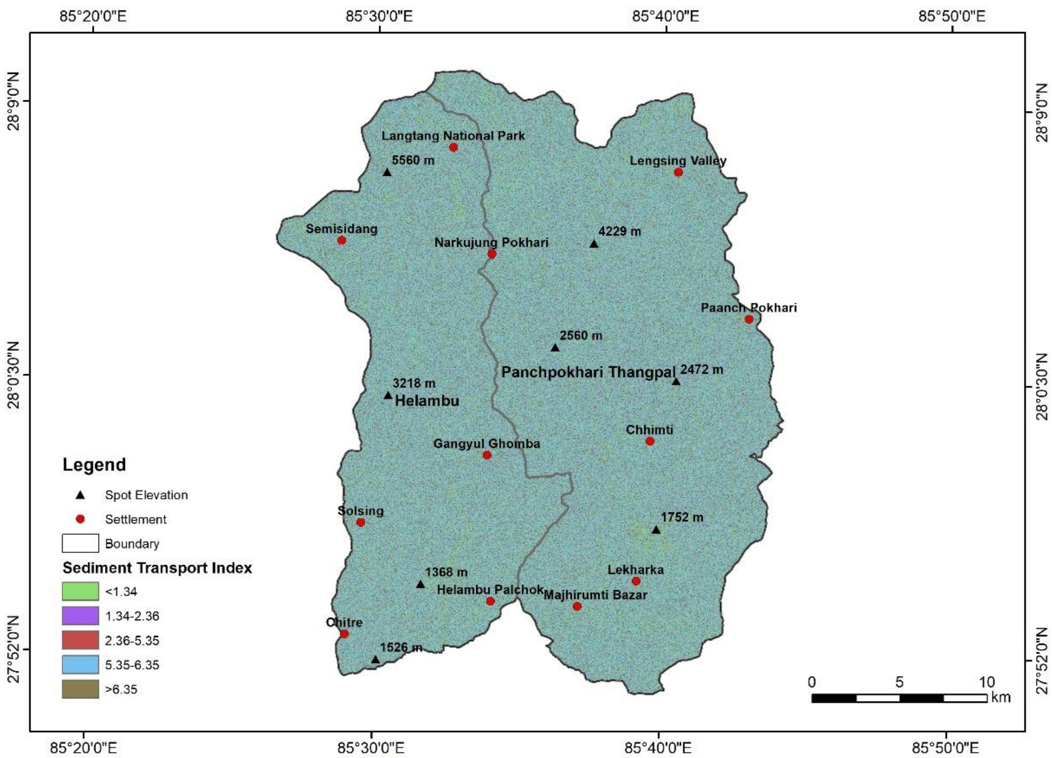

Figure 27: Sediment Transport Index Map of Helambu and Panchpokhari Thangpal area

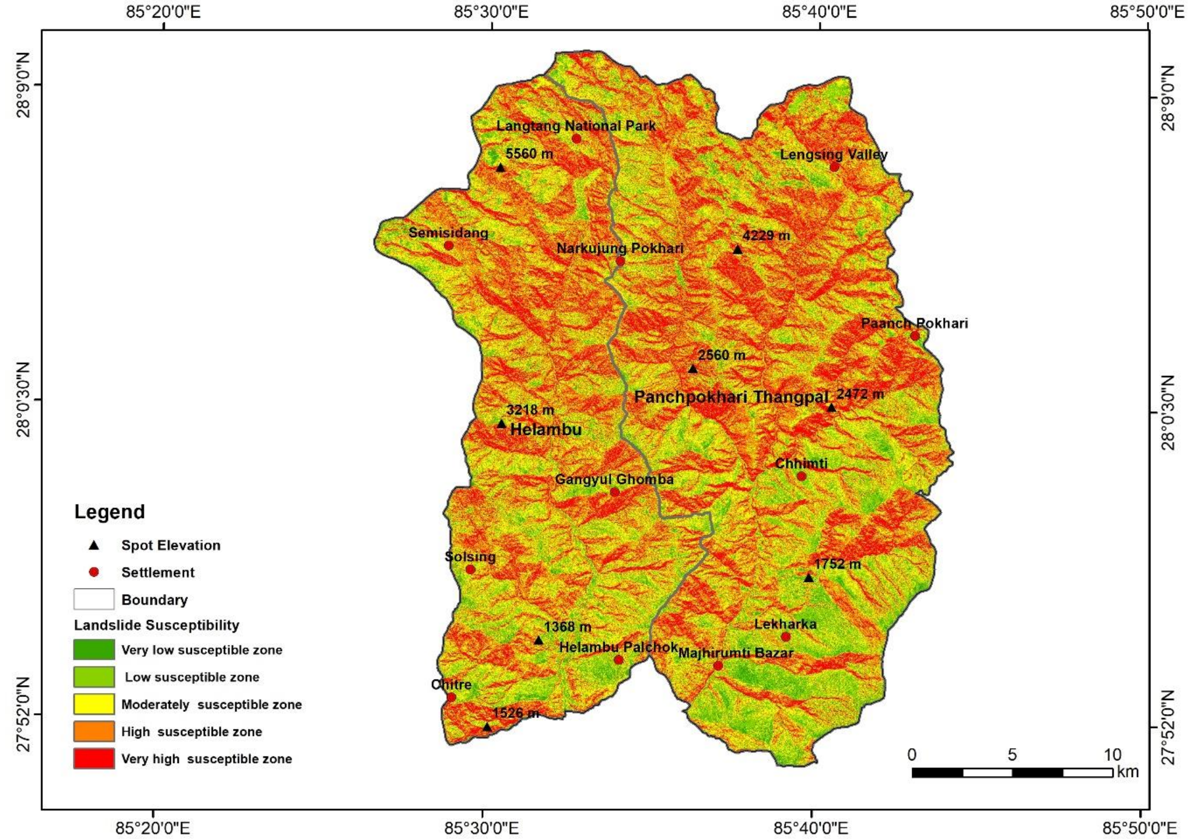

Figure 28: Landslide Susceptibility Map of Helambu and Panchpokhari Thangpal area.

4. Rainfall threshold determination

4.1. Calculation of rainfall for specified time

After collecting the data from field, the daily rainfall data was collected from DHM. The rainfall data for no rainfall 24 hr. was considered as a break of cumulative rainfall and the hourly data was calculated by Equation 1.

$$\frac{P_t}{P_{24}} = Sin(\frac{\pi.t}{48})^{0.4727} \qquad \text{Eqn 1}$$

Where t is specified time (in hours) for which rainfall amount needs to be estimated, Pt is rainfall in t hours and P24 is total rainfall in 24 h sine in radians. Eq. (1) is useful for estimating event rainfall at the time of failure. For example, if the failure time of one landslide is 7:00 PM on 24 July 2022 and the continued precipitation record of 24 and 25 July (daily precipitation of 123 mm and 110 mm respectively) is available, the event rainfall duration for this landslide will be 35 h (total rainfall of 7:45 AM of 23 July to 7:45 AM of 24 July and the time between 7:45 AM and 7:00 PM of July 24, i.e. ~11 h) and the total estimated event rainfall will be 213 mm. For each landslide the rainfall data is calculated for each station for the event time and cumulative rainfall is taken for dry period till one day.

4.2. Spatial Analysis (Interpolation)

Spatial interpolation refers to a method adopted in the field of Geographic Information Systems (GIS) in which unknown values within an area of interest are determined based on the values at known points in that same area. However, this method is more beneficial in generating continuous surfaces from discrete information including elevation and temperature readings, rainfall measures. One of the more often applied interpolation techniques is Inverse Distance Weighting (IDW).

IDW works on the assumption that points closest to the location of interest have a higher influence on the interpolated value than those farther away. The influence of each known point is determined by a weighting coefficient, which specifies how quickly the weight decreases with distance. A greater coefficient indicates that distant locations have less influence on the interpolated value, hence the estimate is more impacted by close points. While IDW is simple and easy to understand and also has some limitations. If the sample points are not evenly distributed, the interpolation quality suffers, and the approach may generate artifacts such as small peaks or pits around the data points.

IDW can oversimplify the surface representation by ensuring that the interpolated surface's maximum and minimum values occur only at the sample points. IDW is popular creating 2D raster layers from field data in GIS applications, despite these drawbacks.

The cumulative rainfall data from nine stations is used for interpolation, the landslide points in Figure 29 represent the unknown locations. Rainfall thresholds are developed using the interpolated values obtained from IDW interpolation, which computes the cumulative rainfall at each landslide point. To make sure that the thresholds are established correctly, this procedure is carried out once for every landslide point. Figure 30 provides an illustration of IDW interpolation.

4.3. Analysis of Threshold

To establish a rainfall threshold used for forecasting landslides, the procedure involves analysis of precipitation data from chosen meteorological stations corresponding to the specific landslide event. The GIS is used to map the spatial distribution of landslides and precipitation stations. The closest stations to each landslide site are selected, and their recorded peak one-day precipitation or extended multiday precipitation values are identified as the event rainfall associated with the landslide. This basically is the basis for knowing which rainfall conditions do lead to landslides.

To ensure accuracy, rainfall data is manually counted and matched with the timing of landslide events in addition to GIS analysis. But some rainfall events last for shorter periods of time than can be estimated directly from daily rainfall records. In response to this, a relationship developed by Shakya (2002) is applied. This relationship gives a more accurate understanding of the rainfall conditions preceding landslides by enabling the estimation of rainfall amounts for shorter durations based on the total rainfall over a 24-hour period. Shakya's equation effectively bridges the gap between daily data and the need for more granular insights into rainfall patterns during landslide events.

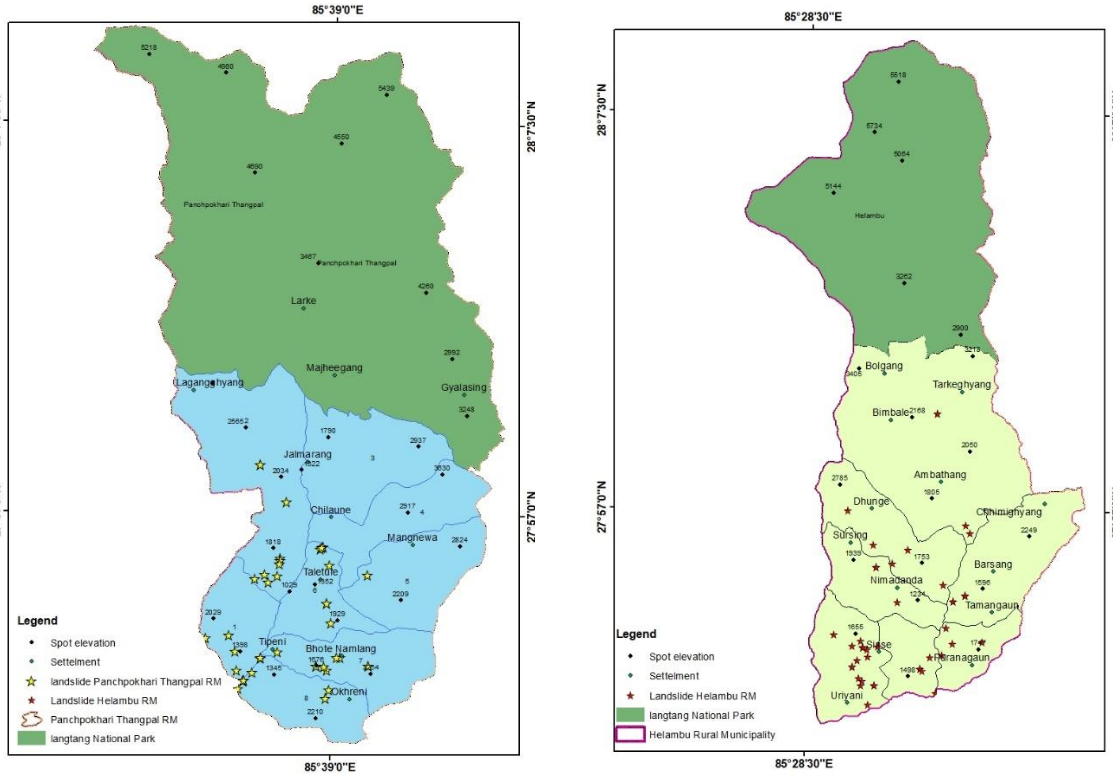

Figure 29: Landslide point for threshold in Panchpokhari Thangpal and Helambu Rural Municipality.

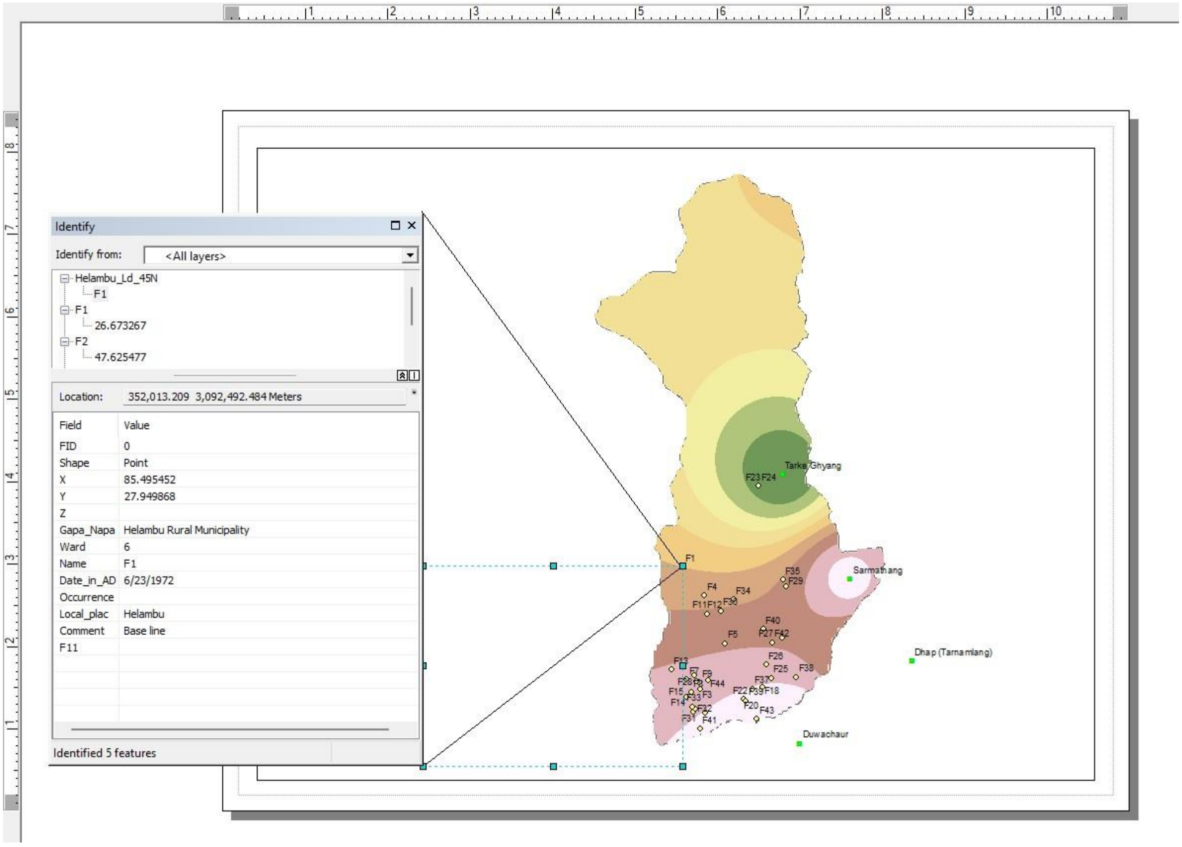

Figure 30: Interpolation of rainfall data for particular landslide, an example

A threshold relationship between rainfall intensity (I) and duration (D) is established for landslide prediction using this extensive dataset, which includes both direct rainfall observations and estimated shorter-duration rainfalls. This threshold can be a useful tool in landslide risk assessment, assisting in the identification of critical conditions under which landslides are likely to occur. This model can predict future risks by identifying the intensity and duration of rainfall events that have historically caused landslides.

4.4. Real time validation

To ensure its accuracy and effectiveness, a real time test of the rainfall threshold will be conducted in 2024 to predict landslides. By using rainfall data from the closest weather stations to landslide locations, the threshold, which relates rainfall intensity (I) and duration (D), was used to predict when landslides might happen. Comparing the actual landslides with the threshold-based predictions was part of this validation process.

5. Result

5.1. Threshold result

Out of 755 landslides in Helambu only 44 landslides were identified with respect to rainfall duration. And for Panchpokhari out of 213 landslides, 43 landslides are identified for rainfall duration. Figure 31 and Figure 32 give the cumulative rainfall and duration curve of rainfall threshold for landslides in Helambu and Panchpokhari Thangpal rural municipality respectively. The threshold as defined as the lower boundary of the points representing landslide -triggering rainfall events.

In Helambu, the threshold relation for landslide-triggering event is expressed by:

$I=41.029\ D^{-0.651}$

having coefficient of determination of 0.9984. Where 'I' is hourly rainfall intensity in millimeters (mm/hr) and duration D in hours.

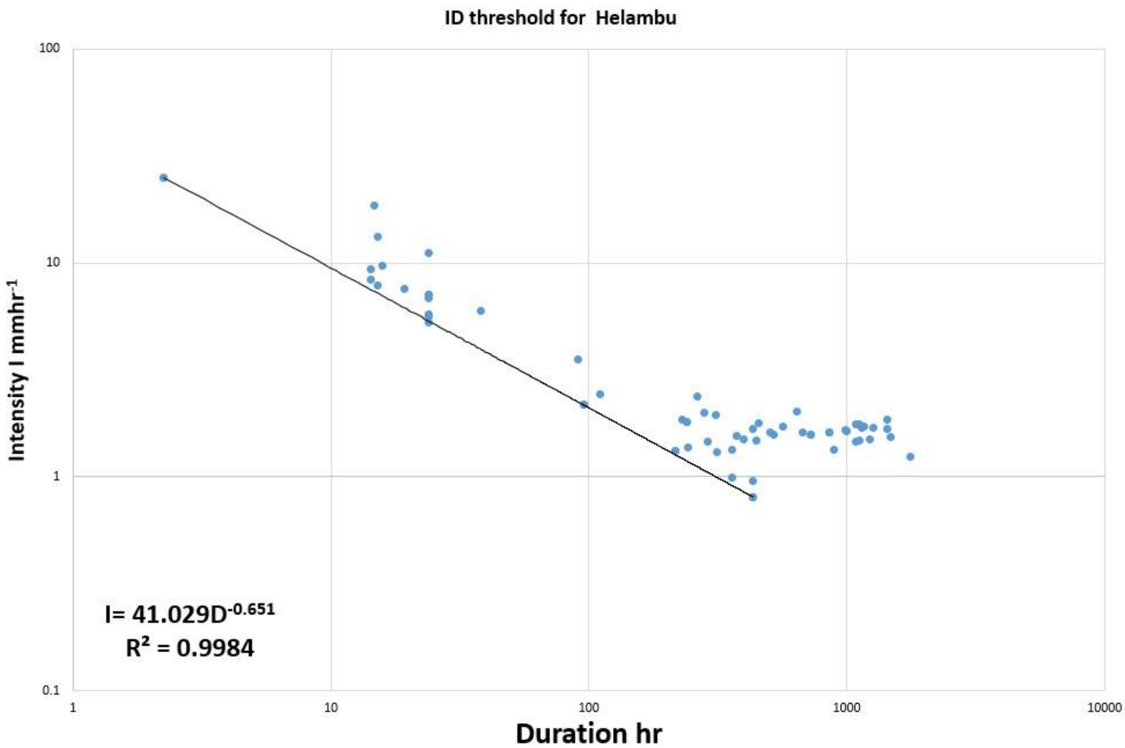

Figure 31: Rainfall intensity and Duration curve for the rainfall threshold for Helambu.

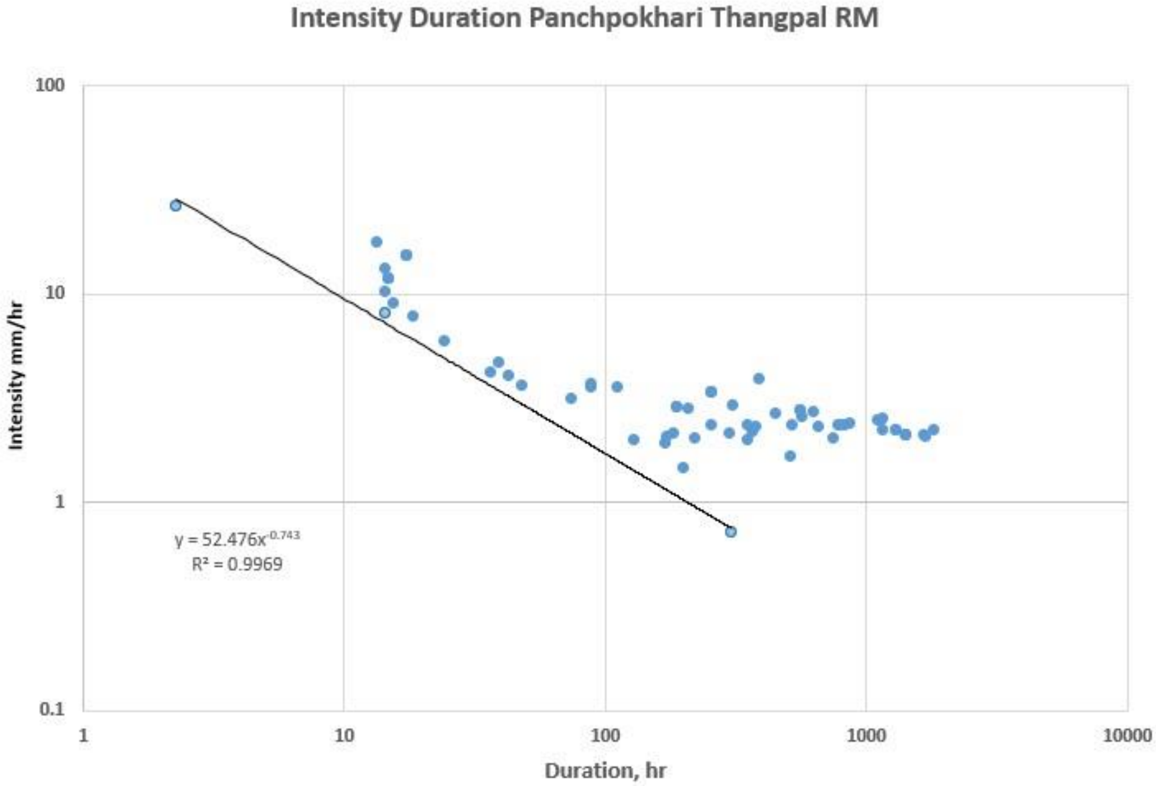

Figure 32: Rainfall intensity and Duration curve for the rainfall threshold for Panchpokhari.

The recommended curve best describes the triggering criteria for rainfall episodes lasting 14 to 450 hours.

In Panchpokhari, the threshold relation for landslide-triggering rainfall events is expressed by: $I=52.476D^{-0.743}$

where 'I' is the hourly rainfall intensity in millimeters per hour (mm/hr) and D is the duration in hours. The coefficient of determination for this equation is 0.9969. The recommendation curve best describes the triggering criteria for rainfall episodes lasting 13 to 300 hours.

6. Discussion

With major implications for improving landslide management in Helambu and Panchpokhari Thangpal area, a new set of rainfall thresholds has been developed. For the purpose of creating and enhancing Landslide Early Warning Systems (LEWS), these municipalities need this set of thresholds.

The recently established rainfall thresholds provide an essential foundation for designing and implementing effective LEWS. By providing a more methodological approach to risk assessment and mitigation, these thresholds aid in the prediction of the probability of landslides based on recorded rainfall data. The real-time data collection is essential for accurately tracking rainfall patterns and assessing whether they meet the threshold for potential landslides.

6.1 Climate and landslides

The seasonal appearance and the year of landslide collected is presented in pie chart and radar. Figure 33 presents two charts that analyze landslide data for Helambu Rural Municipality. The pie chart on the left illustrates the year-wise distribution of landslide events. It reveals that the highest proportion of landslides occurred in 2024, accounting for 36% of the total incidents. Other significant years include 2022, with 16% of the landslides, and 2021, contributing 9%. Smaller percentages are observed for earlier years like 1972, 1977, 1990, and 1997, each ranging from 1% to 5%.

On the right, the radar chart displays the monthly distribution of landslides, showing a clear seasonal pattern. The highest concentration of landslides is seen in July, with a noticeable frequency also in August and September. Conversely, the winter and early spring months, such as January, February, March, and December, experience fewer landslides. This seasonal trend indicates that landslides are more common during the monsoon season, aligning with the region's rainfall patterns. Together, these charts provide insight into both the temporal and seasonal dynamics of landslides in the area.

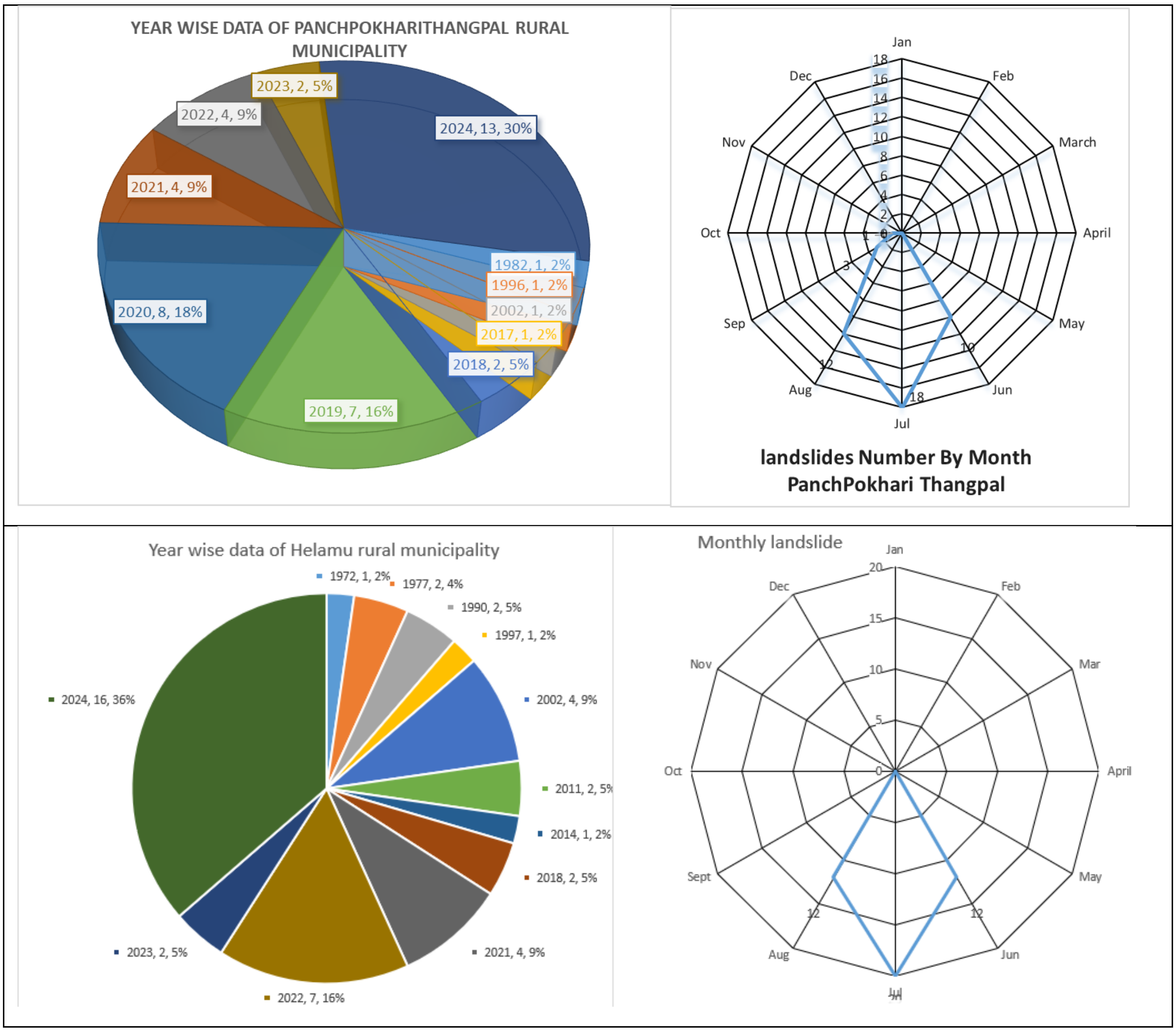

Figure 33: Time and month data of landslide selected for threshold calculation.

6.2 Threshold comparison

The threshold established nationally and internationally is compared with the present study of Helambu and Panchpokhari Thangpal Rural Municipality. The study shows that it needs lower intensity in the short period than proposed by Dahal and Hesegawa (2008). Here, in Helambu rural municipality, threshold suggests the landslide to initiate at 124.38 mm 118.76mm of rainfall in 24 hr and Panchpokhari Thangpal Rural Municipality threshold suggests 118.76mm of rainfall in 24 hr to initiate landslide in the area. Dahal (2008) suggests the rainfall of about 145 mm in 24 hr to initiate landslide. According to this threshold relation for rainfall events of shorter duration such as <10 hr, a rainfall intensity of 10.0 mm hr−1 is necessary to trigger landslides, while an average precipitation of less than 2 mm hr−1 appears sufficient to cause landsliding if continued for more than 100 hr. Moreover, for continuous rainfall of more than one month, landslides may be triggered even by an average rainfall of less than 1 mm h−1 and this is possible during monsoon periods.

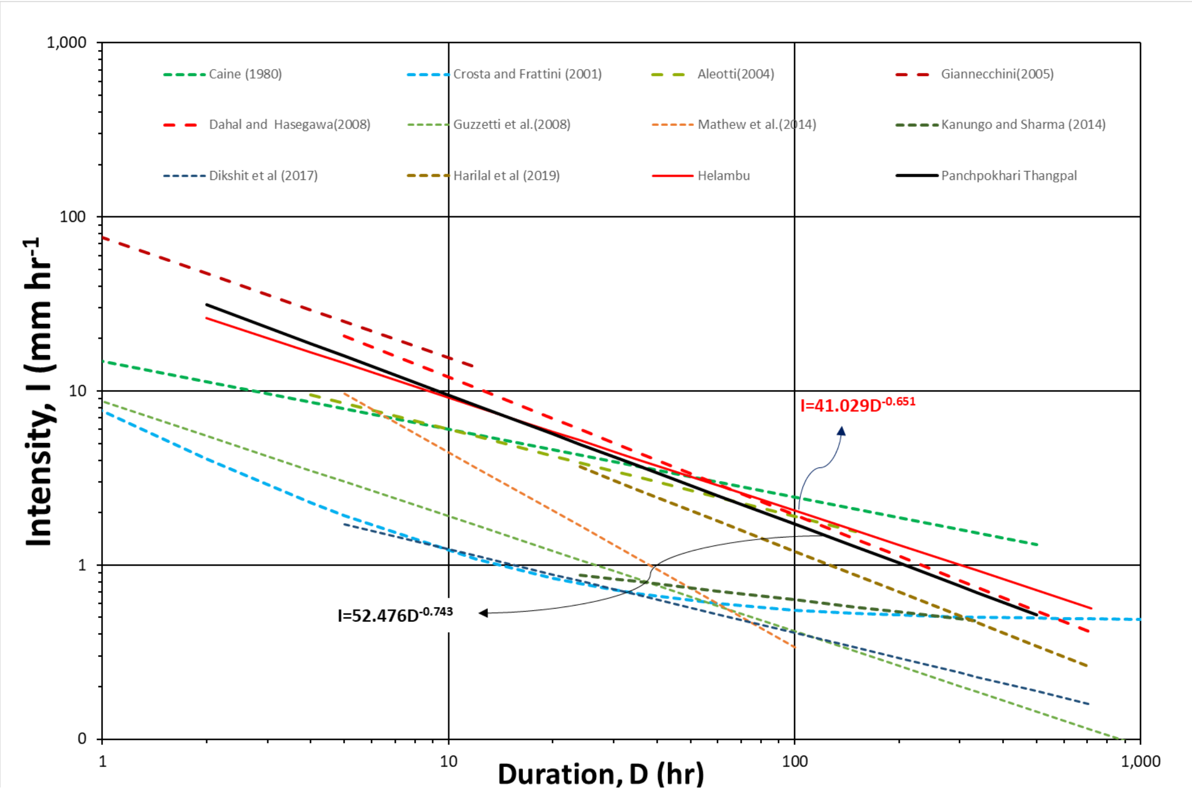

Figure 34: Comparison of threshold.

The study is similar to the study of Harilal et al (2019) done in local scale at Sikkim but the intensity of landslide is less required in Sikkim for initiation of landslides.

The table below shows the intensity of the rainfall of different researchers.

Table 2: Threshold published by different researcher.

Extent Type	Researcher	Equation	
World	Caine (1980)	$I= 14.82\ D^{-0.39}$	0.167<D<500
World	Crosta and Frattini (2001)	$I =0.48+7.20D^{-1.00}$	0.1<D<1000
Regional	Aleotti (2004)	$I=19.00\ D^{-0.50}$	4<D<150
Local	Giannecchini (2005)	$I=76.20\ D^{-0.69}$	0.1<D<12
World	Guzzetti et al. (2008)	$I=8.70\ D^{-0.66}$	0.1<D<1000
Regional	Dahal and Hasegawa (2008)	$I=73.90D^{-0.79}$	5<D<720
Regional	Mathew et al. (2014)	$I= 58.7\ D^{-1.12}$	6<D<100
Regional	Kanungo and Sharma (2014)	$I= 1.82\ D^{-0.23}$	24<D<336
Local	Dikshit et al (2017)	$I= 3.72D^{-0.48}$	
Local	Harilal et al (2019)	$I= 43.62\ D^{-0.78}$	24<D<720
Present Study	Helambu	$I=41.029D^{-0.651}$	14<D<450
Present Study	Panchpokhari Thangpal	$I=52.476D^{-0.743}$	13<D<300

7. Conclusion and recommendation

Conclusion

This study analyzed the rainfall thresholds for landslide-triggering events in Helambu and Panchpokhari Thangpal Rural Municipalities. Out of 755 recorded landslides in Helambu during inventory map preparation, 44 were identified in relation to rainfall duration, while in Panchpokhari, 43 out of 213 landslides were identified for the same purpose. The analysis focused on determining the rainfall intensity-duration (ID) thresholds that could predict landslide occurrences in these regions.

In Helambu, the threshold for landslide-triggering events was determined to be $I = 41.029\ D^{-0.651}$, where 'I' represents the hourly rainfall intensity (mm/hr) and 'D' the duration of rainfall in hours. This threshold equation, with a high coefficient of determination ($R^2 = 0.9984$), provides a reliable method for predicting landslide events triggered by rainfall lasting between 14 to 450 hours.

Similarly, in Panchpokhari Thangpal, the threshold relation was found to be $I = 52.476\ D^{-0.743}$, with a coefficient of determination of 0.9969. This threshold is applicable for rainfall episodes lasting between 13 to 300 hours. The close fit of the data to these equations suggests that these thresholds effectively capture the relationship between rainfall intensity, duration, and landslide initiation in these areas.

The findings indicate that both Helambu and Panchpokhari Thangpal have distinct, well-defined rainfall thresholds that can be used to predict landslide risks with a high degree of confidence. These thresholds serve as critical tools for developing early warning systems and guiding disaster preparedness strategies in these regions.

The landslide susceptibility map prepared using the polygon of landslide that was found in inventory and field data has shown that the area with the gully and stream has the high susceptibility and high hill is more susceptible for landslide a glacial outburst (supported by Google Earth image). The middle part of the study area in low is susceptible to landslide as compared to surrounding area.

The comparison of threshold suggests the strong match with their previous research of Dahal and Hasegawa (2008), representative rainfall thresholds for landslides in the Nepal Himalaya.

Recommendation

The rainfall intensity-duration thresholds identified in this study should be incorporated into local Landslide Early Warning Systems (LEWS) for Helambu and Panchpokhari Thangpal. These thresholds will enhance the precision of landslide predictions, enabling timely alerts to be issued to communities at risk.

To improve the accuracy of rainfall data used in threshold calculations, it is essential to increase the number of automatic weather stations and high-resolution rain gauges in Helambu and Panchpokhari. The proposed rainfall station with coordinates is presented in Annex 5. The rainfall station should be free from shade and should be monitored on daily basis. Enhanced data collection will allow for continuous refinement of the thresholds and more accurate predictions.

A centralized body should be established to oversee the collection, management, and analysis of landslide data in these regions. This will ensure consistent data quality and provide a robust foundation for refining landslide prediction models and enhancing disaster response strategies.

Given the variability in environmental conditions, ongoing data collection and analysis are necessary to refine these thresholds over time. Monitoring changes in land use, vegetation cover, and other factors that influence landslide susceptibility will help maintain the accuracy and relevance of the thresholds.

Local authorities should conduct awareness campaigns and provide training to communities on the use of early warning systems. Understanding the significance of rainfall thresholds and how they relate to landslide risk can empower residents to take proactive measures during heavy rainfall events.

By implementing these recommendations, Helambu and Panchpokhari can significantly improve their landslide risk management strategies, reducing the impact of such events on vulnerable communities.

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Annex

Annex 1: Primary data for landslide occurrence time and spatial distribution

Gapa_Napa	Ward	Name	Occurrence date BS	Occurrence time	Local place name	Comment	Longitude	Latitude	Elevation
Helambu Rural Municipality	7		3/13/2047	12am	Dii	field	85.520833	27.9094440	
Helambu Rural Municipality	7	306	2068-04-15	rati	raod slope pating	field	85.510186	27.9249780	1744.15
Helambu Rural Municipality	7	306	2068-04-21	rati	raod slope pating	field	85.510186	27.9249780	1744.15
Helambu Rural Municipality	6		2071-05-11	11pm	sabije ko pahiro	field	85.489093	27.8951600	
Helambu Rural Municipality	2		3/16/2078		tamangdhodini	field	85.554975	27.9128090	
Helambu Rural Municipality	2		3/17/2078		tamangdhodini	field	85.554975	27.9128090	
Helambu Rural Municipality	3		2078-04-17	3:00 AM	chilaune ghari	field	85.543528	27.8863950	
Helambu Rural Municipality	5	286	2078-05-15	rati	mane danda	field	85.509743	27.8727450	1775.98
Helambu Rural Municipality	4	283	2079-03-10	rati	gelthum	field	85.532651	27.8801730	1252.64
Helambu Rural Municipality	5	287	2079-03-12	rati	mane danda	field	85.509745	27.8727080	1782.90
Helambu Rural Municipality	4	283	2079-03-15	rati	gelthum	field	85.532651	27.8801730	1252.64
Helambu Rural Municipality	3	312	2079-04-12	2:00 AM	kartike danda	field	85.548920	27.8914320	1260.56
Helambu Rural Municipality	3		2079-04-28	rati	sera	field	85.545517	27.8986160	
Helambu Rural Municipality	2	228	2080-03-06	rati	Dhodeniko Pahiro	field	85.549042	27.9102550	1110.94
Helambu Rural Municipality	5	297	2080-05-06	2pm	labagaun	field	85.502805	27.8922930	1374.14
Helambu Rural Municipality	1	225	2081-03-12	11:00 AM	Cheure kharka	field	85.557045	27.9401680	1453.40
Helambu Rural Municipality	2		3/12/2081		tamangdhodini	field	85.554975	27.9128090	
Helambu Rural Municipality	5	288	2081-03-14	rati	manedanda	field	85.502861	27.8728740	1836.48
Helambu Rural Municipality	5	289	2081-03-16	12:00 AM	Kaluyulchi	field	85.503792	27.8747580	1804.03
Helambu Rural Municipality	5	290	2081-03-17	11:30 PM		field	85.501972	27.8758040	1807.23
Helambu Rural Municipality	6				kharka danda	field	85.525833	27.9327780	
Helambu Rural Municipality	1	224	2081-03-22	rati	Dumdung	field	85.555087	27.9437210	1495.52
Helambu Rural Municipality	6				kharka danda	field	85.518233	27.9267490	
Helambu Rural Municipality	4	282	2081-03-29	2:00 PM	gelthum	field	85.537582	27.8855870	1072.89
Helambu Rural Municipality	3	313	2081-03-29	3:00 PM	lapsile tol	field	85.563712	27.8922260	1602.98
Helambu Rural Municipality	4	284	2081-04-03	rati		field	85.533814	27.8793390	1329.81
Helambu Rural Municipality	6	311	2081-04-03	11:00 PM	thapatar	field	85.543842	27.9173340	1123.02
	5	327	2081-04-10	12am	orleni	field	85.506632	27.8642247	1338.00
Helambu Rural Municipality	2	228	2081-04-13	3:00 AM	Dhodeniko Pahiro	field	85.549042	27.9102550	1110.94
Helambu Rural Municipality	4	280	2081-04-16	rati	talamarang	field	85.540533	27.8697640	1421.35
Helambu Rural Municipality	4	300	2081-04-16	3:00 AM		field	85.511176	27.8899470	1306.70
Helambu Rural Municipality	5	291	35 yr ago			field	85.499928	27.8855370	1758.07
Helambu Rural Municipality	1	221	2072/03/.... 2013/04/...last		ringur Khola pahiro	field	85.547429	27.9535450	1391.32
Helambu Rural Municipality	1	222	2063/03/..			field	85.548616	27.9539440	1402.76
Panchpokhari Thangpal Rural Municipality	5	272	2039-04-16	12:15:00 AM	Gunsa	field	85.668323	27.9230160	1704.02
Panchpokhari Thangpal Rural Municipality	6	268	2074-04-03	11:45:00 PM	Siyale	field	85.645610	27.9355000	1557.38

Gapa_Napa	Ward	Name	Occurrence date BS	Occurrence time	Local place name	Com-ment	Longi-tude	Latitude	Eleva-tion
Panchpokhari Thangpal Rural Municipal-ity	8	325	2076-03-14	rati	Uttish ghari	field	85.610532	27.8787149	1200.25
Panchpokhari Thangpal Rural Municipal-ity	8	262	2076-04-27	3:00pm	Tipeni	field	85.614621	27.8852470	926.65
Panchpokhari Thangpal Rural Municipal-ity	8	232	2076-05-19	12:00:00 AM	Tipeni near dam	field	85.606315	27.8754110	896.75
Panchpokhari Thangpal Rural Municipal-ity	8	232	2076-05-26	12:00:00 AM	Tipeni near dam	field	85.606315	27.8754110	896.75
Panchpokhari Thangpal Rural Municipal-ity	7	276	2077-03-19	rati	ratmateko pahiro	field	85.642926	27.8818250	1668.93
Panchpokhari Thangpal Rural Municipal-ity	7	276	2077-04-13	7:30:00 AM	ratmateko pahiro	field	85.642926	27.8818250	1668.93
Panchpokhari Thangpal Rural Municipal-ity	6	271	2078-03-15	rati	Dhadkharka	field	85.649114	27.9272460	1642.75
Panchpokhari Thangpal Rural Municipal-ity	7	326	2078-03-28	9:00:00 PM	Pipalbot	field	85.623273	27.888087 0	1174.00
Panchpokhari Thangpal Rural Municipal-ity	8	230	2079-03-09		Khalade khola	field	85.605996	27.8749880	891.37
Panchpokhari Thangpal Rural Municipal-ity	7		3/18/2079	beluka	neawar tol	field	85.653221	27.8859480	
Panchpokhari Thangpal Rural Municipal-ity	6		5/10/2079	rati	Amdurgey	field	85.650076	27.9013710	
Panchpokhari Thangpal Rural Municipal-ity	8	264	2079-06-23	4:00:00 PM	mandigaun	field	85.614879	27.8853720	934.53
Panchpokhari Thangpal Rural Municipal-ity	8	230	2080-03-05		Khalade khola	field	85.605996	27.8749880	891.37
Panchpokhari Thangpal Rural Municipal-ity	2	316	2081-03-13	rati	baruwa	field	85.622832	27.9223020	1623.63
Panchpokhari Thangpal Rural Municipal-ity	6	268	2081-03-14	12:00:00 PM	Siyale	field	85.645610	27.9355000	1557.38
Panchpokhari Thangpal Rural Municipal-ity	6	270	2081-03-15	1:00am		field	85.644244	27.9344850	1550.82
Panchpokhari Thangpal Rural Municipal-ity	7		3/20/2081		ratmateko pahiro	field	85.648102	27.8801120	
Panchpokhari Thangpal Rural Municipal-ity	7	276	2081-03-22	rati	ratmateko pahiro	field	85.642926	27.8818250	1668.93
Panchpokhari Thangpal Rural Municipal-ity	8	230	2081-03-31		Khalade khola	field	85.605996	27.8749880	891.37
Panchpokhari Thangpal Rural Municipal-ity	2	322	2081-03-31	12:00:00 PM	dadamarang	field	85.624134	27.9299790	1569.96
Panchpokhari Thangpal Rural Municipal-ity	6	269	2081-04-02	1:00 am	Siyale majhatol	field	85.644904	27.9349290	1553.32
Panchpokhari Thangpal Rural Municipal-ity	1	314	2081-04-03	rati	bajkharka	field	85.586861	27.8941390	1648.12
Panchpokhari Thangpal Rural Municipal-ity	7		4/14/2081	10:00:00 AM		field	85.646611	27.8815810	

Gapa_Napa	Ward	Name	Occurrence date BS	Occurrence time	Local place name	Comment	Longitude	Latitude	Elevation
Panchpokhari Thangpal Rural Municipality	2	319	2081-04-15	11:00:00 AM	Deuso	field	85.624203	27.9291730	1572.49
Panchpokhari Thangpal Rural Municipality	8	232	2081-04-16	12:00:00 AM	Tipeni near dam	field	85.606315	27.8754110	896.75
Panchpokhari Thangpal Rural Municipality	2	318	2081-04-18	12:30:00 AM	Damrang lamako bari	field	85.623660	27.9275130	1575.91
Panchpokhari Thangpal Rural Municipality	7	265	2066-02-...		danuwar tol	field	85.620695	27.8886210	1083.52
Panchpokhari Thangpal Rural Municipality	3	266	2045-04-...			field	85.652238	27.9588150	1793.13

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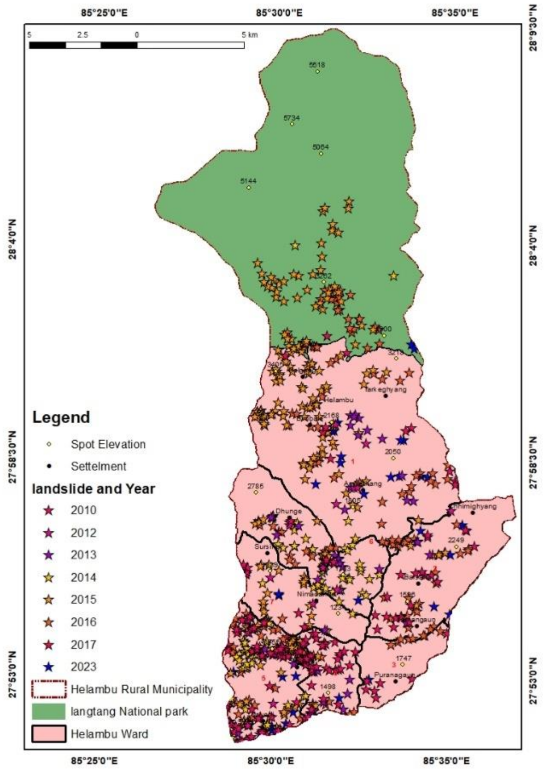
Annex 2: Secondary data collected from different source

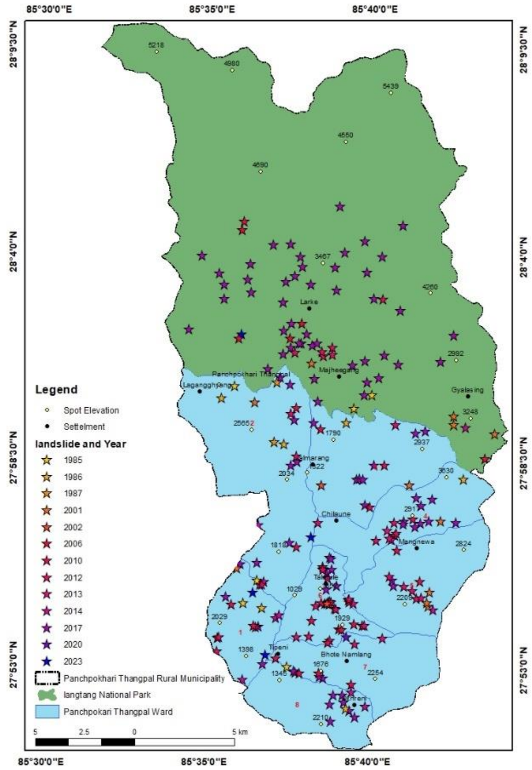
Gapa_Napa	Ward	Name	Date in AD	Occurrence time	Local place name	Comment	Longitude	Latitude	Elevation
Helambu Rural Municipality	6		1972-06-23		Helambu	Base line	85.49545	27.94987	
Helambu Rural Municipality	5		1977-07-27		Mahankal	Base line	85.50398	27.88948	
Helambu Rural Municipality	5		1977-08-12		Mahankal	Base line	85.50643	27.88536	
Helambu Rural Municipality	6		1990-06-26		Ichok	Base line	85.50847	27.93475	
Helambu Rural Municipality	5		1997-08-12		Mahankal	Base line	85.50398	27.88948	
Helambu Rural Municipality	5		2002-08-04		Mahankal	Base line	85.49852	27.89014	
Helambu Rural Municipality	5		2002-08-05		Mahankal	Base line	85.50101	27.88375	
Helambu Rural Municipality	5		2002-08-05		Mahankal	Base line	85.50599	27.88868	
Helambu Rural Municipality	5		2002-08-18		Mahankal	Base line	85.50398	27.88948	
Helambu Rural Municipality	5		2018-07-09			Base line	85.49843	27.88105	
Helambu Rural Municipality	1		2022-07-26			Base line	85.54008	27.993	
Helambu Rural Municipality	5		2018-07-09			Bipad	85.49843	27.88105	
Helambu Rural Municipality	1		2022-07-26			Bipad	85.54008	27.993	
Panchpokhari Thangpal Rural Municipality	7		2018-08-08			bipad	85.66921	27.8822	
Panchpokhari Thangpal Rural Municipality	6		2019-07-12			bipad	85.64771	27.91016	
Panchpokhari Thangpal Rural Municipality	2		2020-08-03		Baruwa	bipad	85.61348	27.97198	
Panchpokhari Thangpal Rural Municipality	8		1996-08-08		lagarche	Base line	85.64756	27.86734	
Panchpokhari Thangpal Rural Municipality	8		2002-06-24		lagarche	Base line	85.6493	27.87131	
Panchpokhari Thangpal Rural Municipality	7		2018-08-08			Base line	85.66921	27.8822	

Panchpokhari Thangpal Rural Municipality	6		2019-07-12			Base line	85.64771	27.91016	
Panchpokhari Thangpal Rural Municipality	2		2019-09-04		Bolgaun. Dalit basti	Base line	85.62703	27.95549	
Panchpokhari Thangpal Rural Municipality	7		2020-08-03		Ratamate, Bhotenamlang	Base line	85.65478	27.88581	
Panchpokhari Thangpal Rural Municipality	2		2020-08-03		Baruwa	Base line	85.61348	27.97198	
Panchpokhari Thangpal Rural Municipality	1		2020-08-14		Baskharka, jatan	Base line	85.60189	27.88823	
Panchpokhari Thangpal Rural Municipality	1		2020-08-14		Baskharka, Misseppa	Base line	85.60283	27.87974	
Panchpokhari Thangpal Rural Municipality	8		2020-08-14		Tipenin bajar, kharsebaluwa	Base line	85.60343	27.87134	
Panchpokhari Thangpal Rural Municipality	2		2021-06-15		Baruwa, Toshiba	Base line	85.61647	27.92268	
Panchpokhari Thangpal Rural Municipality	2		2021-06-15		baruwa sunchaur	Base line	85.61135	27.92081	
Panchpokhari Thangpal Rural Municipality	2		2023-07-18		Baruwa, Dale	Base line	85.61809	27.91922	

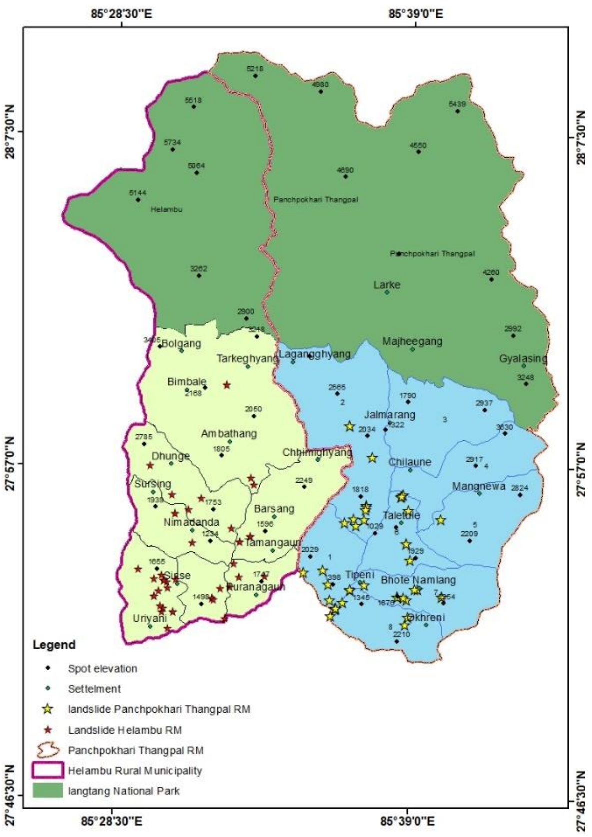
Annex 3: Landslide inventory map of study area.



Landslide inventory from Google Earth 1990-2023 of Helambu rural municipality



Landslide inventory from Google Earth 1990-2023



Landslide point obtained from field with respect to time

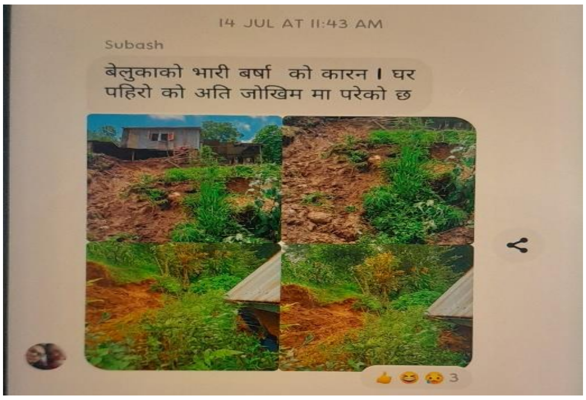
Annex 4: Field Photograph showing the collection of data

Discussion with DRR focal person of Helambu Rural Municipality.

Shallow landslide observed at Ward no 1 Helambu RM Cheure kharka 2081-03-12 11am

Discussion with local focal person regarding the date of the landslide

Landslide at Tipeni village 2076/04/27

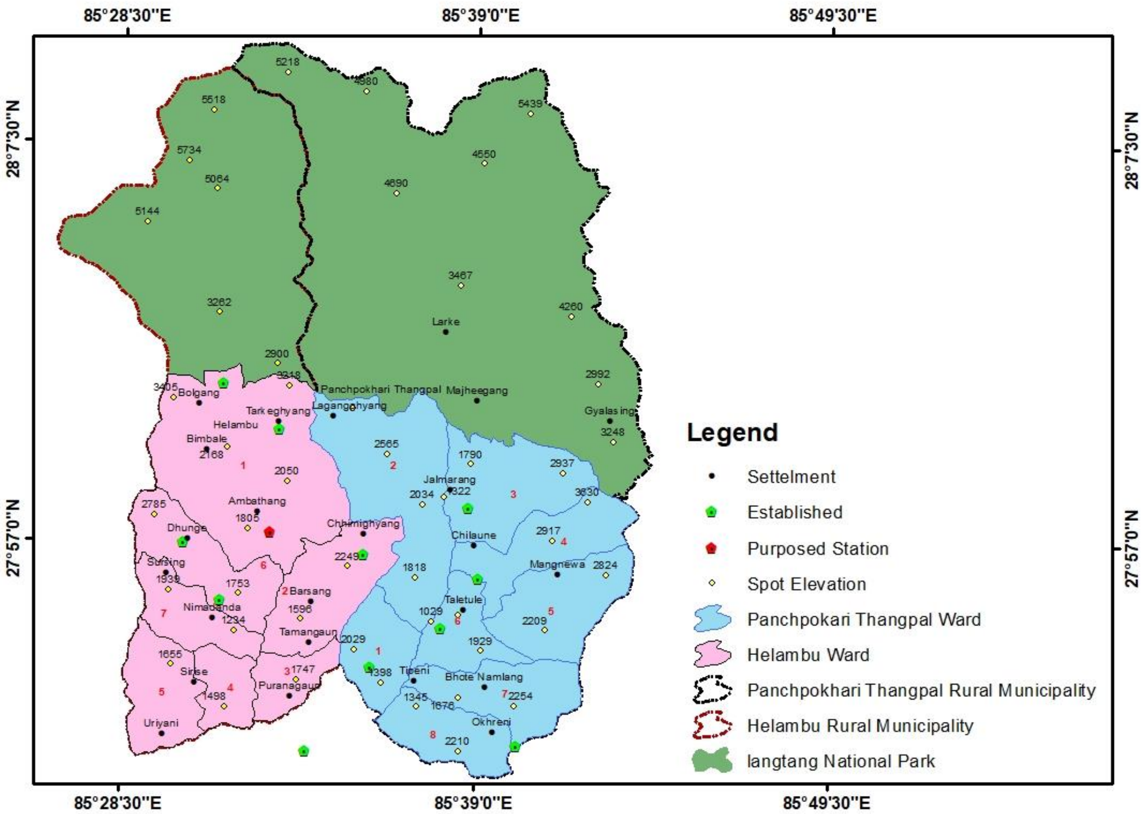


Example of time data obtained from local people from their social media.

Discussion with local to know the history of landslide at Manekharka

Annex 5: Rainfall station in study area with proposed station.

Name	Longitude	Latitude	Status
Banskharka	85.598545	27.895454	Established
Bhotang	85.64686	27.965573	Established
Bolde	85.524275	27.924032	Established
Dhap	85.633379	27.912452	Established
Dhunge	85.505655	27.949378	Established
Duwachaur	85.56695	27.858368	Established
Gobre	85.671111	27.861111	Established
Manekharka	85.652091	27.934514	Established
Melamchi ghyang	85.525195	28.019277	Established
Proposed station	85.5485	27.954	Proposed Station
Sarmathang	85.595136	27.944561	Established
Tarkeyghyang	85.553066	27.999171	Established



Map showing proposed rainfall station

BIG CHANGE
starts small

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