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An integrated analysis of snow and ice avalanche hazards in the Annapurna Conservation Area, Nepal Himalaya

（ネパール，アンナプルナ保全地域における雪崩ハザードの統合的分析）

Ph.D. thesis submitted to the Graduate School of Environmental Science, Hokkaido University, Sapporo, Japan

By

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Abstract

The cryosphere in High Mountain Asia (HMA) serves not only as a vital source of water for the populations living downstream but also possesses the potential for hazards. One such hazard, avalanches, has received inadequate attention, as the complex relationship between climate and potential triggers is not well understood due to a lack of long-term observations, inaccessibility, severe weather conditions, and financial and logistical constraints. This study aims to address this gap by focusing on the current state of knowledge regarding avalanche hazards in HMA. It examines the research and societal gaps, proposes potential future research directions and mitigation strategies, and develops an avalanche susceptibility map for the Annapurna Conservation Area (ACA). This study also delves deeper into the impact of avalanches on lives, livelihoods, and vulnerable communities in the ACA, and evaluates the existing disaster risk management strategies at the local level.

First, existing literature was examined, encompassing the period between 1972 and June 2022, to identify research and societal gaps and propose future research directions and mitigation strategies. In addition to scientific literature, technical reports, newspapers, social media, and other local sources were consulted to create a comprehensive, open-access, version-controlled database of avalanche events and their associated impacts.

The avalanche susceptibility map of the Annapurna Conservation Area was developed using a Multi-Criteria Decision Analysis (MCDA)–Analytical Hierarchy Process (AHP) model within a Geographic Information System (GIS) environment. The terrain parameters, including slope, curvature, terrain roughness, elevation, and aspect, were derived from ASTER GDEM V3 (ASTGTM), as well as ground cover data from ESRI land use/land cover, lithology (NTB), and meteorological data, such as air temperature and precipitation datasets from the Department of Hydrology and Meteorology (DHM), Nepal. The relative weights of the criteria and sub-criteria were determined using MCDA-AHP based on expert judgment, literature, and historical avalanche events.

Two areas, the Annapurna Base Camp (ABC) route (Area 1) and the Kobang area (Area 2) in the ACA, were considered for the questionnaire survey to analyze exposure to avalanche hazards. A total of 30 questions about avalanches were asked in 24 and 69 households in Areas 1 and 2, respectively. Focus group discussions were conducted in both areas with relevant stakeholders to analyze existing disaster management strategies.

A total of 681 avalanches have been documented in eight countries, resulting in the loss of 3131 human lives. Afghanistan experienced the highest number of avalanche fatalities with 1057 casualties, followed by India with 952 and Nepal with 508. Furthermore, 564 individuals

perished while attempting to climb peaks that were higher than 4500 m a.s.l., with one-third of them serving as guides or porters. Although this represents a lower fatality rate than in the less populated European Alps, for example, but the number of affected individuals who did not willingly expose themselves to avalanche risk is noteworthy. The region lacks comprehensive adaptation or mitigation measures for avalanches, which typically rely on local and indigenous knowledge that has been adapted to modern technology. Considering the significant fatalities and long-term local impacts of avalanches, further development of adaptation measures, such as hazard zonation maps, based on historical event datasets and modeling efforts, is recommended. However, this should be done in collaboration with communities, local governments, and civil society stakeholders, as well as by recognizing and building upon the existing knowledge in the region. Future research should focus on identifying the trends and drivers of avalanches in this region.

The susceptibility map was evaluated using the natural breaks method, which yielded five distinct zones: very low, low, moderate, high, and very high susceptibility. The high and very high zones accounted for approximately 37.0% of the total area, while the moderate zone covered 23.9%. The validation was carried out using an inventory map of 120 cases derived from documented avalanche locations, field surveys, and satellite imagery. The prediction accuracy was evaluated using the area under the ROC curve (ROC-AUC) method, resulting in an approximate accuracy rate of 89%. The findings of this comprehensive hazard analysis have the potential to enhance preparedness and mitigation planning in the study area.

The results of the social survey conducted in the ABC route (Area 1) and Kobang area (Area 2) revealed that 133 individuals in Area 1 and 313 individuals in Area 2 were continually exposed to the threat of avalanches. The exposed population primarily consisted of migrant workers in Area 1. In contrast, most of the local population, along with some migrant workers engaged in agricultural activities, was highly vulnerable to avalanche hazards in Area 2. Both areas experienced avalanche impacts, resulting in a significant number of casualties and livestock losses, particularly in Area 2. Area 1 demonstrated better preparedness and mitigation efforts than Area 2. While a certain percentage of households in both areas mentioned implementing avalanche mitigation measures, a smaller proportion actually took steps towards prevention and mitigation. Focus group discussions revealed a lack of concrete mitigation mechanisms in both areas. However, community members in Area 1 exhibited greater awareness and proactive measures, such as constructing control structures to mitigate avalanche impacts. By contrast, Area 2 predominantly relied on short-term compensation measures, highlighting the need for more robust mitigation strategies.

This study advances our comprehension of avalanche risks and introduces an avalanche susceptibility map as a fundamental resource for future investigations. An extensive social survey was executed in two areas prone to avalanches to explore the prevailing avalanche scenarios, coping mechanisms, and the roles of local authorities in mitigating these hazards. This study suggests a comprehensive approach that incorporates avalanche susceptibility modeling and socioeconomic surveys to gain in-depth insights into avalanche dynamics, thereby facilitating the formulation of effective policies and control measures. These findings constitute the foundation for future research and policy development to enhance the resilience of avalanche-prone communities.

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Table of Contents

List of figures

List of tables

List of acronyms

AAR	:	Accumulation Area Ratio
ABC	:	Annapurna Base Camp
ACA	:	Annapurna Conservation Area
ACAP	:	Annapurna Conservation Area Project
AHP	:	Analytical Hierarchical Process
AKAH	:	Aga Khan Agency for Habitat
ALOS	:	Advanced Land Observing Satellite
ARM	:	Annapurna Rural Municipality
ASTER	:	Advanced Space-borne Thermal Emission and Reflection Radiometer
AUC	:	Area Under the Curve
AVPT	:	Avalanche Preparedness Team
BC	:	Before Christ
CAMC	:	Conservation Area Management Committee
CBDRM	:	Community-Based Disaster Risk Management program
CERT	:	Community Emergency Response Teams
CR	:	Consistency Ratio
CRRT	:	Community Rapid Response Team
CYC	:	Century Youth Club
DEM	:	Digital Elevation Model
DGRE	:	Defence Geoinformatics Research Establishment
DHM	:	Department of Hydrology and Meteorology
DRR	:	Disaster Risk Reduction
ESRI LULC	:	Environmental Systems Research Institute, Inc, Land Use/Land Cover
FDA	:	Full-depth dry snow avalanche
FGD	:	Focus Group Discussions
FOCUS	:	Focus Humanitarian Assistance
FWA	:	Full-depth Wet snow Avalanche
G.H	:	Guest House
GDEM	:	Global Digital Elevation Model
GIS	:	Geographic Information System

GLOF	:	Glacial Lake Outburst Flood
GPS	:	Global Positioning System
H.N.	:	Heading Number
HKH	:	Hindu Kush Himalaya
HMA	:	High Mountain Asia
HVRA	:	Hazard Vulnerability and Risk Assessments
ICIMOD	:	International Centre for Integrated Mountain Development
IPCC AR6	:	Intergovernmental Panel on Climate Change, Sixth Assessment Report
km^2	:	square kilometer
MBC	:	Machhapuchre Base Camp
MCDA	:	Multi-criteria decision analysis
NE	:	North East
NPR	:	Nepalese Rupees
NTB	:	Nepal Tourism Board
NW	:	North West
RAMMS	:	Rapid Mass Movement Simulation
RI	:	Random Index
RL	:	Rocket Launchers
RM	:	Rural Municipality
ROC	:	Receiver operating characteristic
SAMOS	:	Snow Avalanche Modelling and Simulation
SAR	:	Synthetic Aperture Radar
SASE	:	Snow & Avalanche Study Establishment
SDA	:	Surface-layer Dry snow Avalanche
SERT	:	School Emergency Response Teams
SWA	:	Surface-layer Wet snow Avalanche
TMC	:	Tourism Management Committee
TRM	:	Thasang Rural Municiplaity
USA	:	United States of America

Chapter 1: Introduction

1.1 Background

The High Mountain Asia (HMA), a unique region encompassing the Hindu Kush Himalaya (HKH) and the Tien Shan mountains, is often referred to as the “Third Pole”. It holds the distinction of having the largest expanse of snow, glaciers, and permafrost outside of the North and South Poles. Spanning 4.2 million km^2, with 1.4% glaciated and 0.76 km^2 covered in perennial snow (Bajracharya et al. 2015), this region acts as a vital water tower, supplying water to 10 major river systems and supporting approximately 1.9 billion people downstream, primarily in China, Nepal, and India (Wester et al. 2019).

Moreover, this region is home to four global biodiversity hotspots and boasts 330 crucial bird areas (Chettri et al. 2008), making it vital for sustaining ecosystems and biodiversity. Its significance extends further as it ensures water availability for agriculture, domestic needs, industry, and hydropower, providing essential ecosystem services to support the livelihoods of 240 million people in the mountainous and hilly regions (Immerzeel et al. 2010; Wester et al. 2019).

However, the cryosphere in the HMA presents not only valuable natural resources but also the potential for numerous mountain hazards, such as glacial lake outburst floods and avalanches, and indirect impacts, such as disrupted irrigation channels, receding glaciers, and changing climate patterns (Richardson and Reynolds 2000).

Snow and ice avalanches are also significant among all mountain hazards, with annual fatalities of around 250 worldwide (Schweizer et al. 2021). Avalanches, rapid gravity-driven masses of snow moving down mountain slopes (Ancey 2001), can range from small surface sluffs of a few cubic meters to massive events involving masses of several hundred thousand cubic meters (Schaerer 1967; Luckman 1977). In mountainous countries such as Switzerland, avalanches account for 37% of all natural hazard fatalities, with an average of 5.5 fatalities per year between 1946 and 2015 (Badoux et al. 2016), making it one of the deadliest natural hazards in mountainous terrain such as the Himalayas.

Avalanches cause considerable property and infrastructure damage annually and can severely affect socio-economic activities and livelihoods (McClung and Schaerer, 2006). The number of avalanche fatalities yearly due to snow avalanches is estimated to be about 250 worldwide. In Europe and North America alone, avalanches claimed the lives of about 1900 people between the winters of 2000–2001 and 2009–2010 (Schweizer et al. 2021). In Switzerland, avalanches caused 37% of 1023 fatalities associated with natural hazards between

1946 and 2015 (∼5.5 fatalities per year), making it by far the deadliest category (Badoux et al. 2016). A later study finds a considerably higher number of >20 fatalities per year between 1995 and 2014 (Berlin et al. 2019), indicating the challenge of such records, considering that Badoux et al. (2016) found a general decrease in avalanche fatalities. In the European Alps, ∼100 fatalities per year occurred between 1937 and 2015 (Techel et al. 2016). In the USA, ∼16 fatalities per year occurred between 1950 and 2018 (Peitzsch et al. 2020). Mainly deadly events have historically been associated with mountain warfare, ranging from an event during an Alps traverse in 218 BC to the Alps traverse by Napoleon in the 19th century, fighting in the Dolomites during World War I, as well as impacts along the Indo-Pakistan border (Schweizer et al. 2021). Individual death tolls of many thousands have also been recorded in the more recent past in the Andes (Plafker and Ericksen 1978; Carey 2005). Beyond human life, avalanches can significantly impact ecosystems (Bebi et al. 2009), livelihoods (Carey 2005), and infrastructure. Compared to cryosphere hazards such as glacier lake outburst floods (Emmer et al. 2022), avalanches have received considerably less attention in the literature.

The earliest investigations into avalanche hazards date back to the late 19th and early 20th centuries in Europe, North America and Japan (Ancey et al. 2005) but started much later in HMA regions (Deng 1980; Yanlong and Maohuan 1986, 1992). Prediction of snow cover and snow avalanche behavior is very crucial in addressing adaptation, risk management and resilience strategies (Hovelsrud et al. 2018). In Switzerland, Bois et al. (1975) first attempted to develop models for avalanche forecasting, and Buser (1983, 1989) further worked on developing statistical models based on nearest neighbor methods for local forecasting. Numerical one-dimensional models such as AVAL-1D, Voellmy–Salm or VAlanghe RAdenti (VARA) (Bartelt et al. 1999; Barbolini et al. 2000; Christen et al. 2002) were used extensively in Switzerland and elsewhere in Europe, America and Asia. Their limitations in open terrain and terrain with several possible flow channels led to two-dimensional and three-dimensional models such as SAMOS, a model developed to simulate dry snow avalanches (Sampl and Zwinger 2004) and RAMMS (Rapid Mass Movement Simulation), a model to simulate flowing snow avalanches in a complex terrain (Christen et al. 2010). Many of these modelling studies were motivated by risk assessments, especially after large avalanche events that caused considerable damage (e.g. the case of Galtür in 1999; Bründl et al. 2004; Fuchs et al. 2004; Keiler, 2004). As another direct result, mitigation and adaptation measures in Europe and North America have received considerable attention, and in countries such as Canada, Switzerland and Norway, the link between scientific evidence and agencies responsible for avalanche forecasting and hazard evaluation has been close. Parallel to model development, numerous studies have investigated the potential of remote sensing to detect and investigate snow avalanches (Bühler et al. 2009; Lato et al. 2012; Eckerstorfer et al. 2016; Korzeniowska et al. 2017; Eckerstorfer et al. 2019; Bühler et al. 2019). While some model studies have been attempted in the HMA in the 1990s and 2000s (Singh et al. 2005; Joshi et al. 2018), advanced remote sensing of avalanches in the region remains largely unexplored.

Ice avalanches have received less attention in literature due to a less frequent and often much more remote occurrence but have nevertheless been of interest for many years (Röthlisberger 1977; Alean 1985). They have been specifically investigated in the context of unstable ice in steep terrain in the Alps, with an interest in characterizing their magnitude (Vincent et al. 2015; Margreth et al. 2017) as well as predicting potentially hazardous break offs (Pralong et al. 2005; Pralong and Funk 2006; Caplan-Auerbach and Huggel 2007; Faillettaz et al. 2012, 2016). More recently the compound occurrence of ice and snow (Margreth and Funk 1999; Bartelt et al. 2016) as well as ice and rock (Huggel et al. 2005; Lipovsky et al. 2008; Shugar et al. 2021) as part of a mass movement has received more attention, often resulting in very high-impact and long-runout scenarios.

Beyond the focus on avalanches as hazards, their response to climate change has been of interest, but so far no clear links are apparent, and studies remain largely limited to the French Alps (Martin et al. 2001; Eckert et al. 2010, 2013; Giacona et al. 2021). To investigate avalanche occurrence and return periods in the past, dendrochronology has been extensively used (Muntán et al. 2004; Casteller et al. 2008, 2011; Malik and Owczarek 2009; Tumajer and Treml 2015).

1.2 Avalanche Types

Snow avalanches in alpine environments are characterized based on their release type, sliding surface, motion, and free water content (Perla 1980; Munter 1999; Hübl et al. 2002; McClung and Schaerer 2006) as shown in Figure 1.1.

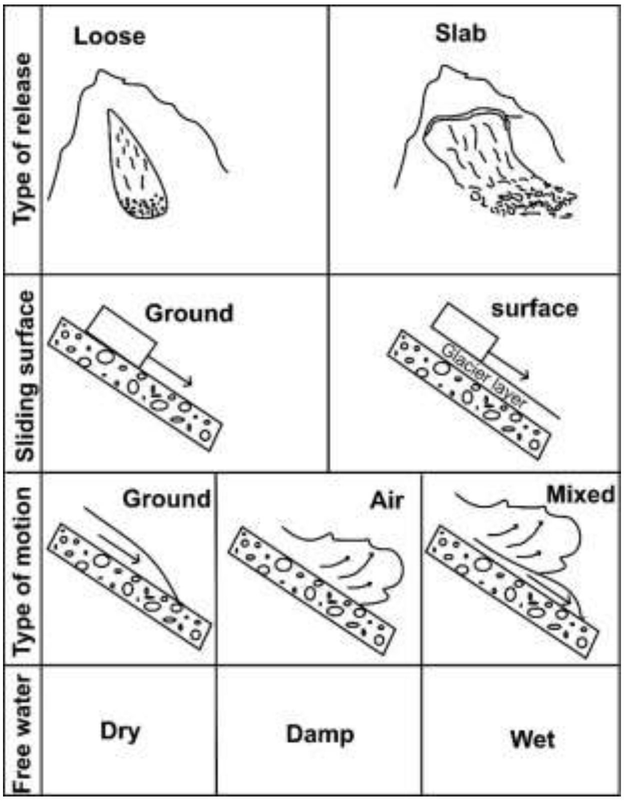

Figure 1.1 Types of loose snow and slab snow avalanches (by the author); Source: (Hübl et al. 2002)

The most common types of avalanches are discussed in detail in the following sections.

1.2.1 Loose-snow avalanches

This type of avalanche generally starts at a single point or area where cohesionless snow is prominent and is spread out in a triangular shape as it moves downslope (Hübl et al. 2002; McClung and Schaerer 2006; Pfurtscheller and Thieken 2013). These avalanches start at or near the surface and mainly involve only surface or near-surface (Figure 1.2). Loose snow avalanches can be both dry and wet based on the water content present in the snowpack. Wet loose snow avalanches are regarded as more dangerous and massive compared to dry loose snow avalanches. However, the primary mechanism for the occurrence is the same. The slope is a crucial variable, and motion generally only starts when it exceeds a critical value (angle of repose). The angle of repose responsible for causing loose-snow avalanches depends on snow temperature, cohesiveness, grain geometry, and snowpack's water content (McClung and Schaerer 2006). The local loss of cohesion due to metamorphism or the effects of sun and rain are responsible for loose-snow avalanches. Locations near rock outcrops with high local surface temperatures are mostly considered starting zones for these avalanches. Both natural and artificial activities, including skiing, walking, rockfall, or even snowfall, are also potential triggers.

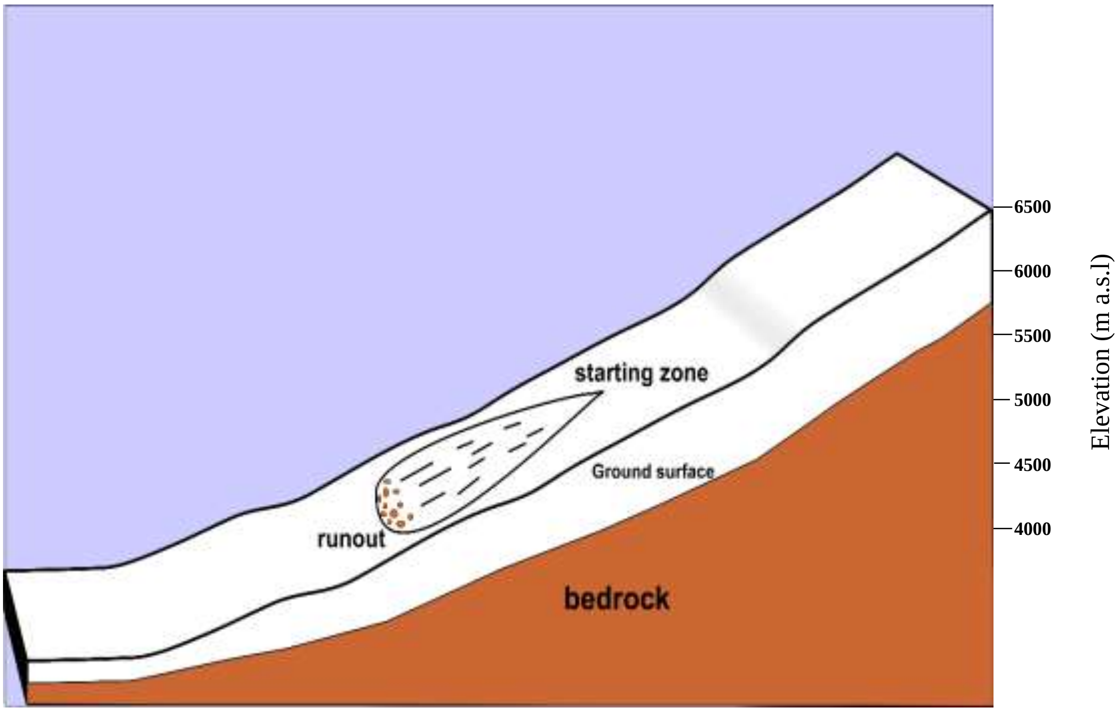

Figure 1.2 Typical schematic diagram of a loose snow avalanche, a profile of a glacier in Nepal (by the author)

1.2.1.1 Wet loose-snow avalanches

Wet loose avalanches can cause damage to vehicles, highways, and structures. These avalanches are more dangerous to mountaineers on steep faces or gullies during warm weather or rainy conditions. Heavy melt due to direct solar radiation or precipitation in the form of rain on the snowpack (rain-on-snow or ROS) is the most important trigger factor for causing wet loose-snow avalanches. This melting of the snowpack increases the water content of the snowpack which ultimately decreases cohesion between snow grains and accelerates their metamorphism. The chances of wet loose snow avalanche occurrences are higher when the near surface water content increases or bonding between grains is otherwise weakened (McClung and Schaerer 2006).

1.2.1.2 Dry loose-snow avalanches

Unlike wet snow avalanches, this type of avalanche loses cohesion due to cold temperatures and relatively calm conditions. These avalanches are generally less dangerous and dense than wet snow avalanches; however, they sometimes pose severe threats to mountaineers while climbing steep faces. If there is no wind, snow will lose cohesion due to the lack of wind packing and breakage effects, and bonds cannot form under icy circumstances.

This type of avalanche involves low-density snow and unrimed snow crystals (stellar crystals). However, they can also involve relatively high-density heavily rimmed crystals like graupel.

1.2.2 Slab avalanches

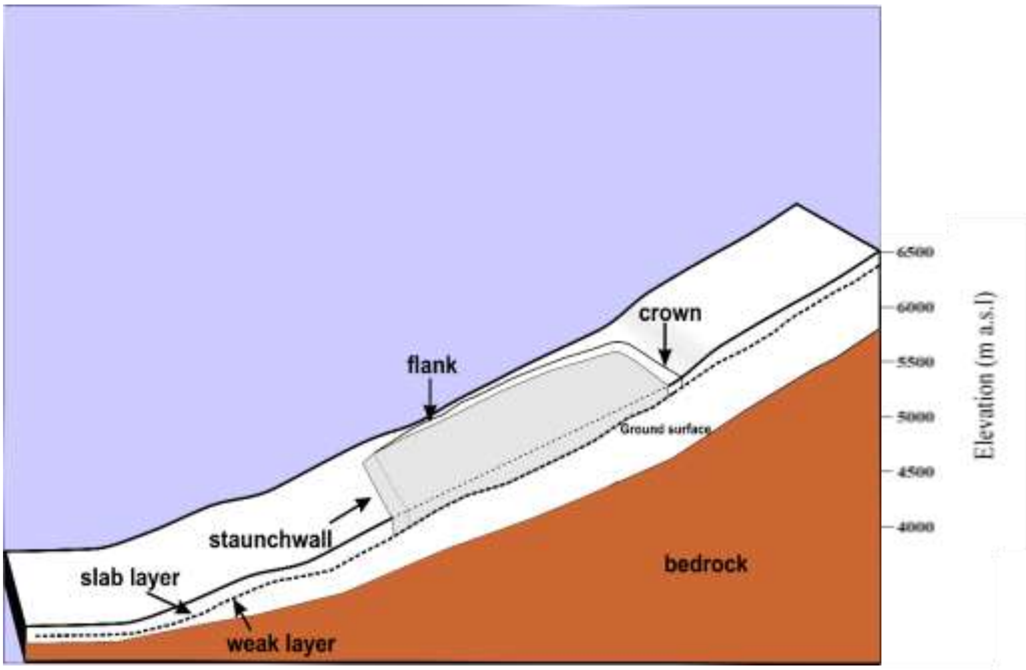

Figure 1.3 Typical schematic diagram of a slab avalanche, a profile of a glacier in Nepal (by the author)

This type of high-density avalanche can occur anytime during the snow season. The Figure 1.3 shows the typical schematic diagram of a slab avalanche In these avalanches, a cohesive snow layer sitting above the weak layer slides is induced when shear deformation exceeds the maximum value the snow layers can withstand. Figure 1.3 shows a schematic diagram of the slab avalanche. These avalanches, associated with a thin, weak layer at a certain depth, result in the sliding of the block of snow, which is usually rectangular(Ancey 2001; Hübl et al. 2002; McClung and Schaerer 2006; Pfurtscheller and Thieken 2013). A slab avalanche is likely to occur when snow strength, cohesion and friction, are low in a layer below the surface compared to neighboring layers directly above and below it.

1.2.2.1 Wet slab avalanches

This type of avalanche is associated with releasing a wet, cohesive layer of snow (a slab). Melting water makes the interface moist, wet, or saturated, weakening the bond between the slab and the surface beneath. These phenomena are prominent during prolonged warming events resulting in snowmelt or during rain-on-snow (ROS) events. These avalanches occur following three basic principles, namely loading by precipitation (rain), changes in the strength of a buried weak layer due to water, and lubrication of a sliding surface, which may be partially or totally impermeable to water (McClung and Schaerer 2006). These avalanches are prominent in shallower snowpack and mainly concentrated at lower elevations, especially during the melt season.

1.2.2.2 Dry slab avalanches

Unlike wet slab avalanches, dry avalanches often happen because of increased load. Most slab avalanches are observed because of loading by new snowfall, especially in cold conditions at slightly higher elevations. The snowpack deforms slowly with increasing shear stress and can fail without previous fractures. The shear stress should reach the shear strength in the weak layer, and the deformation rate in the weak layer should be fast enough to induce fracture. The intermediate condition, where only the first pre-requisite is fulfilled, poses a threat to a person crossing the snow because, at this stage, failure is already there, but the fracture is yet to occur. Natural activities such as adding weight by new snowfall and wind, impacts by falling cornices, and seismic activity are common triggers for dry slab avalanches (McClung and Schaerer 2006).

1.2.3 Ice avalanche

Ice avalanches are very common in glacierized and glaciated mountain ranges and have been responsible for substantial avalanche disasters, including the Huascaran avalanches in Peru in 1962 and 1970 and the Mattmark/Allalin disaster in Switzerland in 1962 (McClung and Schaerer 2006).

In the HMA, these avalanches are quite frequent along high peaks and ridges and have been reported on peaks such as Mount Everest and K2 (Bartelt et al. 2016; McClung 2016). Ice avalanches can be divided into two classes: collapsing hanging glaciers or avalanching glaciers (Faillettaz et al. 2012) and glacier detachments (Kääb et al. 2021).

The first type of ice avalanche is characterized by the calving/falling of ice masses or seracs at positions where glacier ice flows over a steep slope or along a ridge. This occurs due to a tensile failure of the ice induced by the combination of internal flow (creep) and sliding of the glacier over its bed. The intriguing aspect is that multiple external factors can contribute to such an event, including meltwater as well as the extra load on top of the ice (Faillettaz et al. 2012). The collapse of glacier seracs in icefalls has led to numerous fatalities in the HKH. For instance, the 2014 Khumbu ice fall avalanche claimed 16 lives in 2014 and 23 in 2015 (Thakuri et al. 2020). In 2008, serac falls at the bottle neck below the peak and claimed 11 lives on K2

(Kutsch et al. 2017). Seismic activity can also induce failure. The Gorkha Earthquake triggered the avalanche in Langtang Valley in 2015 (Kargel et al. 2016), and the same earthquake was responsible for the avalanche in Khumbu Icefall in 2015 (Bartelt et al. 2016). Ice avalanches are more frequent in spring or summer as more basal meltwater becomes available (McClung and Schaerer 2006).

The second type of ice avalanche, a considerably rarer occurrence, occurs when a large piece of the glacier detaches to form an ice avalanche. Recent studies have been instrumental in shedding light on previously unknown cases attributed to this process (McClung and Schaerer 2006; Kääb et al. 2018, 2021).

1.3 Motivation and research objectives

While High Mountain Asia (HMA) serves as a lifeline for millions of people, ensuring water availability and fostering biodiversity, it remains vulnerable to the recurrent threat of avalanches. The comprehensive overview of the state of knowledge on snow and ice avalanches in the HMA remains lacking. The Annapurna Conservation Area lies within this region, with a rich ecosystem boasting diverse flora and fauna yet susceptible to avalanche hazards. Only a few fatalities have been documented (McClung 2016; Thakuri et al. 2020). Earthquake-triggered ice avalanches in Langtang received some limelight (e.g., Fujita et al. 2017). However, no assessment of the entire region has been carried out even though avalanches are the prominent type of cryospheric hazard there. The studies related to avalanche hazards, all in terms of mapping, prediction, and modeling, are concentrated mainly in the Western Himalayas (Ganju and Dimri 2004; Bühler et al. 2013; Kumar et al. 2017), but very few studies have been carried out in eastern and central Himalaya (Sherpa et al. 2019; Tuladhar et al. 2021). The complex nature of the terrain, high altitude, and financial and logistic constraints exacerbate these studies.

Recent events such as the Seti flood due to a suspected avalanche in the Annapurna IV in 2012 killed 72 people (Kargel et al. 2014), a snowstorm in 2014 led to a series of avalanches claimed 43 lives (Thakuri et al. 2020), and the avalanche in the ABC route (Deurali) in January 2021 killed seven people. These examples show the urgency of research. The frequency and magnitude of such disasters are on the rise, as evidenced by the area that experienced a massive avalanche with significant livestock fatalities in Kobang, Mustang, in November 2021, only to face another avalanche in March 2022 (Shrestha 2022).

With the increasing movement of people for recreational and research purposes in the inner part of the Himalayas in recent decades, avalanches have affected not only the locals but also other individuals who encounter numerous avalanches on their way. Avalanches have significantly impacted the livelihoods of surrounding communities, the natural environment, and the socio-economic stability of the region. Therefore, it is crucial to conduct an avalanche hazard analysis in the Annapurna Conservation Area (ACA).

The overall objective of this research is to carry out the avalanche hazard analysis of the HMA region with a particular focus on the Annapurna Conservation Area (ACA) to enhance the resilience of the mountain people. The specific objectives are as follows:

1. To analyze the available avalanche hazard literature to identify research and societal gaps and propose future directions of research and mitigation strategies,
2. To derive an avalanche hazard susceptibility map of the ACA using Multi-Criteria Decision Analysis (MCDA)-Analytical Hierarchy Process (AHP) in a GIS environment,
3. To analyze the exposure of life, livelihoods, and infrastructure to the avalanche hazards and vulnerability to the avalanche hazards in the ACA, and,
4. To analyze the existing disaster risk management strategy at the local level in the ACA.

1.4 Thesis structure

The dissertation comprises seven chapters structured to fulfill the four main objectives of the research. While these chapters are interrelated and progressively ordered, they are also designed to stand alone, and the readers can read them separately. **Chapter 2** provides a comprehensive overview of the study area, detailing the datasets utilized and methodologies applied to achieve the research objectives. **Chapter 3** highlights the overview of the knowledge and data on snow and ice avalanches in the HMA region based on all available scientific literature, media coverage, and local and Indigenous knowledge records. **Chapter 4** outlines the results of the methodological approach to developing an avalanche hazard susceptibility map using Multi-Criteria Decision Analysis (MCDA) and the Analytical Hierarchy Process (AHP) within a Geographic Information System (GIS) framework. **Chapter 5** discusses the findings, focusing on the exposure of life, livelihoods, and infrastructure to avalanche hazards, as well as the vulnerability of communities and the effectiveness of existing local-level disaster risk management strategies in two areas: ABC route and Kobang region in the Annapurna Conservation Area. **Chapter 6** presents the general discussions linking the findings of the research. Finally, **Chapter 7** concludes the research findings by proposing recommendations. A comprehensive bibliography listing all references cited throughout the dissertation is provided at the end.

Chapter 2: Methodology and Study Area

2.1 Selection of Study Area

High Mountain Asia (HMA) consists of 22 subregions namely Dzhungarsky Alatau (01), Eastern Tien Shan (02), Central Tien Shan (03), North/Western Tien Shan (04), Pamir Alay (05), Western Pamir (06), Eastern Pamir (07), Eastern Hindu Kush (08), Karakoram (9), Western Himalaya (10), Central Himalaya (11), Eastern Himalaya (12), Western Kunlun Shan (13), Eastern Kunlun Shan (14), Altun Shan (15), Tibetan Interior Mountains (16), Gangdise Mountains (17), Nyainqentanglha (18), Tanggula Shan(19), Hengduan Shan (20), Eastern Tibetan Mountains (21), Qilian Shan (22) with an area coverage of about 4 million km^2 ((Bolch et al. 2019). It is the largest source of cryosphere outside polar regions (Bolch et al. 2019).

It is characterized by extreme topographic and climatic heterogeneity. The climatic patterns are predominantly influenced by the East Asian and Indian monsoon systems, which contribute the majority of precipitation to the central and eastern Himalayas from June to September (Bookhagen and Burbank 2006), with annual total precipitation up to 3,000 mm (Bookhagen and Burbank 2010; Maussion et al. 2014). Conversely, the western Himalayas experience intense winter snowfall due to westerly disturbances, with over 80% contribution to the total precipitation, typically ranging between 1,000 to 2,000 mm annually (Barlow et al. 2005; Bookhagen and Burbank 2010; Maussion et al. 2014), but the monsoon-influenced central and eastern areas experience comparatively drier winters (Shrestha et al. 2000). The region's complex topography creates annual temperature differentials of up to 40°C within short distances, and precipitation gradients vary significantly across the mountain ranges (Shrestha et al. 2012).

Over one billion people in HMA are at risk of exposure to increasingly frequent and severe natural hazards. Multiple hazards such as Floods, flash floods, avalanches, landslides, droughts, and earthquakes are very common in the region. The multi-hazard environment in the region creates cascading events that link upstream and downstream areas, often with transboundary impacts (Vaidya et al. 2019).

Avalanches are one of the significant hazards in mountainous terrain, leading to an annual loss of life and property in countries such as Afghanistan, Bhutan, India, Nepal, and Pakistan. Numerous cases of avalanches have been reported in the region. The avalanche studies have been conducted across the High Mountain Asia (HMA) region and comprehensively within the Annapurna Conservation Area (ACA). Figure 2.1 shows the location map of the study areas.

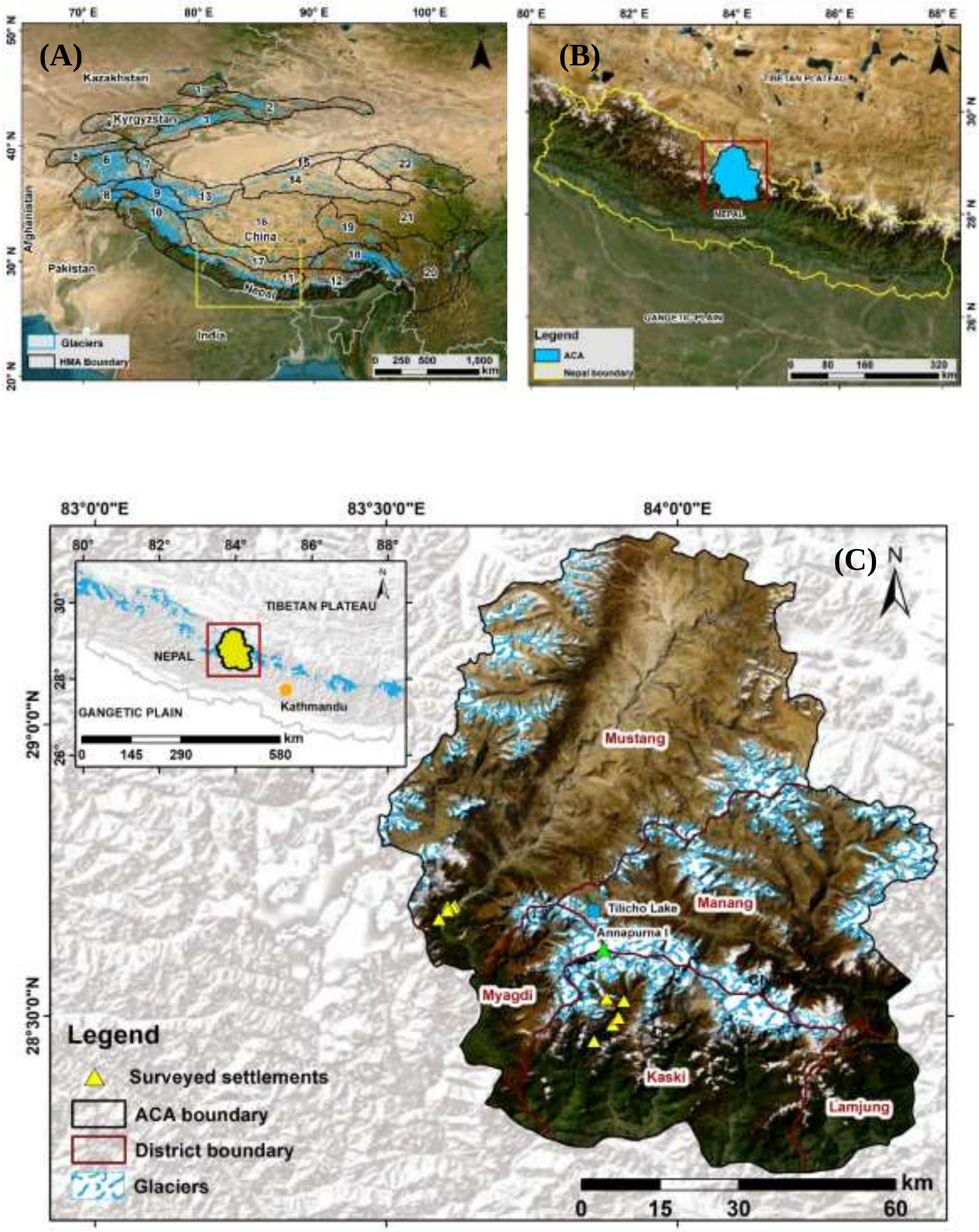

Figure 2.1 Location map of HMA (A), Nepal (B), and ACA(C) (by the author)

2.2 Methodology

The overall methodology employed in this research has been shown in Figure 2.2. Primary and secondary datasets were collected from various sources. A field visit to Annapurna Conservation Area was conducted to collect primary datasets. In contrast, different databases such as Nepal Tourism Board (NTB), Department of Hydrology and Meteorology (DHM), ESRI Land use land cover, Advanced Spaceborne Thermal Emission and Reflection Radiometer Global Digital Elevation Model (ASTER GDEM) version 3 were accessed for secondary datasets.

In order to examine the overview of avalanche hazards in the HMA region, information on avalanches was collected from sources including peer-reviewed articles, newspaper articles, technical reports, social media, and interaction with people in high mountain catchments in the region. The period covered ranges from the earliest records of deaths in the late 20th century to June 2022. Moreover, this is discussed in the methodology section of **Chapter 3.**

The MCDA-AHP method, a significant aspect of our research, was employed to derive the susceptibility map of ACA. This method, which considers seven terrain parameters and two meteorological parameters, is detailed in **Chapter 4.**

Similarly, questionnaire surveys and Focus Group Discussions (FGDs) were conducted in Annapurna Conservation Area (ACA) areas, Area 1: ABC Route and Area 2: Kobang Area. Five settlements in each area were considered for detailed questionnaire surveys to identify the exposure and impacts of avalanches and investigate the prevention and mitigation efforts applied in the region. The detailed methodology is discussed in **Chapter 5.**

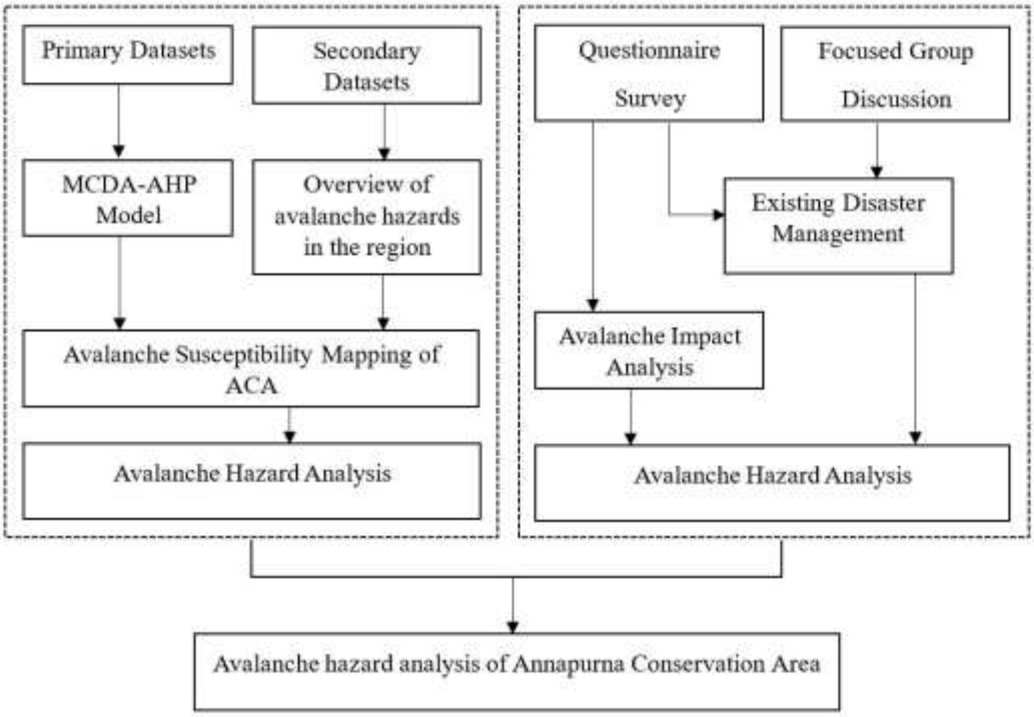

Figure 2.2. Conceptual flowchart of the methodology employed.

Chapter 3: Result 1- Overview of Snow and Ice avalanches in the HMA

3.1 Introduction

High Mountain Asia (HMA) comprises the largest expanse of snow, glaciers, and permafrost outside of the polar regions, and the meltwater from these cryospheric sources feeds ten major river systems of Asia, sustaining the lives and livelihoods of approximately 1.9 billion people residing downstream. As such, it is critical to ensure water availability for agriculture, domestic needs, industry, hydropower, and ecosystem services (Wester et al. 2019). However, the cryosphere in HMA also holds the potential for multiple hazards. Direct glacial hazards such as snow or ice avalanches, glacial lake outburst floods (GLOFs) after calving events or high melt, glacier detachments, and surges have been widely documented (Richardson and Reynolds 2000). This is also true for indirect hazards like breaching moraine-dammed lakes after intensive rainfall or disrupted irrigation channels associated with receding glaciers. Among all hazards, snow and ice avalanches (hereafter just referred to as avalanches) have received little attention in the scientific literature in the region.

The scientific literature on avalanches in HMA is limited. This contrasts the frequent occurrence of the hazard and repeated concerns by local mountain populations, who identify avalanches as a prime hazard of concern. It's crucial to note that the inclusion of local or indigenous knowledge in our understanding of avalanches, their impacts, and potential adaptation strategies is not just rare, but also invaluable (Butler 1987; Carey 2005; Alcaraz Tarragüel et al. 2012). The recent IPCC AR6 report has highlighted the importance of local and indigenous knowledge in mountain areas in our understanding of impacts and adaptation , acknowledging the significant role of local communities in this research (Adler and Wester 2022).

In HMA, a comprehensive overview of the state of knowledge on snow and ice avalanches remains lacking. Therefore, this chapter has reviewed knowledge and data on avalanches in the region. All available scientific literature, media coverage as well as records of local and Indigenous knowledge were considered in order to (a) quantify avalanches as a cryosphere hazard in the region for human life, livelihoods, and infrastructure; (b) identify the sources of knowledge and its application for adaptation solutions, including a review of previously established programs in response to avalanches; (c) identify gaps and propose future directions of research and mitigation that should be undertaken to further strengthen the resilience of mountain communities against this hazard.

3.2 Study Area

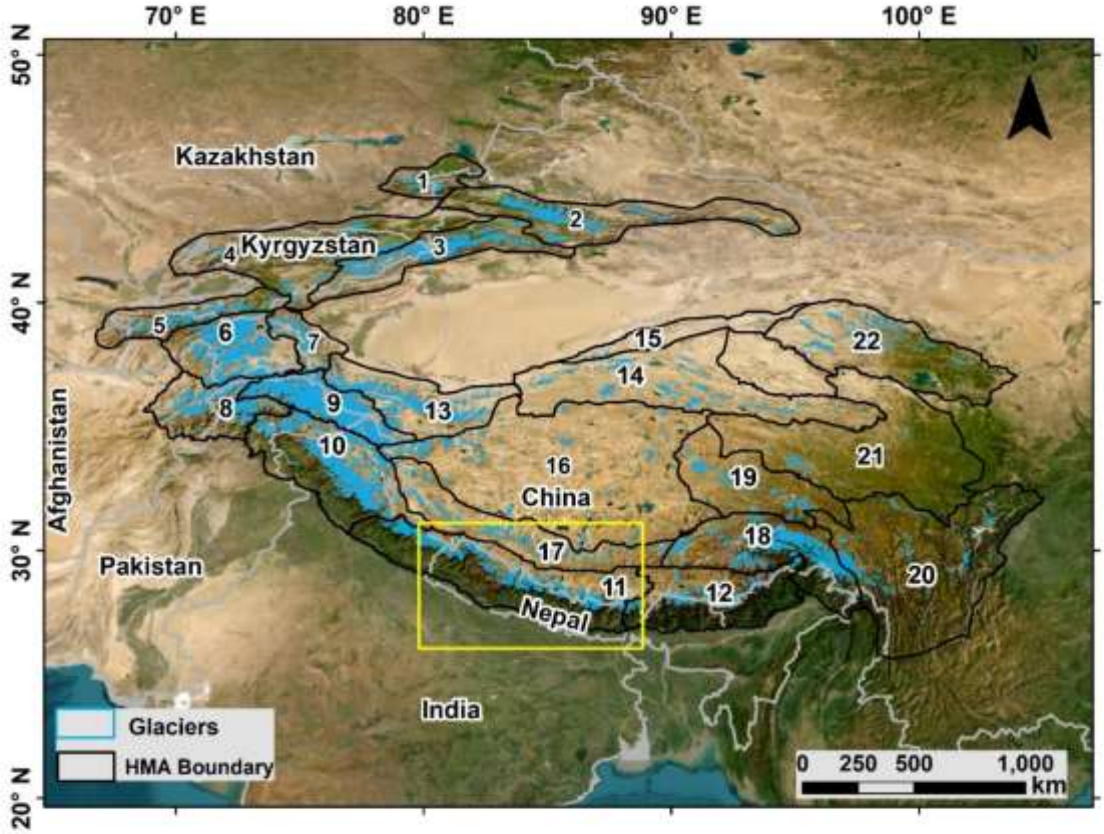

Figure 3.1 Location map of HMA with 22 subregions.

3.3 Methodology

In this study, data were collected from sources including peer-reviewed articles, newspaper articles, technical reports, social media and interaction with people in high mountain catchments in the region. The time period covered ranges from the earliest records of deaths in the late 20th century to June 2022. Information from the internet was verified by cross-checking with multiple other websites and reports. The information gathered likely does not include all events due to generally poor documentation of hazard events in the region (Emmer et al. 2022). An open-access and version-controlled database of events (HiAVAL) with all available information regarding the individual events and their impacts is available, where future updates can be traced. The events that affected high-altitude climbers (at peaks above 4500 m a.s.l.) are recorded separately, with the argument that these are people who willingly expose themselves to avalanche risk. Due to the relatively high number of fatalities from high-altitude mountaineering in HMA, these data would otherwise skew any statistics, and conclusions drawn are different than when speaking about impacts on civilians, exposed military personnel or tourists at lower elevations with no intentions of high-altitude mountaineering. In the data on high-altitude mountaineering the focus is more on the fraction of avalanche fatalities among guests (often foreign) and employees (guides, porters; often local).

While separation is not always strictly possible, this study focuses on snow and ice avalanches. Rock avalanches (Deline et al. 2015) and events that include a mixture of ice, snow, rock and debris (Shugar et al. 2021) have received increased attention globally but especially in HMA in recent years. In this study, however, they are consider only when the initial dominant source was, and the initial release mechanism is, related to either ice or snow (as in the case in Nepal in 2015; Kargel et al. 2016) rather than, for example, rock fracturing (as in India in 2021; Shugar et al. 2021). While not strictly avalanches, glacier detachments were considered to be a sub-class of ice avalanches in this review (Kääb et al. 2021).

An overview of the number and type of sources investigated in this study, and where the numbers on avalanche events and fatalities come from, is provided in Table 3.1. A full source document is provided in the **ANNEXURE A.**

Table 3.1 Type and number of most important sources used in this study, including the number of events and fatalities they cover. "Peer-reviewed literature" includes thesis documents. "Disaster reports" are online reports by agencies like UNOcha (United Nations Office for the Coordination of Humanitarian Affairs), published after disaster events. "Databases" include public databases, like the Himalayan Database for high-altitude mountaineering accidents as well as non-public repositories, like those kept by AKAH (Aga Khan Agency for Habitat).

Type of source	Number	Events / fatalities
Peer-reviewed literature	14	42 / 733
Technical reports	4	7 / 883
News reports	33	35 / 394
Websites	5	29 / 151
Disaster reports	12	14 / 950
Oral sources	5	6 / 45
Databases	3	743 / 539

3.4 Results

3.4.1 Avalanche types and triggering mechanism

Currently, no documentation of the specific frequency distribution of avalanches exists for HMA, nor does a systematic categorization of their type. Snow avalanches are characterized based on their release type, sliding surface, motion and free water content. They are broadly classified into loose and slab avalanches, and both of these can be wet, dry and damp and can be either grounded, aerial or mixed. In glaciated, steep high mountain environments, the occurrence of hanging glaciers and seracs adds other potential processes. As parts of ice collapse and drop over headwalls, often more than 1 km in height, the ice and snow mix turns into a powder cloud that travels at high speed and has a large impact potential (Pralong and Funk 2006; Margreth et al. 2017). As a consequence, such glaciers are also referred to as avalanching glaciers.

3.4.2 Snow avalanches on the Tibetan Plateau and the Chinese Tian Shan

General climate conditions of the avalanche areas are considered to describe snowpack conditions of the mountain areas. Three types of snow climates in mountain ranges have been categorized: maritime, transitional, and continental (Yanlong and Maohuan 1992; Mock and Birkeland 2000). Several studies on the Tibetan Plateau have investigated such classifications. In China, avalanches may occur throughout the year in an alpine zone with perennial snow cover, mostly wet avalanches in summer and dry avalanches in winter. Intermediate zones of mountains in the Tibetan Plateau with ample solid precipitation and low temperatures favor avalanches during the winter to spring season and in some places from late autumn to early summer (Yanlong and Maohuan 1986). Continental-type avalanches are common in Tian Shan and Altay Shan (Yanlong and Maohuan 1986; Hao et al. 2021a). In south-eastern Xizang (Tibet), maritime avalanches are common, and transitional types are common over the northern slope of Daxue Shan in Sichuan, the western Nyainqentanglha Shan, and Gangdise Shan in southern Xizang (Yanlong and Maohuan 1986). Similarly, Hao et al. (2021a) classified central Tian Shan mid-latitude regions as the continental snow climate type.

Early studies along highways built on the Tibetan Plateau in China found hazardous large avalanches in the south-east to be mostly wet snow avalanches, with occasional full-depth avalanches and traces of fresh dry snow avalanches (Yanlong and Maohuan 1986, 1992), but release mechanisms were not discussed. Avalanches occur mainly in February and March, when both temperature and snowfall increase sharply. Avalanches were generally recorded when mean daily temperatures were between 2 and 0°C, with successive heavy snowfalls, or when mean monthly air temperatures were above −3°C. Similarly, a deep snowpack (>0.7 m) on steeper slopes (>35°) favors full-depth avalanches (or what the authors call depth-hoar avalanches) in the same region (Wang 1988).

Hao et al. (2021a) provided a comprehensive study from a research station in Tian Shan, relying on field data between 2015 and 2019 along the National Road (G218), which is often affected by avalanches in the spring and winter. They categorized avalanches into four categories: full-depth dry snow avalanche (FDA), full-depth wet snow avalanche (FWA), surface-layer dry snow avalanche (SDA), and surface-layer wet snow avalanche (SWA), based on failure layers and the properties of snow and avalanche deposits. They identified SDAs as the most hazardous type, occurring in the middle of the snow season, triggered by heavy snowfall and wind. They caused the highest avalanche volumes as a result. FWAs occurred late in the season as temperatures were rising quickly. In the same region, Hao et al. (2018) found avalanche release prevalent when precipitation was >20.4 mm during a single storm period during the study period from November 2011 to April 2017. Of 37 avalanches, 18 were directly associated with precipitation as a trigger, followed by 10 events associated with rising temperatures as the leading cause; six were associated with earthquakes with magnitudes, and other factors triggered three events. Heavy snow precipitation followed by rising temperatures within 3 d and daily mean temperature approaching 0.5°C the next day tends to increase the risk of avalanches in late February to mid-March. Generally, avalanches release at slopes between 30 and 50° (Schweizer and Jamieson 2003; McClung and Schaerer 2006). Release zones of two-thirds of mapped avalanches in Hao et al. (2018) (n=64) were between 36 and 42°steep, (μ=37.2°) and even shallower in a regional study using remote sensing data, with slopes predominately between 25 and 35° (Yang et al. 2020). This is considerably shallower than release areas in the Himalaya or than in previous studies in the Alps (38.8°) or Japan (41.2°). The density of the deposits of dry avalanches ranged from 150 to 300 kg m^{-3}, whereas wet avalanches mostly occurred when the temperature rose sharply and had a deposit density of 500–700 kg m^{-3} (Hao et al. 2018).

More recently, a study at one of these research areas showed that the size and number of avalanches between 1968 and 2021 increased, albeit insignificantly, following an increase in high-intensity snowfall events (Hao et al. 2023). They also found an indication that during this time period snow avalanches occurred approximately 1 week earlier than before.

3.4.3 Snow avalanches in the Himalaya

In the western Himalaya, Sharma and Ganju (2000) classified snow climate as the lower Himalayan zone or subtropical zone (3200–4100 m a.s.l.), the middle Himalayan zone (3500–5300 m a.s.l.), and the upper Himalayan zone or high-altitude zone (5000–5600 m a.s.l.). They used this to categorize avalanching based on terrain parameters together with 11-year meteorological datasets. The lower Himalayan zone is subject to high avalanche activity due to warm temperatures, high precipitation, and relatively short cold seasons, resulting in slab avalanches in peak winter and wet avalanches in late winter, often mixed with debris and soil. The middle Himalayan zone is mostly affected by shallow slab avalanches, massive slab avalanches from wind-loaded slopes, and wet avalanches in April and May, with incidences of loose snow avalanches.

In a study in the western Himalaya, 42% of avalanches were found to be loose snow avalanches, and the failure of soft slabs accounted for 17% (Ganju et al. 2002). In the Himalayas, avalanche formation zones are usually above the tree line at very high altitudes (above 4000 m a.s.l.) and on critical slopes (30 to 45°), where heavy snow deposition due to the wind is prevalent. Similarly, airborne powder avalanches are also common (Rao 1985). Several studies in the Indian Himalaya conclude that release areas lie between 25 to 40° (Sharma and Ganju 2000; Singh and Ganju 2008; Snehmani et al. 2014; Kumar et al. 2017; Singh et al. 2018).

Most avalanche events in the central Himalaya occur during the drier periods due to higher temperature variability in the pre-monsoon season, making it favorable for wet avalanches. Weakened snowpack from the warm monsoon season, formed as the increased water content breaks down bonds between snow grains, results in avalanches during the post-monsoon season. In the western part of the Himalaya, most avalanche events occur during the winter season due to excessive snow loading on snow-covered terrain because of heavy winter precipitation due to westerly disturbances (Prakash et al. 2014). For the European Alps, Ancey (2001) suggests that an accumulation threshold of 30 cm d^{-1} results in widespread avalanching. Beyond an accumulation of 1.5 m during snowstorms, numerous avalanches were observed in the western Himalaya (Sharma and Ganju 2000). Two notable avalanche events in HMA were triggered by seismic movement, namely the avalanches during the 2015 Gorkha earthquake (Kargel et al. 2016; Fujita et al. 2017) and the Lenin Peak avalanche in 1990, although the initial source of these events was the failure of glacier ice, possibly exacerbated by excessive snow loading.

A number of events that caused severe impacts happened in the central Himalaya when monsoon precipitation came incredibly late (e.g. post-monsoon season, 2022) or typhoons in the Bay of Bengal (e.g. post-monsoon season, 2014; see Norris et al. 2015; Cannon et al. 2017). These weather systems caused excessive snowfall that led to avalanches in the short (Figure 3.2; see also news reports from the post-monsoon season, 2022, which left at least 30 people dead and post-monsoon season, 2014, which left at least 40 people dead in Nepal and India) as well as the long run (Fujita et al. 2017).

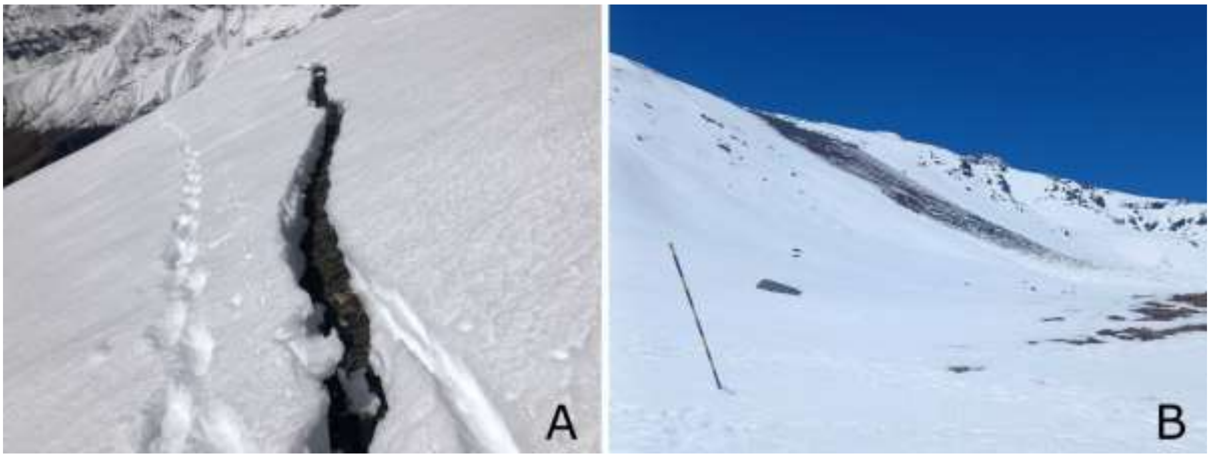

Figure 3.2: (A) Glide crack in the snowpack (d~40 cm) propagating to the ground in a 20-25° slope as a potential precursor to a glide avalanche (October 2022, Thapa Khola, Mustang, Nepal, 4900 m a.s.l. SE exposition; Pasang Tshering Sherpa). The snowpack at this location is only 1 week old after an exceptional late monsoon precipitation event, combined with still relatively high temperatures. (B) Ground avalanche at same elevation but W exposition (October 2022, Jakob Steiner).

On a much larger temporal scale, Ballesteros-Cánovas et al. (2018) find that in the western Himalaya warming is responsible for the increasing number of avalanches. Rising temperatures during winter and early spring mostly favored snow wetting and releasing wet snow avalanches, whose runout can reach subalpine slopes and pose threats to livelihoods, infrastructure, and ecosystems.

3.4.4 Ice avalanches

Ice avalanches are common in glaciated mountain ranges and have resulted in avalanche disasters, including the Huascaran avalanches in Peru in 1962 and 1970 and the Mattmark/Allalin disaster in Switzerland in 1962 (McClung and Schaerer 2006), events that resulted in 22088 deaths and heightened awareness of this hazard at the time. Ice avalanches can be divided into two classes: collapsing hanging glaciers or avalanching glaciers (Faillettaz et al. 2012) and glacier detachments (Kääb et al. 2021). The first refers to the calving or falling of ice masses or seracs at positions where glacier ice flows over a steep slope or along a ridge. This occurs due to a tensile failure of the ice induced by the combination of internal flow (creep) and sliding of the glacier over its bed. Multiple external factors can contribute to such an event, including meltwater as well as the extra load on top of the ice (Faillettaz et al. 2012). The second case results when a large piece of the glacier tongue detaches to form an ice avalanche.

In HMA, both types of ice avalanches have been frequently reported. The collapse of glacier seracs in icefalls is responsible for many fatalities in the HMA. For instance, the 2014 Khumbu ice fall avalanche claimed 16 lives and again 23 in 2015 (Thakuri et al. 2020). In 2008, serac falls at the bottleneck below the peak claimed 11 lives on Chhogori (Kutsch et al. 2017). Seismic activity, a significant factor, can also induce failure. The Gorkha earthquake triggered the avalanche in Langtang Valley in 2015 (Kargel et al. 2016), and the same earthquake was responsible for the avalanche in the Khumbu icefall in 2015 (Bartelt et al. 2016). The so-called Lenin Peak disaster that killed 43 people on 13 July 1990 was also caused by a serac fall after seismic shocks. Ice avalanches from seracs or hanging glaciers can occur multiple times a day at the same location, resulting in runouts and powder clouds of just a few hundred meters to multiple kilometers. Ice avalanches also provide a link between the accumulation and ablation zones in the steep topography of the region (Laha et al. 2017). Ice avalanches are more frequent in spring or summer as more basal melt water becomes available (McClung and Schaerer 2006). Some ice avalanches, like the case in Kobang in 2021 Figure 3.3 B or the Langtang avalanche in 2015, also increase their downstream impact as they pick up more snow and debris along their path and hence become classical examples of cascading hazards.

Glacier detachments are considerably rarer than collapses of hanging glaciers, but recent studies attribute previously unknown cases to this process (Kääb et al. 2021; Leinss et al. 2021). In 2022, 140 people lost their lives in the Kolka–Karmadon rock-ice avalanche (Huggel et al. 2005), and 9 people were killed in the Aru Co detachment (Kääb et al. 2018). The two cases that occurred in 2022, with a lot of media attention in Italy and Kyrgyzstan, have played a significant role in increasing public awareness about these hazards. These cases possibly fall into one of these two types or somewhere in between. Similarly, previous events in the Upper Indus Basin that caused significant repeat destruction have now been identified as a process where melt water accumulates in crevasses and leads to a failure of the tongue, rather than a GLOF as previously suspected.

Figure 3.3: (A) Serac fall at Manaslu (Nepal, stills from a movie; October 2022, Phurba Sonam Sherpa, https://www.instagram.com/p/Ci33N2lpfmW/?hl=en). (B) Kobang avalanche - stills from a mobile movie taken from Kobang Village towards Tukuche Peak (Mustang, Nepal, November 2021; https://www.youtube.com/watch?v=dxWp1D44_v4). Note the dimension of the avalanche towards the second arm on the left. The powder cloud travelled nearly 10 km along the slope, spanning an elevation of nearly 4000 m a.s.l. (C) Serac fall and subsequent power cloud at Langtang Lirung (Langtang Valley, Nepal; November 2021, Jakob Steiner). (D) Ice and snow avalanche deposits below Langshisha Ri (November 2021, Jakob Steiner). Note the gully erosion caused by repeated avalanches, and subsequent small debris flow, runouts over many seasons. (E) Powder avalanche captured on April 17, 1995, on Landsat 5 over Khurdopin Glacier. The total length of the power cloud is just above 7 km along the slope at this moment.

3.4.5 Recorded snow and ice avalanches in HMA

The HiAVAL database, **ANNEXURE A**, has 681 entries between 1972 and 2022. Only one event has an unclear year of occurrence, 97% have a known month, and 95% have a known day. For 91% of the events, the avalanche type is recorded. For 81%, the record notes a slab avalanche, and another 3% each notes a snow or wet snow avalanche. Less than 0.5% are ice avalanches and 2.5% glacier detachments. For 97% of all events, coordinates are known; however, in nearly all cases, that only refers to the general mountain slope and does not allow one to identify the source or runout area precisely. A total of 91% of all avalanche events occur between January and March (76% if only considering events with recorded impacts; Figure 3.4).

Table 3.2 Overview of avalanches with more than or equal to 10 fatalities

Location	Year	Month	Day	Latitude	Longitude	Country	Type	Fatalities
Lahaul and Spiti	1978	3	NA	32.7595	76.19334	India	NA	30
Lahaul Valley	1979	3	NA	31.8413	77.48548	India	NA	237
Shigar	1988	NA	NA	35.5923	75.56803	Pakistan	NA	42
Gokyo	1995	11	12	27.9124	86.6835	Nepal	NA	48
Anzob	1997	10	23	39.0419	68.83696	Tajikistan	NA	46
Banihal, Jammu and Kashmir	1998	2	25	33.4304	75.21488	India	NA	11
Jammu and Kashmir	2005	2	18	33.7932	74.34655	India	snow avalanche	540
Jirgital	2006	1	30	39.4059	71.09177	Tajikistan	snow avalanche	18
Anzob	2007	12	22	39.2729	68.54134	Tajikistan	snow avalanche	16
Ili	2008	3	17	43.92	81.32	China	NA	16
Salang	2009	1	16	35.3058	69.04962	Afghanistan	NA	10
Salang	2010	2	8	35.3102	69.0452	Afghanistan	NA	175

Kohistan	2010	2	16	35.4119	72.94035	Pakistan	snow avalanche	120
Afghanistan Fayzabad	2012	1	18	37.1175	70.57972	Afghanistan	snow avalanche	29
Afghanistan	2012	1	23	36.9499	70.11662	Afghanistan	snow avalanche	43
Badakhshan	2012	3	4	38.2	70.93333	Afghanistan	snow avalanche	196
Gayari Military Base, Ghanche	2012	4	7	35.498	76.75336	Pakistan	ice and rock avalanche	140
Kaicheng Town, Yuanzhou District	2012	6	5	36.21	104.2131	China	NA	10
Kaj-Lar, Raghistan, Badakhshan	2015	2	21	37.7021	70.73572	Afghanistan	snow avalanche	12
Langtang	2015	4	25	28.2376	85.49883	Nepal	ice and rock avalanche	350
Siachen Glacier	2016	2	3	35.4524	77.08547	India	NA	10
2016 Karnali avalanche	2016	NA	NA	29.4302	83.0951	Nepal	NA	16
Gurez Sector	2017	1	25	34.634	74.77326	India	NA	24
Nuristan	2017	2	4	35.3172	70.89867	Afghanistan	NA	137
Barghud, Maimai, Badakhshan	2017	2	4	38.1554	71.23988	Afghanistan	snow avalanche	10
Line of Control	2020	1	14	34.3975	73.86067	India	snow avalanche	10
Line of Control	2020	1	14	34.827	74.35855	Pakistan	snow avalanche	55

Daykundi	2020	2	13	33.704	66.03694	Afghanistan	NA	22
Zarandabad, Khahan, Badakhshan	2021	3	5	NA	NA	Afghanistan	snow avalanche	14
Salang	2021	3	NA	35.3102	69.0452	Afghanistan	NA	14
Chamoli	2021	4	23	30.8223	79.96627	India	ice avalanche	15
Kunar Province, Afghanistan	2022	2	7	35.1171	71.55907	Afghanistan	snow avalanche	19

Only 145 (21%) of all events have some reported impact, and in the discussion of the results, we will only refer to this fraction in Figure 3.4. A large number of avalanches without any recorded impact were mapped in Afghanistan, where a dedicated monitoring project has been put in place after 2015. A total of 44% of these events occurred in the Pamir, 18% in the central Himalaya, 17% in the Hindu Kush, 11% in the western Himalaya, 3% each in the Karakoram and the Tian Shan, and less than 1% on the Tibetan Plateau. Additionally, 48% of these events with impacts were recorded in Afghanistan, 16% in India, 15% in Nepal, 9% in Tajikistan, 4% in Pakistan, 3% each in Kazakhstan and Kyrgyzstan, and 2% in China. No recorded events exist for Bhutan. There has been an apparent increase in events since 2010, which can be explained by the monitoring project initiated in Afghanistan that comprehensively recorded events in the Hindu Kush and the Pamir. Fatalities are also extreme in this decade, which can be explained by extreme events in both Nepal and Afghanistan in 2015 Table 3.2. In 116 events, a total of 3131 people were killed, 2517 of which were in Afghanistan (1057), India (952), and Nepal (508). In 45 events, a total of 531 injured people were recorded.

In 24 avalanche events, a total of 1902 livestock were recorded killed, often with more than 100 hundred individual yaks or goats killed in a single avalanche.

Avalanches with recorded impacts have been documented in nearly all parts of HMA, naturally clustered around the topographically rougher ring of mountain ranges from the Tian Shan in the north-west to the Pamir, Hindu Kush, Karakoram, and Himalaya in the south-east and virtually no records on the Tibetan Plateau. Large-scale events with more than 100 fatalities have occurred all over the Himalayan arc and the Pamir (Figure 3.4 (B)). In 32 avalanches more than 10 people were killed, with 2435 fatalities making up 78% of the total (Table 3.2).

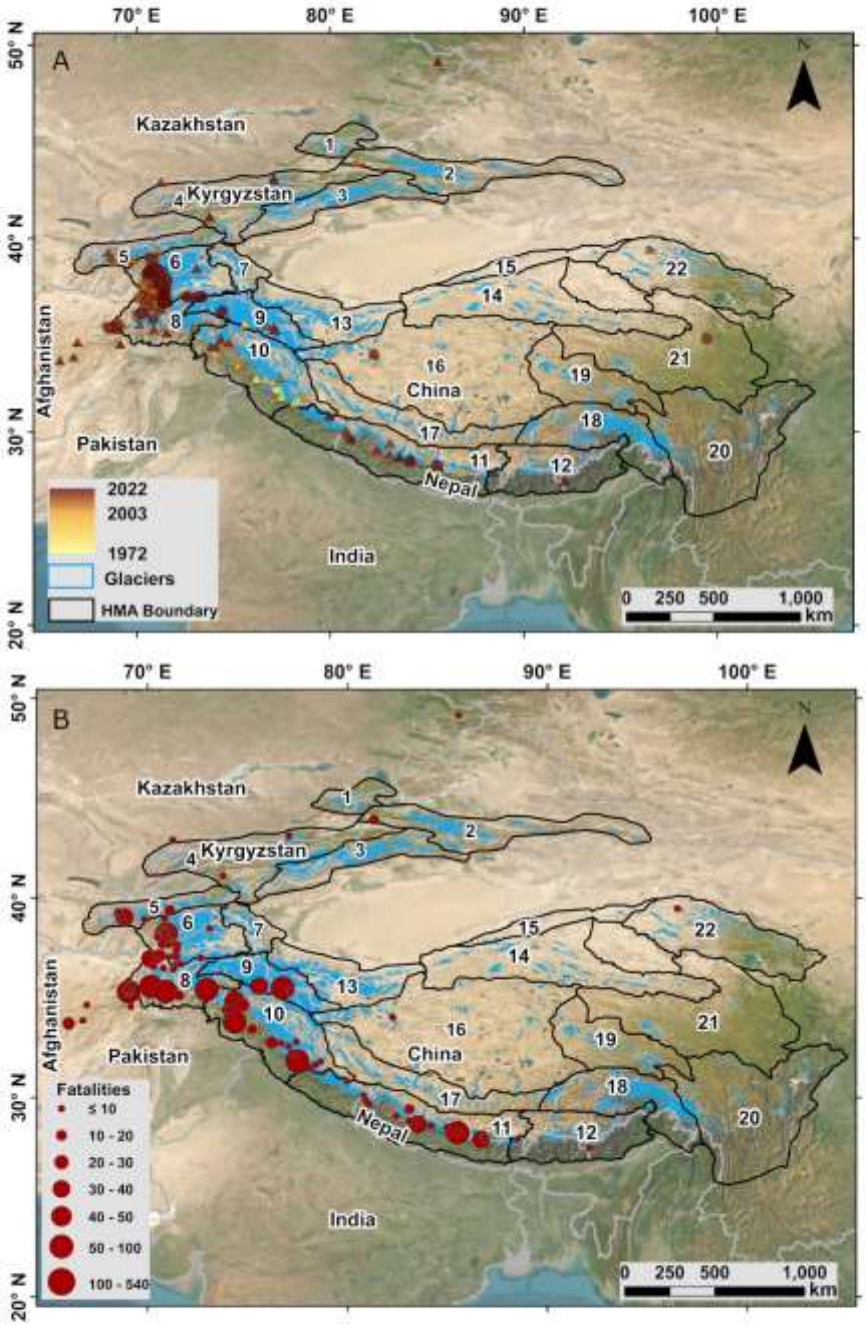

Figure 3.4 (A) Distribution map of avalanche events throughout HMA since 1972. Locations marked with a triangle are events with some recorded impact (fatalities or injured people, livestock killed or infrastructure damaged or destroyed). The colour refers to the year of the record. (B) All events with recorded fatalities from individual events. The black outline shows regional outlines of high mountain Asia, with numbers referring to region-IDs (Bolch et al. 2019) used in the avalanche database.

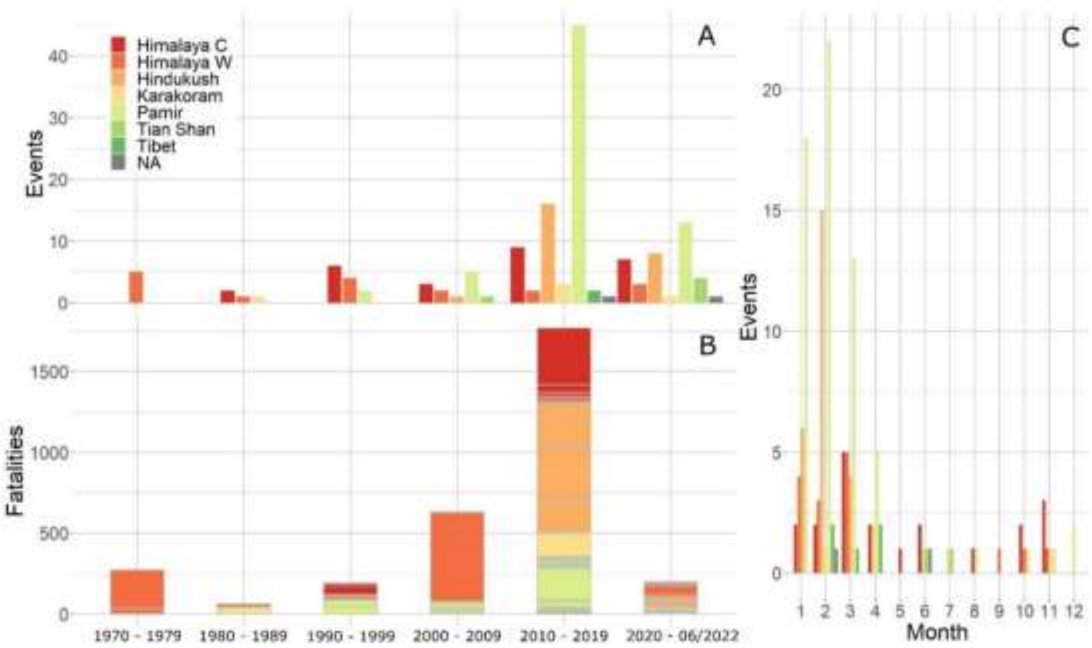

Figure 3.5 **(a)** Decadal avalanche events with some recorded impact (fatalities or injured people, livestock killed or infrastructure damaged or destroyed) and **(b)** fatalities (stacked bars, where grey borders separate individual events). Note that the decade from 2020 only includes 2.5 years of data. **(c)** Avalanche events with recorded impacts by month. Note that for the months from May to December a maximum of 3 events per region and month have been recorded, all happening in different years respectively.

Avalanche fatalities for single events are generally high (μ=27, σ=32). Of all events, 2% (11 events) had more than 50 fatalities, and 12% of events had less than 10 fatalities. However, for many years, no recorded events were recorded at all.

In Afghanistan and Tajikistan predominately, civilians were affected in their respective settlements or during travels on foot or the road. Reported cases in China and Kyrgyzstan often included workers in infrastructure projects. Relatively few events impacted tourists not involved in high-altitude mountaineering (which is discussed separately in Sect. 3.4.6). A total of 201 military personnel (soldiers as well as civilian employees of the army) were killed along borders in the region, predominately in India and Pakistan.

3.4.5.1 Central Asia (Pamir, Hindu Kush, Tian Shan, Inner Tibet; Kazakhstan, Kyrgyzstan, Tajikistan, Afghanistan, Pakistan, China)

Avalanches in the Central Asian Tian Shan and Pamir (and here mainly limited to Kyrgyzstan and Tajikistan, with fewer cases in Kazakhstan and China) have affected skiing areas, blocked roads, and destroyed infrastructure like bridges, schools, hospitals, and buildings and have repeatedly caused loss of life. More than 270 people have been killed since the 1990s (see selected events in Table 3.2). Hotspots were roads like the Anzob Pass between Dushanbe and Khujand, where 77 people died. As a result, preliminary assessments have been conducted. A total of 298 avalanches were recorded in Kyrgyzstan between 1990 and 2009, and an initial susceptibility mapping was conducted for one of the most important roads in the country (Chymyrov et al. 2019). The only country in HMA where avalanche deaths were recorded in a skiing area is Kazakhstan, where two accidents happened at the Shymbulak resort.

Afghanistan has seen especially strong avalanche impacts in recent decades. Nearly 1000 people were killed between 2009 and 2022 alone. With events occurring in very remote regions, relief operations are often difficult. A recent remote sensing study suggests that since 1990, approximately 800,000 large avalanches with an area coverage of 28,500 km^2 occurred in Afghanistan and are responsible for damaging several villages and blocking roads and streams. The avalanche deposits have impacted about 26.2% of the river network in the high mountains in the Amu Panj basin (Caiserman et al. 2022). Hazard and vulnerability risk assessments in three countries (Tajikistan, Afghanistan, and Pakistan) showed that 571 villages are at risk of avalanches, with 30,000 people directly being exposed to avalanches, 75% of which are in Afghanistan (Chabot and Kaba 2016). A World Bank report (Ranghieri et al. 2017) on hazards in Afghanistan notes that 2 million people, USD 4 billion of assets, and 10,000 km of roads are exposed to avalanches, of which USD 990 million are in Badakhshan alone. From 2000 to 2015, more than 153,000 people were affected. More than 300 people were killed in 2015, the majority in Panjshir Valley. No significant efforts in terms of mitigative measures for protecting settlements and infrastructure have been made so far, except for a few attempts to test early warning systems around the Salang Pass.

3.4.5.2 Karakoram and Himalaya (India, Nepal)

Ganju and Dimri (2004) provide an overview of avalanches in the Indian western Himalaya including 109 villages in Himachal Pradesh, 91 in Jammu and Kashmir, and 16 in Uttarakhand. The avalanches created a sudden cut-off in essential supplies, loss of forest cover, loss of soil cover, road damage, hindrance in the hill development schemes, and deposits resulting in dams subsequently causing flooding. Moreover, these avalanches severely affected military operations and border area security. Many important road connections, such as Manali–Leh and the Hindustan–Tibet Road in Himachal Pradesh, remain cut off for at least 5 to 6 months per year due to winter snow and avalanche threats. A case study in Jammu and Kashmir, India, from February 2005 reports the incidences of snow avalanches in the Anantnag, Poonch, Doda, and Udhampur districts. More than 200,000 people were directly affected by a series of avalanches; 278 people lost their lives, and avalanches submerged several houses.

Avalanches with recorded impacts in the central Himalaya are few and are mainly associated with extreme weather events, especially when typhoons from the Bay of Bengal result in intense snowfall. Such events have resulted in countless avalanche deaths every decade since the 1970s. Avalanches released during the 2015 earthquake also caused numerous deaths (>350). Although the primary trigger in this case was the seismic shock, heavy snowfall from the previous year's typhoon potentially exacerbated the impact (Fujita et al. 2017).

3.4.6 Avalanche fatalities in high altitude mountaineering

HMA is home to the highest peaks on the planet, including all those above 8000 m a.s.l. High-altitude mountaineering is an important economy in some regions (India, Nepal, China, and Pakistan; to a more limited degree in the Central Asian states), which started with the first attempts of peaks above 6000 m a.s.l at the end of the 19th century. In areas like the Khumbu in Nepal or the Baltoro region in Pakistan, individual peaks are scaled by more than 500 people annually. depicts the avalanche deaths on all 14 of the 8000 m a.s.l. Peaks (covering a period from 1895 to 2021, although most cases stem from the time after the 1930s), as well as high peaks for which accident records exist in the Himalayan Database (for the Himalayas, recording from 1930 to 2021) or news articles (outside of it) and presented on **ANNEXURE B.** Deaths because of serac falls, icefalls and snow avalanches are incorporated in this Table 3.3. Especially deadly events include an avalanche on Qomolangma on 18 April 2014, claiming the lives of 16, and an earthquake-triggered avalanche on 25 April 2015, killing 23 and halting the expedition season for 2 consecutive years (2014 and 2015).

Table 3.3. Avalanche accidents and associated fatalities on high altitude peaks in HMA between 1895 and 2022.

Peak	Elevation	Country	Accidents	Fatalities	Hired staff	Hired staff [%]
Others	-	-	56	207	49	23.7
Xixapangma	8013	China	8	15	1	13.3
Gasherbrum II	8035	Pakistan/China	3	4	0	0
Faichan Kangri (Broad Peak)	8047	Pakistan	4	5	1	20
Gasherbrum I	8068	Pakistan/China	4	10	4	40
Annapurna I	8091	Nepal	19	41	13	31.7
Diamir (Nanga Parbat)	8125	Pakistan	11	36	11	30.6
Manaslu	8163	Nepal	13	41	14	34.1
Dhaulagiri	8167	Nepal	16	42	18	42.9
Cho Oyu	8201	Nepal/China	4	9	5	55.6
Makalu	8463	Nepal/China	3	3	1	33.3
Lhotse	8516	Nepal	9	13	3	23.1
Kangchenjunga	8586	Nepal/India	4	8	2	25
Chhogori (K2)	8611	Pakistan/China	10	24	4	16.7
Qomolongma (Mt. Everest)	8848	Nepal/China	33	106	70	66
TOTAL			197	564	191	33.9

Overall, out of a total of 564 avalanche deaths, 191 deaths (34%) were of locally hired personnel, with the highest fraction (66%) on the highest peak. These observations have already been made in a previous study focusing on avalanche deaths while climbing the highest peaks (McClung, 2016). These rates are more concentrated in the central Himalaya, where expeditions rely more on large groups of porters and guides. In Khumbu, more locally hired people are affected by avalanches, as they contribute to a larger extent and for a more extended time period to prepare the way to the summit (so-called “icefall doctors”), exposing themselves to avalanche-prone areas. Other mountains with peaks above 4500 m a.s.l. recorded 207 fatalities in 56 different accidents throughout the region.

3.4.7 Avalanches and glacier dynamics

Avalanches pose direct hazards, affect glacier mass balance, and indirectly water resource-related risks downstream. Several studies have shown that avalanches contribute significantly to the net accumulation in HMA. Usually, debris-covered glaciers, associated with high relief and steep headwalls, are fed by avalanches (Benn and Lehmkuhl 2000; Hewitt 2011; Laha et al. 2017; Azam et al. 2018). Benn and Lehmkuhl (2000) state that the avalanche contribution to the mass balance of Khumbu Glacier, Nepal, is 75%. Also, large valley glaciers like Batura Glacier, Karakoram, Fedchenko Glacier, and Pamir receive significant amounts of ice and snow from avalanches from the surrounding high-relief valleys. Ragettli et al. (2015) found that the melt of avalanche deposits contributed 16% of the annual water balance in the Lirung sub-catchment in the Central Himalaya, which constitutes 43% of the total snowmelt in the whole catchment. Another study on the Satopanth, Dunagiri and Hamtah Glaciers in the Western Himalaya shows that avalanches from headwalls contributed more than 95% of the total accumulation. A huge disparity was found while simulating the mass balance of these glaciers with (-0.2 ± 0.5, -0.3 ± 0.2, and -0.5 ± 0.3 m w.e. a^{-1}) and without consideration (-2.0, -1.0, and -1.5 m w.e. a^{-1}) of avalanches (Laha et al. 2017). Glaciers that do not show signs of rapid retreat or considerable downwasting, even if the accumulation area ratio (AAR) of these glaciers is less than 0.2, are likely strongly avalanche-fed (Laha et al. 2017). In the Tian Shan, a study using high-resolution imagery and modeling suggests that the contribution to accumulation is considerably smaller, only up to 10% (Turchaninova et al. 2019).

3.4.8 Mitigation measures for avalanche hazards

Studies with respect to avalanche hazard mitigation have been conducted at a government level largely in the Indian western Himalaya, with some monitoring also documented on the Tibetan Plateau in China and community-based hazard mitigation approaches in Afghanistan, Tajikistan, and Pakistan.

3.4.8.1 Field monitoring and desktop analysis

Avalanche prediction based on nearest neighbors was first adopted in the early 1990s for short-term avalanche forecasts in the Indian Himalaya (Joshi et al. 2018). A few more studies were conducted using the method in the Indian Himalaya (Singh and Ganju 2004, 2008). Singh et al. (2005) also modified this forecast model with a mesoscale weather forecast, allowing for predictions up to 4 d in advance. In the Khumbu (Kattelmann and Yamada 1996) and Langtang regions (Fujita et al. 2017) of the central Himalaya, avalanches have been investigated regarding their triggers, but no comprehensive forecasting exists. Both optical remote sensing (Bühler et al. 2013; Snehmani et al. 2014; Kumar et al. 2017, 2018; Singh et al. 2019b; Caiserman et al. 2022) and synthetic aperture radar (SAR) technologies (Eckerstorfer and Malnes 2015; Patil et al. 2020; Eckerstorfer and Grahn 2021) have been used for avalanche activity detection. SAR technologies have the advantage of being completely independent of light and weather conditions. In Tian Shan, Yang et al. (2022) applied remote sensing image interpretation, drone photographs, and field investigations to determine avalanche susceptibility. In the western Himalaya, SASE (Snow & Avalanche Study Establishment; now under Defence Geoinformatics Research Establishment, DGRE) is using remote sensing and geographic information system (GIS) technology and incorporates multi-spectral, hyper-spectral, SAR, and various other optical and microwave satellite data to extract snow cover and terrain information from inaccessible terrains (Singh et al. 2019a). This also included susceptibility mapping at the regional scale (Kumar et al. 2017, 2018; Singh et al. 2018, 2019a).

Gusain et al. (2019) created a comprehensive system for providing avalanche information with different levels of detail in the Indian Karakoram using the Advanced Space-borne Thermal Emission and Reflection Radiometer (ASTER) Global Digital Elevation Map (GDEM) version-2 at TIR-2 (11.50–12.51) with a spatial resolution of 30 m, as well as Cartosat-4 DEM at a resolution of 10 m, and satellite images from Landsat 8 and Pléiades-1A. The resulting system is supported by GIS and enables easy terrain visualization. Similarly, Dewali et al. (2014) designed a real-time avalanche path warning and navigation system based on a global positioning system (GPS) within a GIS environment for the visualization of terrain maps and navigation in avalanche-prone regions, specifically in the Manali–Dhundi area of the lower Himalaya. Camp locations, pedestrian routes, and avalanche areas along pedestrian routes have been digitized, and past avalanche accidents along pedestrian routes, past avalanche occurrences, and the climatology of the region have also been mapped in a GIS environment. This was paired with an online platform for geospatial data visualization, snow status updates, and avalanche forecast dissemination for Jammu and Kashmir, Himachal Pradesh, and Uttarakhand. A portable GPS-based real-time avalanche path warning and navigation system has also been developed. SASE has a rich network of wireless sensors, with 35 wireless nodes and a total of 128 snow and meteorological sensors recording 14 different climatological variables in an area covering 400 000 m^2 (2890 m to 3350 m a.s.l.) in the Pir Panjal Range in Himachal Pradesh. A database of mechanical properties and snowpack structure information of typical Himalayan snow over the last decade allows for snow cover and avalanche simulations (Singh et al. 2019a). This collective knowledge led to the establishment of an avalanche warning bulletin that is published regularly (https://www.drdo.gov.in/avalanche-warning-bulletin; last access: 22 April 2023). In the Indian Karakoram, Singh et al. (2021) discussed the installation of nine surface observatories and two automated weather stations to help generate avalanche forecasts. Numerical models like RAMMS were applied in the western Himalaya and Karakoram to simulate avalanche incidents, for instance, to simulate avalanche incidents of 5 January 2018 near Chowkibal Village, Jammu, and Kashmir, India (Singh et al. 2020), and on Siachen Glacier (Sardar et al. 2017). In the south-eastern Tibetan Plateau, studies about avalanches were first carried out in 1964, with later extensive field visits between 1981 and 1983 in the Hengduan Shan, where two avalanche observation stations, one each on Baimang mountain and Bomi mountain, were established (Deng 1980). This was more recently complemented by more detailed scientific research (Hao et al. 2018, 2021a, b).

Focus Humanitarian Assistance (FOCUS; now AKAH) is helping vulnerable communities build resilience to disasters like avalanches in Tajikistan, Pakistan, and Afghanistan. It has established a network of 82 manual weather monitoring posts in January 2015 (17 in Afghanistan, 45 in Pakistan and 25 in Tajikistan) to help forecast avalanches in 571 remote high-risk villages to reduce fatalities. They continuously conduct a program for community avalanche education and provide a community training manual on snow avalanche risk management. Furthermore, they are involved in identifying high-risk vulnerable villages through avalanche terrain mapping, managing specialists to analyze meteorological datasets, and training the community trainers in avalanche safety and weather monitoring (Chabot and Kaba 2016). AKAH has been conducting comprehensive training on avalanche safety to empower communities to be prepared for avalanches. For instance, in 2021, AKAH provided training to 2002 people from 205 villages in Afghanistan, equipping them with Avalanche Preparedness Team (AVPT) toolkits. Training covers a range of skills, including data collection from weather stations, which helps predict the likelihood of avalanche occurrence. As a result of such training, 263 villages were provided with avalanche warning messages in 2021. Similarly, AKAH has conducted about 800 HVRAs (Hazard Vulnerability and Risk Assessments) and two habitat assessments. These HVRAs were then utilized to develop nearly 700 village disaster management plans and two habitat plans.

AKAH, (2023) in Badakhshan, Afghanistan, several government and non-government organizations are conducting programs for community resilience, forming community emergency response teams (CERTs), avalanche preparedness teams, and school emergency response teams (SERTs) for disaster management, generally raising avalanche awareness. However, economic challenges and security issues affect effective emergency responses, rescues, and evacuation. In at least one case, the program has also resulted in the relocation of villagers, as the Verizon Village in Shighnan, located in an avalanche-prone area, was completely relocated to a safer location (Lashkari 2022).

3.4.9 Structural measures

Prevention and control methods are divided into permanent (passive) and temporary (active) measures. Temporary measures are applied for short periods when avalanches are expected and are advantageous because of their flexibility and low cost but need a continuous evaluation of avalanche hazards and the application of safety measures. Permanent measures are usually expensive and require significant engineering work but do not require daily hazard evaluation (McClung and Schaerer 2006). In HMA, structural measures, besides being costly, are often challenging to implement due to logistic constraints (Ganju and Dimri 2004). A study in eastern Karakoram found that proposed structural mitigation measures are infeasible due to steep, unstable, and glaciated terrain. Slope stabilization considering preventive triggering of small avalanches has potential, but necessary infrastructure and permits are difficult to obtain, install, and maintain (Singh et al. 2021).

Control structure schemes are designed based on avalanche zones: formation zone control structures, middle zone control structures, and runout zone control structures. Numerous control structures in different zones were implemented in Jammu and Kashmir, Himachal, and Uttarakhand in India (Rao 1985; DRDO 2018; Singh et al. 2019a). Several snow bridges and snow stakes are installed by SASE above the Jawahar Tunnel on the Jammu–Srinagar National Highway. Snow nets, fences, jet roofs and baffle walls are installed along different sections of mountain roads in the Indian Himalaya as formation zone control structures and galleries (e.g., along the Manali-Leh highway) are planned. Retarding mounds used for breaking the momentum of the avalanche mass and catch dams to retain avalanche mass in large depressions (e.g. near Shri Badrinath temple) have been installed as well (Singh et al. 2019a). Artificial triggering was tested in Gulmarg, Jammu and Kashmir, in February 2018, using rocket launchers (84 mm RL) by the Indian Army (Singh et al. 2019a). AKAH has also taken some initiative in implementing tailored mitigation measures such as protective walls, tree planting, and retrofitting buildings to improve resilience in Afghanistan (AKAH 2023).

3.4.10 Indigenous and local knowledge, adaptation, concerns, and community-based disaster management three case studies

Knowledge about the cryosphere, hazards, and adaptation already present in mountain areas has always been known (Fleetwood 2022) but is still rarely included in the development of solutions. At the same time, the value and importance of Indigenous and local knowledge and adaptation solutions in the mountains have been acknowledged (Adler et al. 2022).

Below are three case studies on how local populations have raised their concerns about avalanches concerning livestock (central Himalaya, Nepal), local adaptation solutions where avalanches are turned into opportunities for other climate-related risks (Karakoram, Pakistan), and community-based disaster management stemming from high vulnerability in remote areas (Hindu Kush, Afghanistan).

3.4.11 Avalanches and Yak herding

Yak herding is a common mountain economy prevalent throughout HMA (Wu et al. 2016). In Nepal, it is an important source of income in the lower Mustang and the Langtang Valley, and both areas are also research areas frequented by the authors. Avalanches have been identified as a significant risk for herders in Mustang, where recorded events in 1987, 1998, and 2003 killed 62, 25, and 70 yaks, respectively, of a single owner (Degen et al. 2007) and again 14 of multiple owners at the same location in November 2021 (Figure 3.3B) and 7 more in March 2022. In Langtang, 5 killed yaks were recorded in August 1997 (McVeigh 2004), over a thousand reportedly after co-seismic avalanches in 2015, and locals have noted avalanches as a major concern in the more recent past (Tuladhar et al. 2021). While it is contested indigenous knowledge by some villagers, locals claim that manes or Buddhist sacred walls (Emerman et al. 2016) have also been strategically erected at locations that are or have been avalanche runout zones in the past (their location aligning well with known avalanche locations). This is done to preserve the memory on where to be careful along the path or where not to build and avert the potential wrath from deities expressed through natural disasters like avalanches.

Avalanches have been identified as a threat that can wipe out livelihoods within an instant and potentially force people to move away and look for other professions (McVeigh, 2004; Degen et al. 2007). As a response, the International Centre for Integrated Mountain

Development (ICIMOD) has started a community-based participatory approach to avalanche hazard adaptation. This includes the preparation of participatory maps, constant exchange with communities, and the use of satellite data to visualize the potential of monitoring (Eckerstorfer and Grahn 2021).

In the central Himalayas, no other mechanisms to deal with avalanche hazards have been discussed so far. Efforts generally deal with the immediate impacts caused by the avalanche hazard. For instance, the Conservation Area Management Committee of the Annapurna Conservation Area Project (ACAP) provided NPR 1000 per yak (USD ~7.5; approximate value of a fully grown yak at the time of writing is 150,000 NPR) to every owner that lost their animals in an avalanche in Kobang in November 2021 and March 2022 (Jeevan Thakali, Chairperson of Conservation Area Management Committee, Mustang, personal communication, 2022).

3.4.12 Avalanches and Irrigation

High-altitude irrigation of agricultural land is challenging, as irrigation channels are difficult to upkeep. Such channels, referred to as khul, are commonly maintained in the Hunza Basin. However, their maintenance under the threat of avalanches is challenging (Ashraf and Akbar 2020; Ashraf and Ahmad 2021). Slightly further south in the Rupal Valley, such channels source melt water directly from locations with repeat avalanche deposits, as they are otherwise disconnected from the Chungphare Glacier (Nüsser et al. 2019). In the region, the practice of glacier marriages (or glacier crafting) is also practiced as a response to water scarcity (Tveiten 2007; Faraz 2020). In a complex and long-standing practice combining local myths and precise knowledge of the local cryosphere, glacier ice from lower elevations is placed in caves in permafrost environments at higher elevations, exposed to avalanche activity. This way, the ice deposits grow and are eventually harvested for irrigation water later.

A similar approach, although less stooped in local folklore, is being pursued in Baltistan. In a locality that has been heavily impacted by avalanches in the past, including an event in 1988 that caused 42 deaths, people migrate to lower areas in February and March to stay safe from avalanches. In early spring, water for irrigation here is still scarce, as glacier melt water peaks after May. By retaining, and in the process compressing, avalanche snow in narrow gullies where it generally descends, avalanche snow subsequently melts much slower and can be tapped for irrigation water (Zakir 2021; Figure 3.6). The technique of trapping avalanche ice mass to create a more condensed solid water reservoir is known as avalanche harvesting, exploiting the reduced melt following from increased density and decreased surface area of the snow mass. It serves both as risk reduction and to produce melt water for irrigation at the time of demand during the early months of spring. An avalanche-trapping net is knitted with high-tensile gabion cables in gullies with hard bedrock on both sides. Each structure can have up to three to four layers of netting, with a decreasing mesh size from upstream to downstream. This is designed to reduce the speed and pressure of the avalanche and, subsequently, any downstream damage. Distances between layers vary between 20 and 50 m. The trapping structure itself does not add additional risk in case it is destroyed during an avalanche event, as it does not add any rolling mass. If the area for avalanche trapping is found and selected at an altitude of around 4000 m a.s.l., it can be expected that some of the condensed snow mass will remain and can grow with subsequent snowfall and avalanches, hence producing a permanent mass that could be referred to as an artificial glacier, as in previous attempts using means to create such bodies of ice with water fountains (Balasubramanian et al. 2023).

3.4.13 Community-based disaster management

Considering the increasing concern for snow hazards in Central Asia, FOCUS has implemented a comprehensive risk anticipation and community preparedness program to reduce the adverse impact on vulnerable communities (Chabot and Kaba 2016). Mountainous areas of Afghanistan, Pakistan, and Tajikistan have an avalanche readiness program through a Community-Based Disaster Risk Management program (CBDRM). FOCUS units have worked on identifying avalanche zones based on HVRA maps with high-frequency and high-intensity categorization. Similarly, awareness programs about avalanche-prone areas, dangers, early warning signs, safe places, and routes are being conducted. Moreover, the CERTs of each country are provided with proper training on early warning signs, basic snow rescue, and the use of basic measurement tools to quantify avalanche risk. They also work on stockpiling safety equipment near avalanche-prone areas, archiving avalanche incidents to categorize them, assigning well-trained and resolute staff for data management, gathering weather information, and reporting emergency response officers. Moreover, FOCUS has also sourced an avalanche expert to help develop short- and medium-term plans to mitigate the risk of avalanches in the highest-risk areas (Chabot and Kaba 2016).

Figure 3.6 (A) Lower agricultural areas repeatedly at risk from avalanches but also need irrigation water. (B) The gully in March. (C) One of the multiple installed along the gully to capture avalanche snow.

3.5 Mitigation, adaptation and scientific research

Mitigation and adaptation strategies in HMA have been highly diverse. No known efforts exist in Bhutan. In China, a research station in Tian Shan is tasked to investigate avalanche hazards, specifically on roads (Hao et al. 2018). Any efforts and even accessible research in Central Asia, beyond the recent attention for glacier detachments (Leinss et al. 2021), is mainly limited to the work of FOCUS/AKAH spanning Afghanistan, Pakistan, and Tajikistan (Chabot and Kaba 2016; Bair et al. 2020). Recently, AKAH has installed two new stations in Gunt Valley, Tajikistan, where avalanches are frequent, in order to monitor the concurrent weather conditions. In Uzbekistan, various studies employing RAMMS have been conducted to improve the prediction of avalanche runouts and eventually inform the construction of mitigation infrastructure. Long records of avalanches, including observations, characterization of morphometry, time of release, and their weather conditions, have been compiled (Gidrometeoizdat 1984) and used for mitigation infrastructure construction, especially on Kamchik Pass in the Tian Shan (Semakova et al. 2009, 2018; Semakova and Bühler 2017). In the western Himalaya and the Karakoram, some preliminary studies for specific avalanche events employing RAMMS exist as well; however, they are hampered in their quality by the lack of accurate snow depth data, general snow properties, and local meteorological data (Mahboob et al. 2015; Gilany and Iqbal 2019; Singh et al. 2020).

Afghanistan has by far the most comprehensive database on avalanches and records on their type and impacts. This reflects the country's dependence on snow as a resource and the considerable impact on livelihoods avalanches have had in recent years (34% of all non-mountaineering-related fatalities in HMA have been recorded in the country). The country now also has some records of avalanches retrieved from satellite imagery (Caiserman et al. 2022), hich could provide a solution for regional approaches to map avalanche frequency for both the analysis of drivers as well as impacts. Considering that fatalities in Pakistan were relatively minor (366 deaths, 195 of which are related to military operations along the Line of Control), it is perhaps not surprising that the hazard has received relatively little attention in the country. However, local adaptation attempts like avalanche harvesting are being pioneered here, and Indigenous knowledge is being shown to play a role in adaptation to climate risks. This incongruence between local concern about avalanches as a dominant hazard (Tuladhar et al. 2021) and a lack of coordinated research or adaptation response by government bodies is also true for Nepal.

Conversely, in India, both adaptation and research measures have been top-down and driven by the army and the government, providing a comprehensive approach to tackling the challenge of avalanche risks. This has so far not been expanded beyond the western Himalaya, presumably also because in the east avalanches have been a minor concern so far. Contrary to Afghanistan, no comprehensive database of avalanches without any notable impact exists in India. However, the only study to date linking a changing climate to avalanche frequency has been conducted here (Ballesteros-Cánovas et al. 2018).

In HMA, Central Asia, and other regions of the world, remote sensing is being used for avalanche mapping in three ways: (a) manual digitization of avalanches using a high resolution from origin to runout zones (Abermann et al. 2019; Yariyan et al. 2020; Hafner et al. 2021), (b) automatic detection using radar images (Martinez-Vazquez and Fortuny-Guasch 2008; Eckerstorfer et al. 2016; Vickers et al. 2016; Bühler et al. 2018; Yang et al. 2020; Karas et al. 2022) and (c), automatic detection with optical images (Singh et al. 2019b; Caiserman et al. 2022). Some automatic hazard indication mapping frameworks developed for the European Alps (Bühler et al. 2018, 2022) could be potentially helpful in deriving avalanche hazard maps in HMA, in areas where high-quality and high-resolution DEMs, snow data and information on ground cover are available. These algorithms provide hazard maps for different return periods (Bühler et al. 2018) as well as consider the protective effect of forest cover (Bühler et al. 2022). In the western Himalaya, SASE has developed avalanche hazard data cards and digital avalanche atlases in a GIS environment for several road axes in Jammu and Kashmir and Himachal Pradesh, which give information on avalanche terrain and avalanche activities (DRDO 2018). Another method by Barbolini et al. (2011), with two modules to perform avalanche hazard mapping over large undocumented areas, is equally promising in mountainous areas. This method combines GIS tools, computational routines, and statistical analysis to provide a "semi-automatic" definition of areas potentially affected by avalanche release and motion. It has proven effective in all cases where a preliminary cost-efficient analysis of the territories potentially affected by snow avalanches was needed. Several regional- to local-level avalanche hazard maps and susceptibility maps using frequency ratio, fuzzy and classical analytical hierarchy processes have already been generated in the western Himalaya based on coarse- to fine-resolution digital elevation models for terrain parameters and other ground information (Bühler et al. 2013; Snehmani et al. 2014; Kumar et al. 2016, 2017, 2018; Singh et al. 2019b). Methodologies using airborne (Lato et al. 2012; Korzeniowska et al. 2017; Bühler et al. 2019) and spaceborne (Bühler et al. 2009) optical remote sensing with very high resolution can detect avalanche deposits at a large scale. These algorithms are promising in remote and inaccessible areas in HMA.

All approaches have their advantages and disadvantages. High-resolution images enable a detailed outline of avalanches, resulting in precise surface area estimation. However, the financial cost of single images, limited spatial and temporal coverage, and the time-consuming manual digitization limit their use on a regional scale. Radar sensors offer a global image dataset that assesses terrain evolution using backscatter changes between two sets of images. The change in snow surface area must be intense enough to be detected through radar images.

Moreover, freely available radar products such as Sentinel-1 have commenced relatively recently (2014) and do not allow for long-term monitoring of avalanches. On the contrary, optical images offer more extended datasets from the 1980s. However, automatic detection of avalanches using optical images can be difficult, as the contrast between snow avalanche zones and normal snow cover is often difficult to discern. Hence, it remains up to stakeholders to choose which products and methods match their needs, objectives, and, most importantly, human and financial resources. We suggest, however, that, based on studies in the region as well as in the European Alps, sufficient openly accessible guidelines, as well as data, are available to allow policymakers and agencies responsible for disaster risk reduction (DRR) in the region to develop action plans to mitigate avalanche hazards.

Considering that all aspects of avalanche risk management have been executed somewhere in the region, ranging from local practices on adaptation to state-of-the-art analysis of satellite imagery. However, nowhere are all of them exploited in tandem; it seems prudent to learn from experiences across borders to further advance our understanding of avalanche dynamics in the region. While the runouts of avalanches are rarely transboundary and potentially will only ever be for large-scale ice avalanches or glacier detachments that can mobilize much solid material downstream, seasons with heavy avalanche activity generally extend across borders (e.g., Nepal and India, Pakistan, Tajikistan, and Afghanistan) and ramifications in risk (e.g., effect on international tourism in the Himalaya, labor migration in the Hindu Kush) are transboundary.

3.6 Conclusion

In this Chapter, all accessible snow and ice avalanche records from the HMA region, as well as previous scientific research, local knowledge, and existing or previously active adaptation and mitigation solutions, were investigated.

Our database spans half a century between 1972 and 2022 and records 681 individual events (88% snow, 0.5% ice avalanches, excluding mountaineering accidents on high peaks), of which 21% had some recorded impact, and 17% fatalities were recorded. Avalanches killed more than 3100 people, more than 62 each year on average, most of them in Afghanistan (1057; 34%), India (952; 30%), and Nepal (508; 16%). This suggests avalanches to be an especially deadly hazard in high mountain environments in the region, causing considerably more fatalities than, for example, glacial lake outburst floods. On average, each avalanche in our database killed 27 people, making them also exceptionally high-impact events. Approximately 1900 livestock killed in 24 events are also noteworthy, as this impact on livelihoods has been mentioned as an especially problematic aspect of the hazard in the region.

More than 500 people have been killed in avalanches while climbing mountain peaks above 4500 m a.s.l., a third of which were porters or guides employed during these endeavors.

Scientific studies on avalanches with field investigations are so far limited to research stations on the Tibetan Plateau and the Indian western Himalaya. As a result, modeling studies that have been carried out in several locations remain relatively rudimentary, as information on snowpack and local climate is lacking.

Studies investigating the role of avalanches for glacier mass balances are still limited but suggest significant differences in their relative contribution between the monsoon-dominated Himalaya, where also steep and very high headwalls surrounding glacier tongues are likely more common, conducive to avalanche occurrence (>75%) and the continental and less topographically extreme Tian Shan (<15%). Future studies should investigate their relevance on a more regional scale, also considering the increasing dynamic disconnect of accumulation and ablation areas in many glaciers in the region.

Conversely, several adaptation and mitigation measures have already been taken. In India and China, this has received large-scale funding for specific regions where avalanches have been identified as potential threats to road infrastructure. It includes dedicated monitoring programs coordinating with scientists and investments into state-of-the-art structural measures. Non-governmental efforts have, however, been equally successful. The monitoring of avalanches in Afghanistan is unparalleled in the region and is carried out by local stakeholders. It is the only country that records individual avalanche events irrespective of impact, an effort that is incredibly valuable for future studies investigating meteorological drivers. Other examples of locally carried initiatives, like harvesting avalanche deposits for meltwater to be used in high mountain irrigation in Pakistan, are also a testament to the existence of local solutions in addressing the hazard that should be investigated for potential scaling to other localities in the future.

The database of avalanche events, including geolocation, timing, type of avalanche, and recorded impacts, allows for future investigations of the climatology of avalanche events in HMA. As a first step, they can be used to validate automated mapping efforts using remote sensing on a regional scale and subsequently correlated with distributed climate and snow datasets to understand important regional drivers for avalanche occurrence. This would provide a basis for more robust forecasting of avalanche danger in different parts of HMA, where avalanche risks have been identified as a concern. Efforts by national agencies tasked with hazard monitoring should further invest in pairing scientific investigations of avalanche hazards with developing adaptation and mitigation solutions, an approach that has seen success in other mountain regions. Based on the impacts that we record here that avalanches had in the past in HMA, we suggest that the hazard should be given a higher priority in DRR strategies of the different governmental and non-governmental stakeholders in the domain of high mountain hazards. Methodologies, as well as data, are available to address the issue with both remote sensing data and field-based installations. National and local solutions for such avalanche warning and forecasting should always keep in mind already existing local adaptation solutions and knowledge with respect to the hazard. Future interdisciplinary studies should investigate local solutions in response to avalanche hazards further and record experiences with the hazard and whether and how they have changed in the more recent past. This would allow one to understand whether avalanche risks are changing (either due to climate or more socio-economic exposure) and help in building future adaptation solutions.

Chapter 4: Result 2- Development of the avalanche hazard Susceptibility map of ACA

4.1 Introduction

Avalanches are significant natural hazards, often leading to numerous fatalities and substantial property damage in snow-covered mountainous regions such as the Himalayas. Avalanches can travel up to 200 km h^{-1} and exert pressures of up to 50 Mg m^{-1} (McClung and Schaerer 2006). These immense forces can lead to significant destruction, including the destruction of forests, road damage, communication infrastructure, and erosion (Bebi et al. 2009; Beato Bergua et al. 2018).

Avalanches are not simple events but rather complex phenomena. They are highly dependent on a multitude of factors, including terrain characters, meteorological variables, snowpack properties, and triggering parameters, all of which interact in intricate ways (Ancey 2001; McClung and Schaerer 2006; Bühler et al. 2013; Singh et al. 2019b). These factors can be broadly categorized into two major types: static terrain factors and dynamic meteorological variables (Ancey 2001; Schweizer and Jamieson 2003; Kotlyakov 2007; Parshad et al. 2017).

Due to insufficient public awareness and limited information regarding avalanche-prone areas, significant challenges are posed, leading to severe problems (Sharma and Ganju 2000; Kumar et al. 2017). The frequency of avalanches is rising due to global warming (Gądek et al. 2017) and the resultant shifts in climates (Kumar et al. 2017). There is a great necessity of accurate snow avalanche susceptibility Maps as these maps serve as invaluable tools in identifying regions prone to avalanches, enabling formulation of resilience strategies, engineering effective control measures, and minimizing hazard risks in susceptible zones (Rahmati et al. 2019).

Avalanche prediction is affected by many factors, including temperature, snowfall, wind, rain, snowpack properties, liquid water content, and precipitation intensity(Schweizer and Jamieson 2003). These factors contribute to the complexity of avalanche prediction, which is further compounded by data constraints and inaccessible areas such as the Himalaya. Despite these challenges in avalanche prediction, a susceptibility map of the avalanches is a crucial resource in hazard management and developing avalanche-controlling structures (Hervás 2003; Barbolini et al. 2011).

Geographic information system (GIS)-based tools are highly beneficial for susceptibility mapping due to their ability to easily integrate various geographic data types and handle extensive datasets (Selcuk 2013). Various qualitative and quantitative GIS methods have been utilized to study snow avalanche susceptibility in recent years. Qualitative approaches rely on expert judgment, while quantitative methods, including statistical, probabilistic, and deterministic techniques, use mathematical algorithms (Chapi et al. 2015). Among qualitative methodologies, Multi-Criteria Decision Analysis (MCDA) has emerged as a widely used technique for evaluating regions' potential for specific events such as avalanches (Malczewski 1999; Greene et al. 2011). MCDA offers diverse approaches to tackling complex decision-making problems and facilitates developing, evaluating, and prioritizing alternative decisions (Malczewski 2006; Greene et al. 2011). The integration of GIS with MCDA has proven successful in natural hazard analysis (Ayalew et al. 2004; Gamper et al. 2006; Fernández and Lutz 2010) and other geo-environmental studies (Dai et al. 2001; Joerin et al. 2001; Kolat et al. 2006).

Numerous studies have been conducted to derive avalanche risk and hazard maps using GIS, remote sensing, and multi-criteria decision analysis (MCDA) methods Several studies have adopted GIS-based AHP multi-criteria methods (Snehmani et al. 2014; Kumar et al. 2017; Sardar et al. 2019; Bühler et al. 2022). for avalanche susceptibility mapping. The majority of these studies have relied on static parameters such as slope, elevation, curvature, aspect, land cover, vegetation cover, and terrain roughness to produce susceptibility maps, as these parameters being constant are well-suited for long-term avalanche risk mapping (Bühler et al. 2013; Snehmani et al. 2014; Kumar et al. 2016, 2018; Parshad et al. 2017), while some investigations have also integrated both static and dynamic parameters to generate the avalanche susceptibility maps (Omirzhanova et al. 2015; Singh et al. 2019b; Yariyan et al. 2022).

Avalanche research in the Himalayas of Nepal remains notably limited despite frequent occurrences of devastation in numerous locations such as Kobang, the ABC route, Darchula, and other mountainous regions (Thakuri et al. 2020). The absence of readily available avalanche hazard susceptibility maps exacerbates the risk in critical areas such as the Annapurna Conservation Area. To date, limited studies have been conducted in Nepal. In the Khumbu region (Kattelmann and Yamada, 1996) and Langtang region (Fujita et al. 2017) in the Central Himalaya, avalanches have been investigated regarding their triggers, but no comprehensive study exists. Additionally, while some mention has been made of avalanche fatalities (McClung 2016; Thakuri et al. 2020), primarily related to mountaineering activities (McClung 2016), little attention has been given to mitigation, prevention, or coping mechanisms. However, despite these efforts, no hazard and risk maps have been developed for any avalanche-affected areas in Nepal. Therefore, urgent action is required to create avalanche susceptibility maps for regions experiencing frequent avalanche occurrences before it is too late. In this study, a GIS-based multi-criteria decision analysis AHP model developed by Saaty in 1980 (Saaty and Vargas 2013) s being employed to generate a susceptibility map of the Annapurna Conservation Area (ACA), considering terrain, ground cover, lithology, and meteorological parameters within the ACA.

4.2 Study Area

The study area is the Annapurna Conservation Area (Figure 4.1), Nepal's largest protected area with a geographic extent of 28°47′N to 28.78°N latitude, 83°58′E to 83.97°E longitude, and area coverage of 7,629 km² in the Annapurna range of the Himalayas. The elevation ranges from 790 m to the peak of Annapurna I at 8,091 m, stretching across the Manang, Mustang, Kaski, Myagdi, and Lamjung Districts of Nepal. It was established in 1985, gazetted in 1992, and is being managed by the National Trust for Nature Conservation (NTNC).

ACA harbors a total of 1352 species of plants, 128 species of mammals, 518 species of birds, 40 species of reptiles, and 23 species of amphibians (NTNC 2019). Temperate coniferous and mixed forests are prominent in this area. The main tree species are Pinus wallichiana, Tsuga Dumosa, and Rhododendron arboreum. At the same time, Cupressus torulosa, Abies spectabilis, A. pindrow, Ilex dipyrena, Taxus baccata, Betula alnoides, and Acer spp are other important species found there. Moreover, shrubs such as Berberis spp are crucial sources of firewood. Coriaria nepalensis, Hippophae salicifolia, Lauraceae spp., and Virburnum erubescens are also important plant species found there (Christensen and Heilmann-Clausen 2009).

Large mammals like snow leopards and red fox Vulpes can be seen there, and blue sheep and other small mammals such as Himalayan marmot Marmota himalayana, Royle’s pika Ochotona roller and stone Mattes Fiona are some other important animals found there. The birdlife is comparatively diverse and has birds like vulture Gypatus barbatus and Himalayan griffon Gyps himalayenis, Tibetan snowcock Tetrogallus tibetanus, and Himalayan snow- cock Tetrogallus himalayensis (Oli et al. 1994). Apart from the richness in biodiversity and geodiversity, ACA is also culturally very abundant and diverse and is a famous tourist destination with several trekking trails (Becken et al. 2013; NTNC 2019).

Five settlements (Ghattekhola, Naurikot, Larjung, Kobang, Chhaktang) in Thasang Rural Municipality and five settlements (Annapurna Base Camp (ABC), Machhapuchhre Base Camp (MBC), Deurali, Himalaya, Dovan) in Annapurna Rural municipality were considered for detail avalanche studies (Figure 4.1) with research field visits in May 2023. Avalanche locations nearby and in these settlements were documented based on the avalanche debris and scars, and the local population showed the various avalanche locations where they often encountered avalanches.

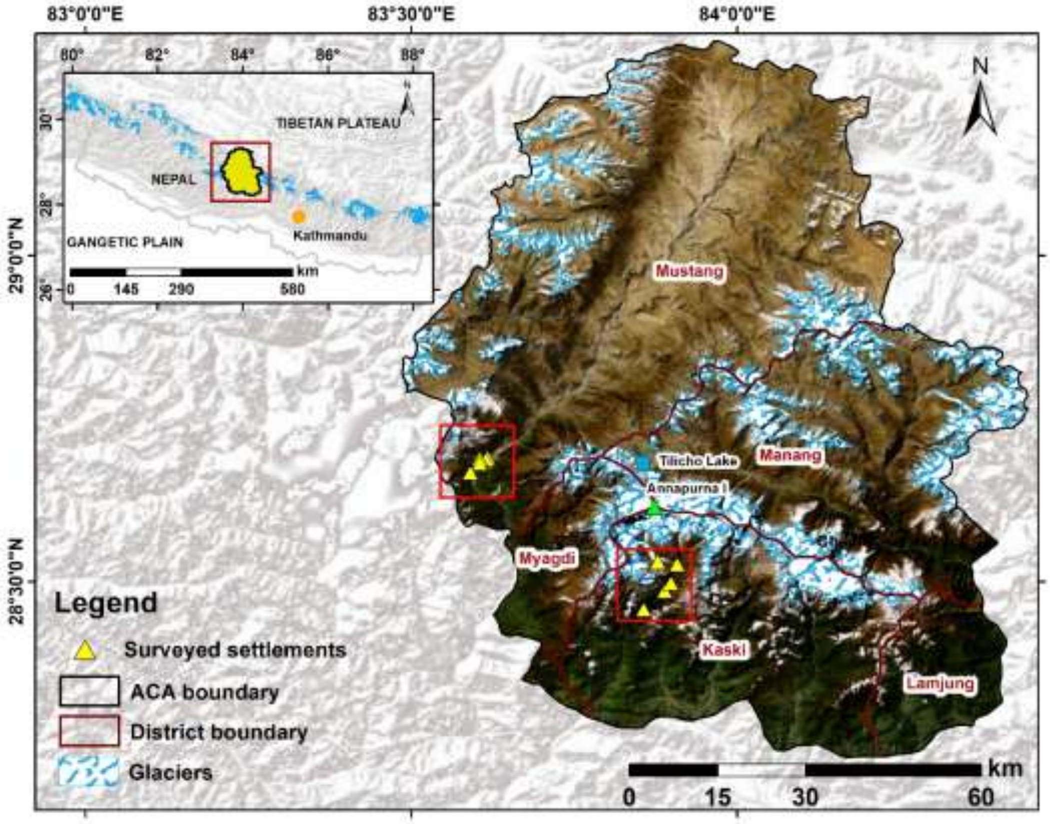

Figure 4.1. Location map of ACA.

4.3 Methodology

The methodology adopted to generate the avalanche susceptibility map of the ACA is shown in Figure 4.2 and discussed in detail in the subsequent sections. This study involves the following steps for generating an ACA Avalanche susceptibility map, and the methodology of the workflow is presented in the flowchart below Figure 4.2.

i. Selection of snow avalanche conditioning factors
ii. Preparation of the avalanche inventory map. 120 avalanche locations were identified based on field visit in May 2023.
iii. Ranking and reclassification of the most significant avalanche conditioning factors after correlating the factors classes with the avalanche inventory map and existing works of literature.

iv. Pairwise comparison matrix between all the considered factors and calculate the weight values of each thematic layer by employing the analytic hierarchy process (AHP) method.

v. The avalanche susceptibility map was validated using the Area under the Receiver Operating Characteristic Curve (ROC AUC).

4.3.1 Avalanche conditioning factors

Table 4.1 below shows the information about all the conditioning factors.

Table 4.1 Information about avalanche conditioning factors

S. N	Conditioning factor	Source
1	Slope	ASTER GDEM V3
2	Curvature	ASTER GDEM V3
3	Elevation	ASTER GDEM V3
4	Aspect	ASTER GDEM V3
5	Terrain roughness	ASTER GDEM V3
6	Ground cover	ESRI LULC
7	Lithology	NTB
8	Precipitation	DHM
9	Air temperature	DHM

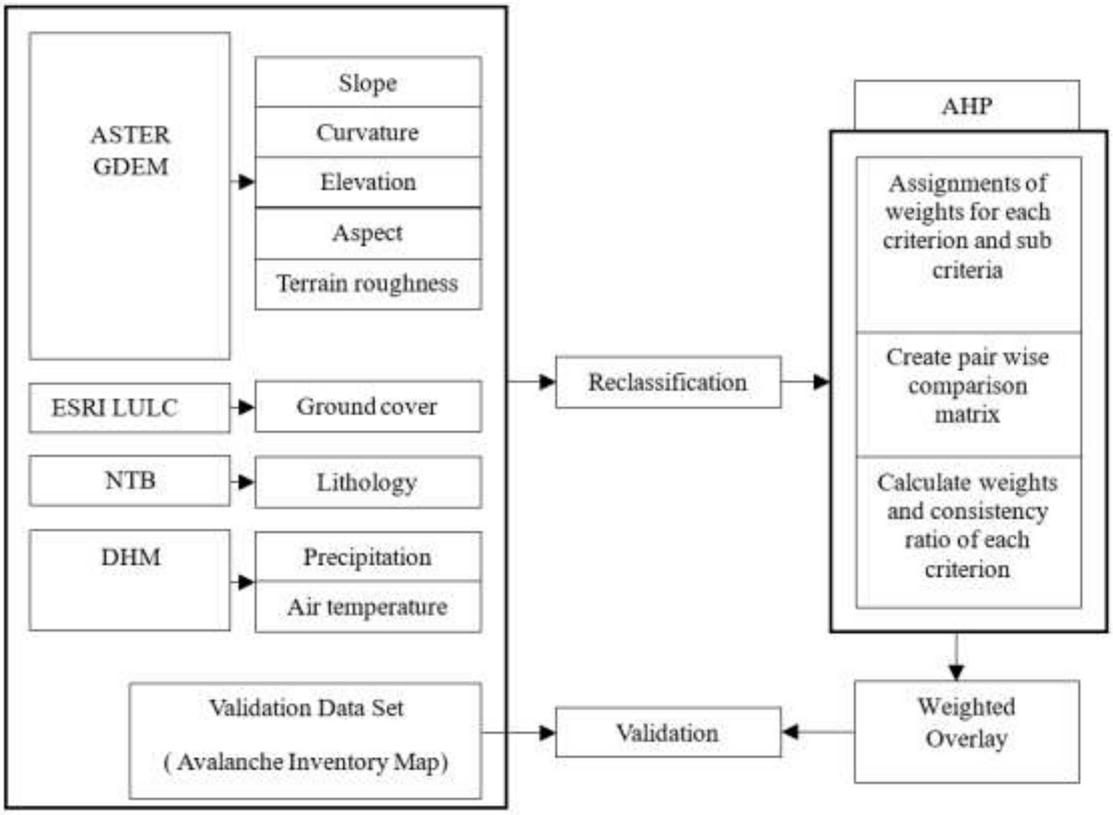

Figure 4.2 Flow diagram of avalanche susceptibility mapping.

ASTER GDEM V3 of 30 m resolution was used to determine the values for terrain parameters such as slope, aspect, curvature, elevation, terrain roughness, and aspect in ArcGIS 10.5. whereas databases of the Department of Hydrology and Meteorology (DHM), Nepal Tourism Board (NTB), and ESRI LULC were used to derive meteorological factors, lithology, and ground cover, respectively.

Slope: Slope is the primary terrain factor for avalanche activity and is widely studied among all determining factors. In most cases, avalanches release at slopes between 30 and 50° (Schweizer and Jamieson 2003; McClung and Schaerer 2006), but lower angles down to 27° have also been suggested (Ancey, 2001). Several studies in the Western Himalayas showed slopes between 25 to 45° were more prone to avalanches (Snehmani et al. 2014) Sharma and Ganju. (2000) concluded avalanche-prone slopes of 28 and 40°, and (Singh et al. 2018) found avalanche slopes to be from 25 to 38°.

The slope in the study derived from ASTER GDEM ranged from less than 12° to greater than 55°, and thus, based on literature and the avalanche locations in the study area, it was reclassified into 5 subclasses. The slope map with 5 classes is shown in Figure 4.3. The subclassifications, along with their weights, are presented in Table 4.5.

Elevation: Elevation is a crucial parameter to consider while forecasting or assessing avalanches, especially for areas in low-latitude regions such as the HKH. Precipitation in the form of snow or rain is highly dependent upon elevation and can be an important trigger for avalanches. Studies in the Himalayas suggest that most avalanche-release areas have been found between 4000 and 5000 m a.s.l. (Singh et al. 2018).

In this study, an elevation map was derived using ASTER GDEM and further classified into 5 classes ranging from less than 4000 m a.s.l to greater than 6500 m.a.s.l (Figure 4.5). The subclassifications, along with their weights, are presented in Table 4.5.

Curvature: Curvature impacts the acceleration and deceleration of flow, directly influencing the snow's erosion and deposition. Because of tensile stress, the convex profile of the terrain leads to an unstable condition for snow cover with significant variation in the snow cover depth (Ancey, 2001), while compressive stress on concave terrain favors the snow equilibrium. A curvature value of 5 was concluded to be the threshold for avalanche release in the Manali, Western Himalayas (Bühler et al. 2013). The curvature map of the ACA was derived from ASTER GDEM and was reclassified into three types reflecting convex, concave, and flat classes (Figure 4.4). The weights of each subclassification are presented in Table 4.5.

Aspect: Aspect defines the day-to-day stability of the snowpack, as the orientation towards the sun changes the properties of the snowpack. For instance, snowpacks on shady slopes in winter receive limited shortwave radiation and lose heat by longwave radiation. As a result, weak layers with faceted crystals and depth hoar are formed, favoring avalanche release. Conversely, slopes on sunny sides encounter numerous avalanches during the late winter or spring due to a temperature rise (Ancey, 2001). The aspect was generated using ASTER GDEM and reclassified into nine classes (Figure 4.6). The subclassification, along with the weights, are presented in Table 4.5.

Terrain roughness: Terrain roughness is essential in anchoring snow to the ground. Rough and irregular features such as broken terrain, starting zones cut by numerous ridges, or giant boulders limit the amount of snow volume released (Schweizer and Jamieson 2003; Bühler et al. 2013). Terrain roughness may also result in snow metamorphism (McClung and Schaerer 2006; Bühler et al. 2013).

For this study, terrain roughness was generated using ASTER GDEM and reclassified into five subclasses (Figure 4.7). The subclasses and weights are presented in Table 4.5.

Ground cover: Ground cover can play a significant role in the occurrence of avalanches. Widely spaced forests and large and open slopes with smooth ground may favor avalanche release (Ancey 2001). However, deciduous vegetation with no leaves during winter is not considered as effective as coniferous vegetation in intercepting falling snow and hindering the formation of a weak layer (Bühler et al. 2013).

For this study, the ground cover was classified into three distinct subclasses, each with its own unique characteristics. The classification was generated using ESRI LULC and is illustrated in Figure 4.8. The subclasses, along with their corresponding weights, are listed in a structured manner in Table 4.5.

Lithology: While rock types may not directly trigger avalanches, they are instrumental in delineating areas most prone to avalanche formation (Akay 2021), as different lithological units can influence the susceptibility to avalanches (Choubin et al. 2019). The lithological map was extracted from the Nepal Tourism Board. It was classified into four groups according to lithological units (Figure 4.9). The subclasses and the weights are shown in Table 4.5.

Precipitation: Precipitation is a pivotal meteorological influencer shaping snow accumulation and the formation of weak layers within the snowpack (Choubin et al. 2019). The precipitation data was collected from the Department of Hydrology and Meteorology (DHM), Nepal, for 14 stations in the study area, a dataset spanning three decades (1993-2022), which was then distributed throughout the study area using the IDW interpolation method. The annual precipitation map was classified into three groups (Figure 4.10). The subclasses and the weights of annual precipitation are shown in Table 4.5.

Air temperature: Among two meteorological parameters, one is mean annual temperature. Regions experiencing higher annual air temperatures experience more snow cover melting, consequently reducing the likelihood of snow avalanches. Conversely, lower air temperatures prolong snow retention on surfaces, facilitating the accumulation of new snow deposits and reducing stability (Yariyan et al. 2022).

The air temperature data was collected from the Department of Hydrology and Meteorology (DHM), Nepal, for three stations in the study area, a dataset spanning three decades (1993-2022). The dataset was then extrapolated to other stations using the annual temperature lapse rate of -5.2°C/km (Kattel et al. 2013) which was then distributed throughout the study area using the IDW interpolation method. The annual air temperature map was classified into three groups (Figure 4.11). The subclasses and the weights of annual temperature are shown in Table 4.5.

4.3.2 Snow avalanche inventory map

Avalanche locations were identified and tracked through the interpretation of aerial photographs and field surveys conducted in various places in the ACA. In total, 120 avalanche locations were identified and used in this study to validate the generated susceptibility map.

4.3.3 MCDA-AHP modelling

Saaty in 1980 devised a method for multi-criterion-based decision-making called the Analytical Hierarchical Process (AHP). It assists in making a comprehensive decision on selecting the best options among different alternatives. The idea behind AHP is to give a numeric scale from 1 to 9 for each criterion based on its importance in decision-making. The scale used for relative comparison is presented in Table 4.2 below.

Table 4.2 Pairwise Comparison Scale (Saaty 2001)

Importance Degree	Definition	Description
1	Equally preferred	Both factors are equally valued.
3	Moderately preferred	One factor is slightly favored over the other.
5	Strongly preferred	One factor is significantly favored over the other.
7	Very Strongly preferred	One factor is highly favored over the other.
9	Extremely Preferred	One factor is favored to the highest degree possible.
2,4,6,8	Intermediate Values	When compromise between factors is necessary.

The process of determining the weight or relative importance begins with constructing a pairwise decision matrix for the criteria and sub-criteria under consideration. If p_{ij} and p_{ji} are the two entries of the square pairwise matrix, it must satisfy Equation 1.

$$p_{ji}=\frac{1}{p_{ij}} \tag{1}$$

The average of the normalized row of the matrix will be the weight of each criterion. Normalization is done by dividing each entry in the column by the sum of the total elements in that column. The average of each row's entries yields the relative weight of the criteria.

Following the computation of weights, validation of the created AHP model becomes necessary. A factor called the consistency ratio, or the CR, helps evaluate the consistency of the pairwise comparison. The value of the consistency ratio must be less than 0.1; otherwise, the pairwise comparison needs reevaluation. The CR is calculated using Equation 2.

$$CR=\frac{CI}{RI} \quad (2)$$

CI is the consistency index, and RI is the random index. Saaty defines CI as the deviation measure calculated using Equation 3.

$$CI=\frac{\lambda_{max}-N}{N-1} \quad (3)$$

In this context, λ_{max} represents the maximum eigenvalue of the pairwise comparison matrix, while N denotes the order of the comparison matrix. As specified by (Saaty 2001), the random index varies according to the number of criteria under consideration, as illustrated in Table 4.3.

Table 4.3 Random Index for different number of criteria (Saaty 2001), n = order of the matrix.

n	2	3	4	5	6	7	8	9	10	11	12
RI	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48

The final weight, or the global weight, is the summation of the product of the weights of criteria and subcriterion, as stated in

$$W=\sum_{i=1}^{n}(c_i s_i) \quad (4)$$

Where W implies the sum of the product of weights of criteria c_i and sub criteria s_i.

The susceptibility map is then generated applying the equation 5 which the application of equation 4.

$$ASI=\sum_{i=1}^{n}(0.288*S+0.094*C+0.259*E+0.093*A+0.044*TR+0.043*GC+0.031*L+0.095*P+0.052*T) \quad (5)$$

Where, ASI, S, C, E, A, TR, GC, L, P and T represent Avalanche Susceptibility Index, Slope, Curvature, Elevation, Aspect, Terrain roughness, ground cover, lithology, precipitation and air temperature, respectively.

4.4 Results

4.4.1 Application of MCDA-AHP model

This section consists of the results after applying the model in terms of weight for each criterion and sub-criteria. Nine factors, including seven terrain and two meteorological factors, were used to derive the susceptibility map of the ACA. The development of weight values for each criterion in the GIS layer is based on a pairwise comparison matrix. Before completing the matrices, the relative ranking of the criteria in each layer was evaluated by expert judgments, and the literature and characteristics of the layers were explained above. The results of pairwise comparison matrices are shown in

Table 4.4. The CRs obtained from the matrices were well within the ratio equal to or less than 0.10, as recommended by Saaty. (2001). The weight values for each factor are 0.288 for slope, 0.094 for curvature, 0.259 for elevation, 0.093 for aspect, 0.044 for terrain roughness, 0.043 for ground cover, 0.031 for lithology, 0.095 for precipitation, and 0.052 for air temperature. Similarly, weights for individual sub-criteria have been derived, and the results are shown in Table 4.5.

Table 4.4 Pairwise comparison matrix of considered factors to calculate thematic weight

Criteria	S	C	A	TR	E	GC	L	P	T
S	1	4	4	5	2	6	5	3	5
C	0.25	1	1	3	0.33	3	2	1	2
A	0.25	1	1	3	0.2	3	2	1	3
TR	0.2	0.33	0.33	1	0.14	2	4	0.25	0.5
E	0.5	3	5	7	1	7	5	5	3
GC	0.17	0.33	0.33	0.5	0.14	1	4	0.5	1
L	0.2	0.5	0.5	0.25	0.2	0.25	1	0.5	0.5
P	0.33	1	1	4	0.2	2	2	1	3
T	0.2	0.5	0.33	2	0.33	1	2	0.33	1

Table 4.5 Weights of different criteria and sub-criteria

SN	Particulars	Range	Criteria Weight	Sub Criteria Weight	Global Weight
1	2	3	4	5	6=4*5
1	Slope	<12°	0.288	0.037	0.011
		12-28°		0.108	0.031
		28-45°		0.632	0.182
		45-55°		0.161	0.046
		>55°		0.062	0.018
2	Curvature	Convex	0.094	0.793	0.075
		Flat		0.131	0.012
		Concave		0.076	0.007
3	Elevation	<4000 m	0.259	0.022	0.006
		4000-4500 m		0.235	0.061
		4500-5000 m		0.235	0.061
		5000-5500 m		0.179	0.046
		5500-6000 m		0.131	0.034
		6000-6500 m		0.108	0.028
		>6500 m		0.089	0.023
4	Aspect	Flat	0.093	0.011	0.001
		North		0.192	0.018
		Northeast		0.236	0.022
		East		0.052	0.005
		Southeast		0.088	0.008
		South		0.276	0.026
		Southwest		0.063	0.006
		West		0.036	0.003
		Northwest		0.045	0.004
5	Terrain Roughness	<0.39	0.044	0.07	0.003
		0.39-0.46		0.211	0.009
		0.46-0.53		0.147	0.006
		0.53-0.60		0.471	0.021
		>0.61		0.101	0.004
6	Ground cover	Snow/ice	0.043	0.709	0.031
		Bare land		0.231	0.01
		other		0.06	0.003
7	Lithology	Two-mica leucogranite	0.031	0.218	0.021
		Phulchouki group of Kathmandu		0.661	0.063
		Schist, Quartzite, Gneiss and Migmatite		0.079	0.008
		Others		0.041	0.004

SN	Particulars	Range	Criteria Weight	Sub Criteria Weight	Global Weight
7	Precipitation	<100 mm	0.095	0.096	0.009
		100-150 mm		0.407	0.039
		150-200 mm		0.437	0.041
		>200 mm		0.06	0.006
8	Air Temperature	<8°C	0.052	0.2	0.01
		8-13°C		0.727	0.038
		>13°C		0.073	0.004

4.4.2 Avalanche Susceptibility Map

The susceptibility map of the ACA was subdivided into the following five susceptibility zones (Figure 4.12): (i) very high, (ii) high, (iii) moderate, (iv) low, and (v) very low hazard zones. The boundaries of these subclasses were determined by Jenks optimization (natural breaks). Analysis reveals that high and very high susceptibility zones collectively cover 36.9%, comprising 1632.1 km^2) and 1191.7 km^2) of the study area, respectively. Moderate susceptibility zones account for 23.3% (1786.1 km^2) of the study area. Meanwhile, the remaining low and very low susceptibility zones encompass 24.0% (1839.8 km^2) and 15.7% (1204.4 km^2) of the study area, respectively. For a detailed breakdown of the area distribution across avalanche susceptibility zones/levels, refer to Table 4.6. Zone-wise distribution of avalanche susceptibility zones.

Table 4.6. Zone-wise distribution of avalanche susceptibility zones.

Susceptibility zones	Percentage (%)	Area (km^2)
Very low	15.7	1204.4
Low	24.0	1839.8
Moderate	23.3	1786.1
High	21.3	1632.1
Very high	15.6	1191.7

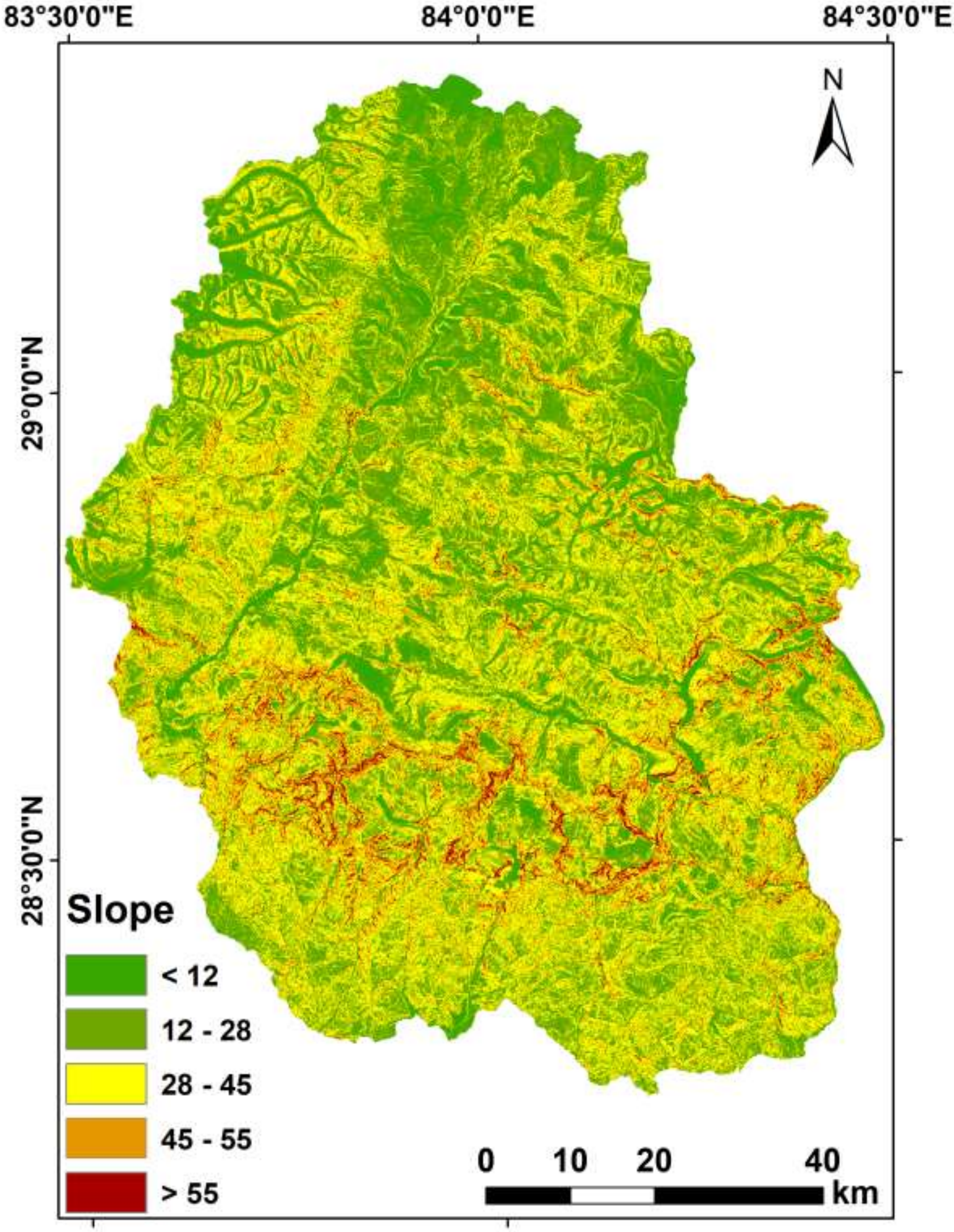

Figure 4.3 Slope map of ACA

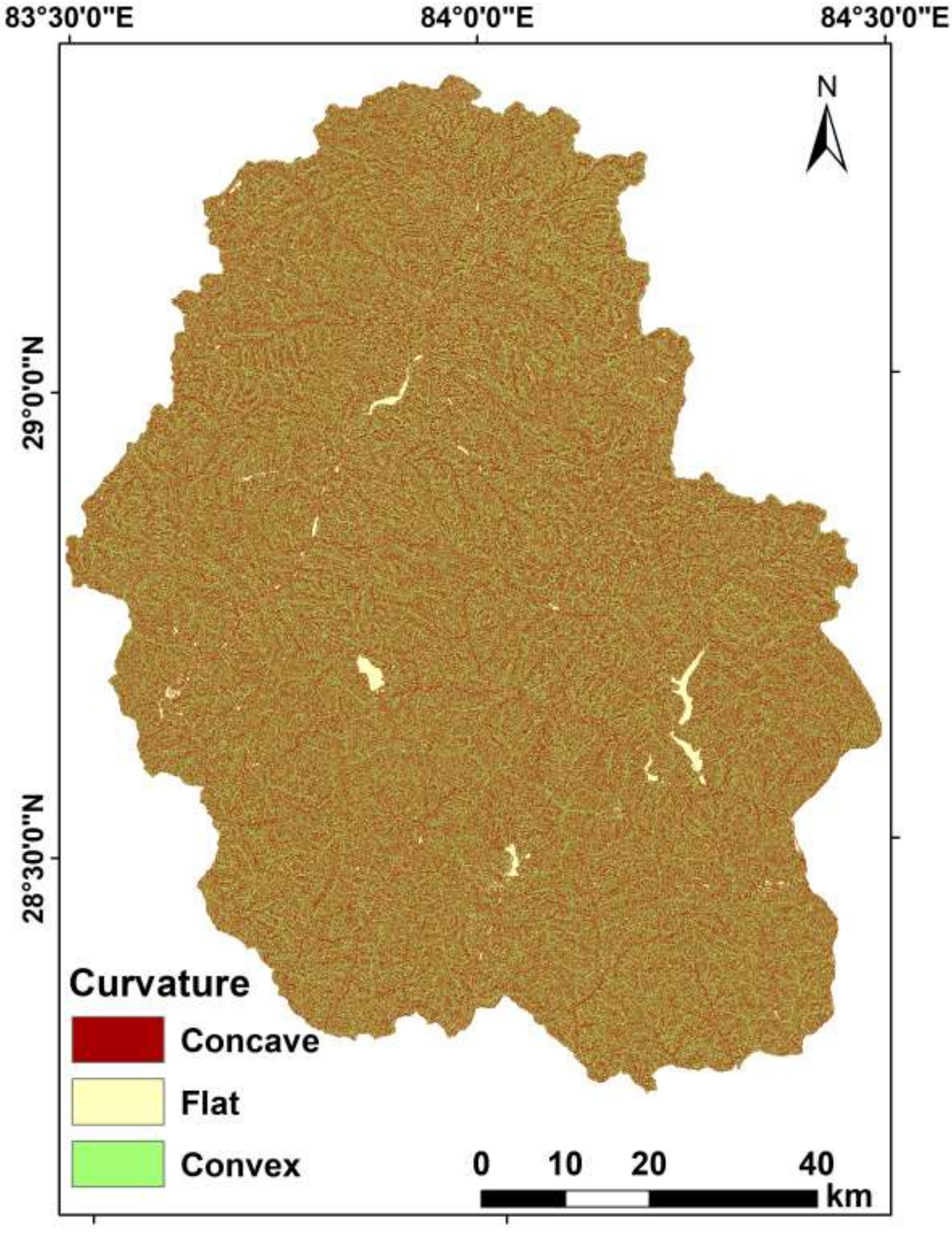

Figure 4.4 Curvature map of ACA

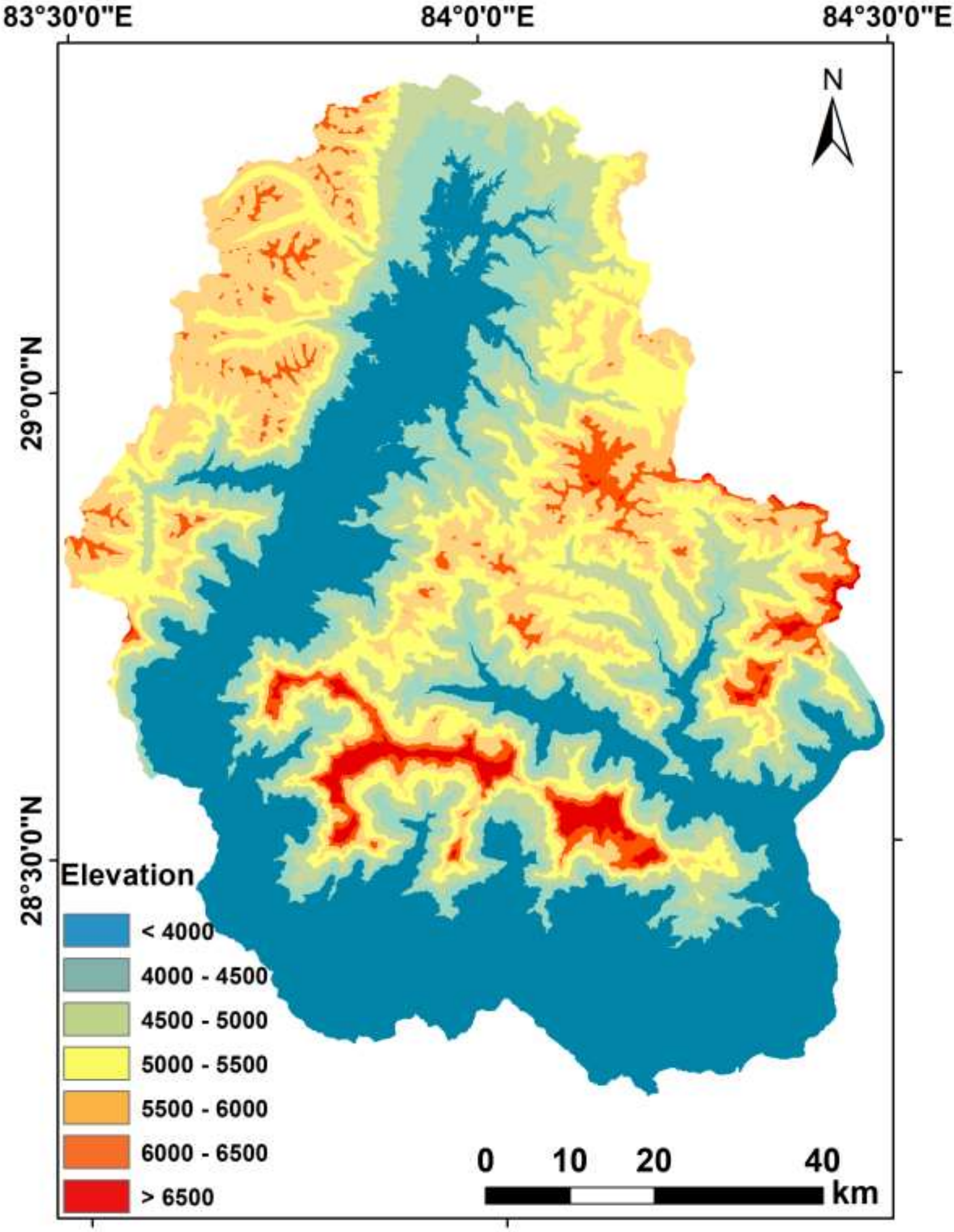

Figure 4.5 Elevation map of ACA

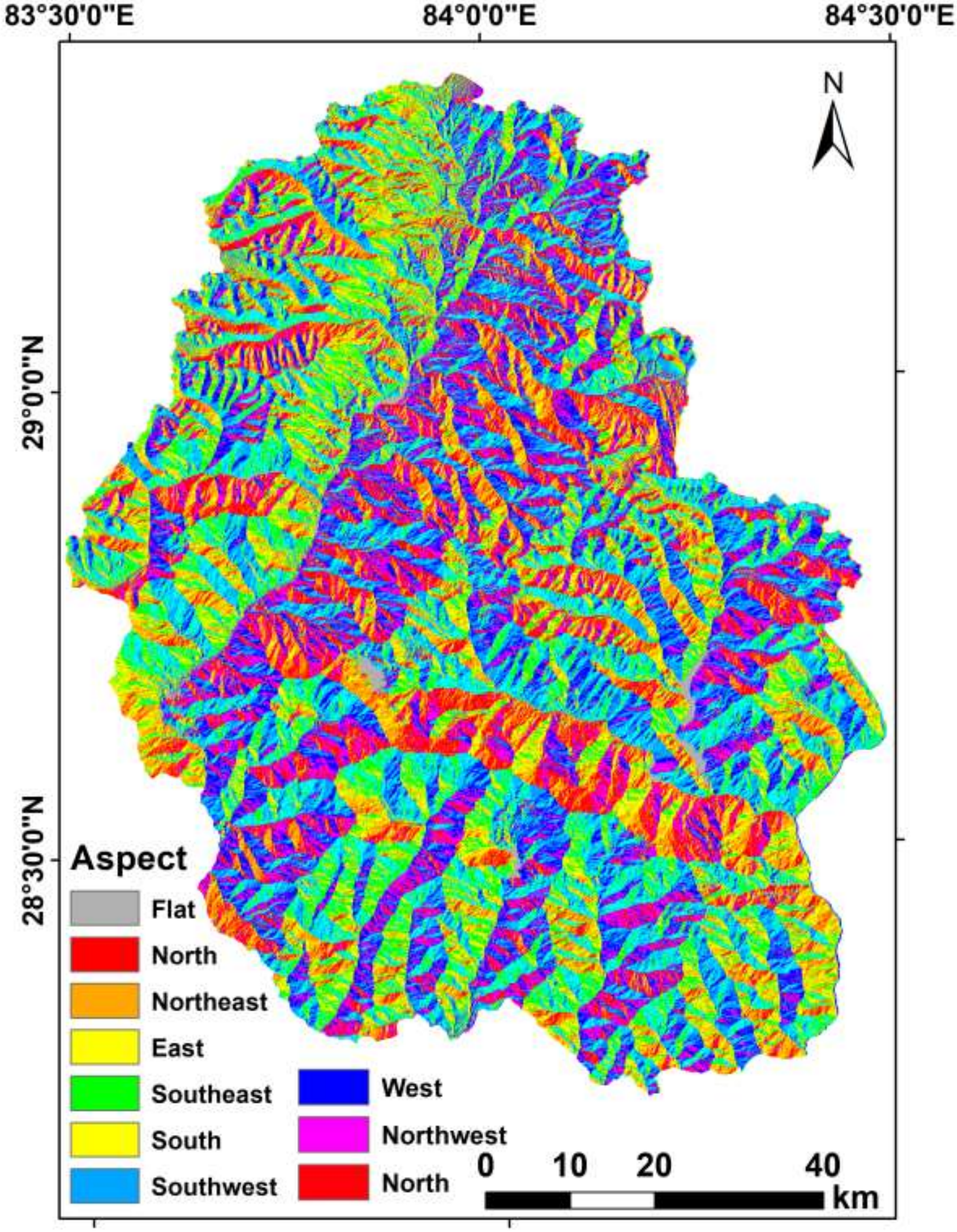

Figure 4.6 Aspect map of ACA

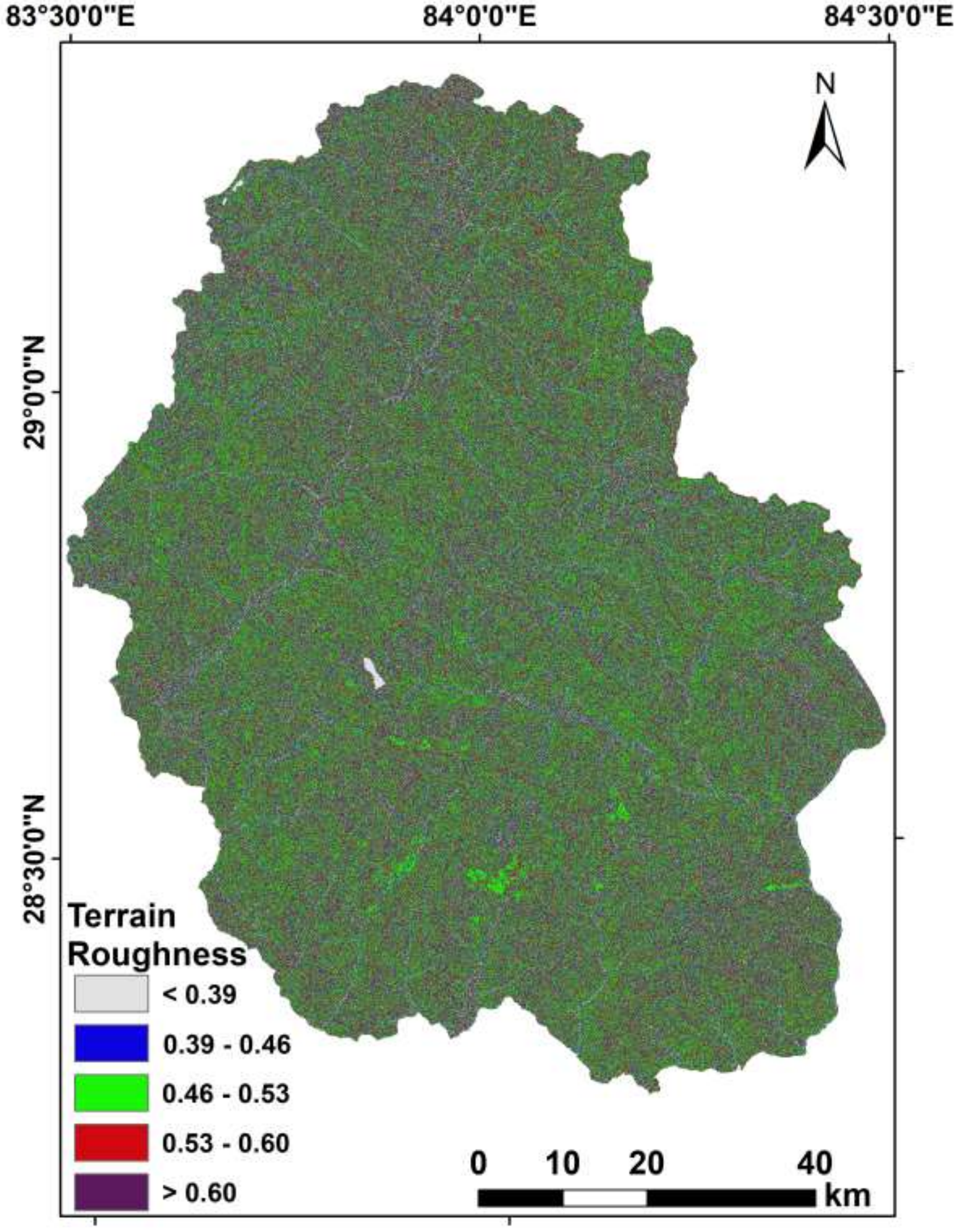

Figure 4.7 Terrain roughness map of ACA

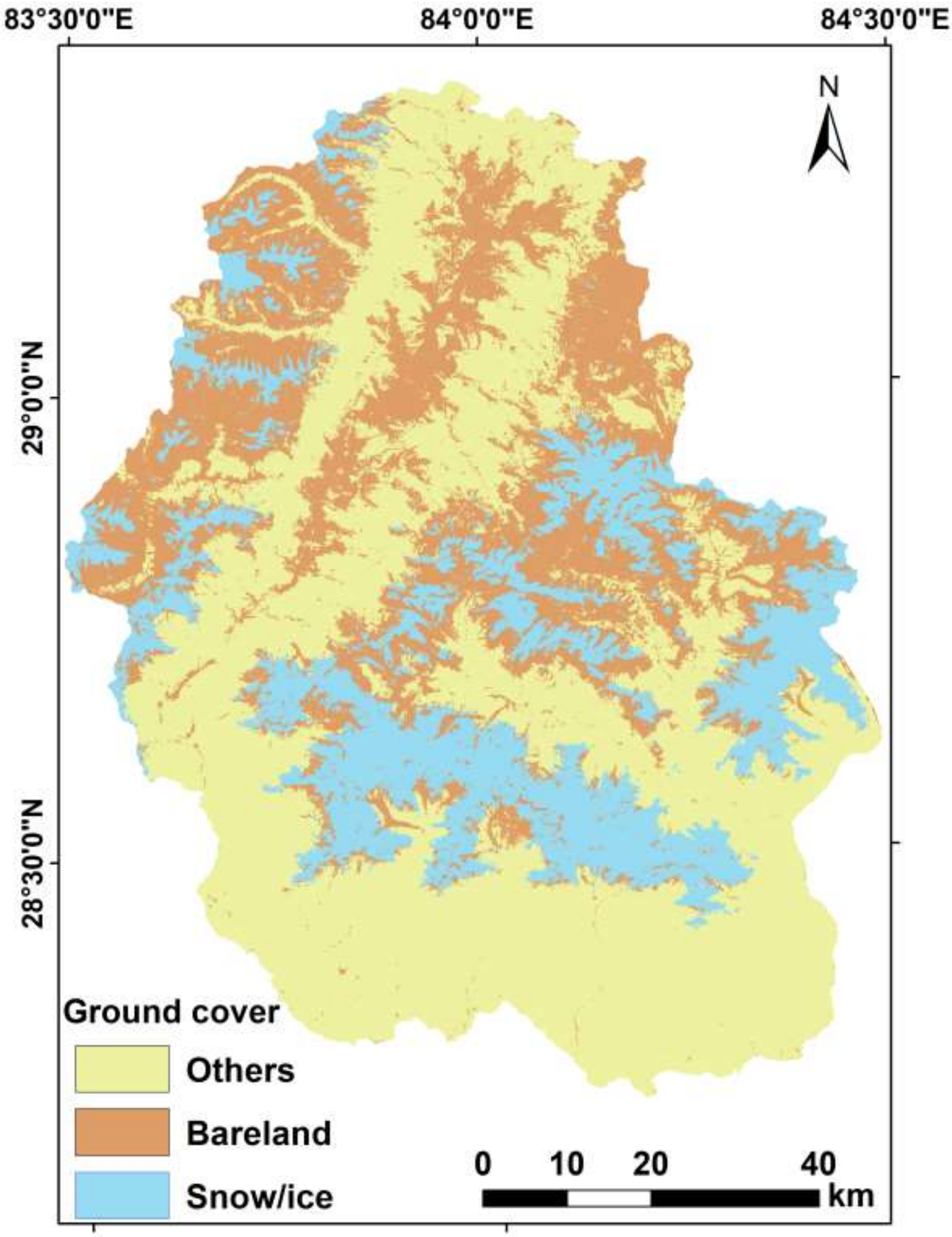

Figure 4.8 Ground cover map of ACA

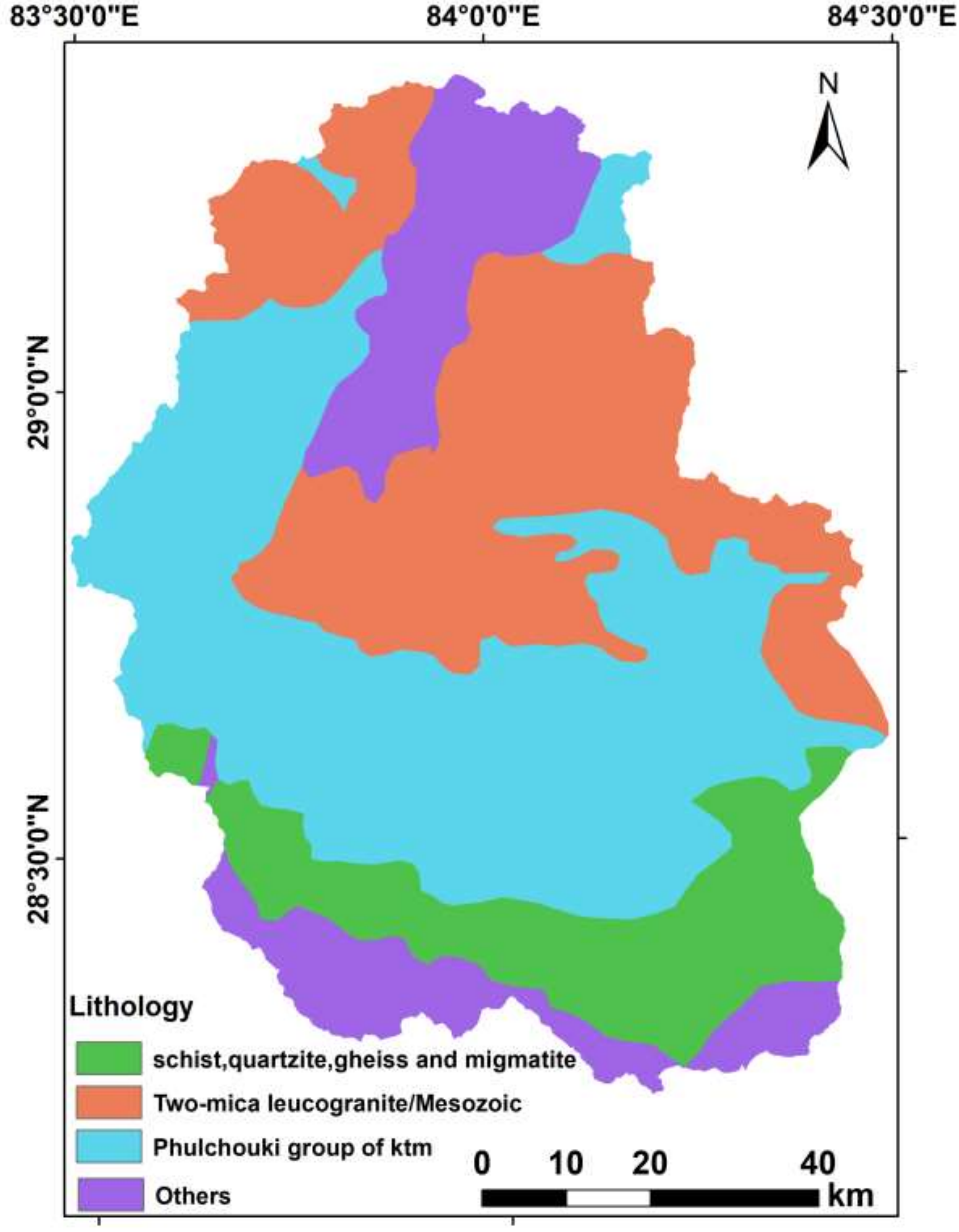

Figure 4.9 Lithology map of ACA

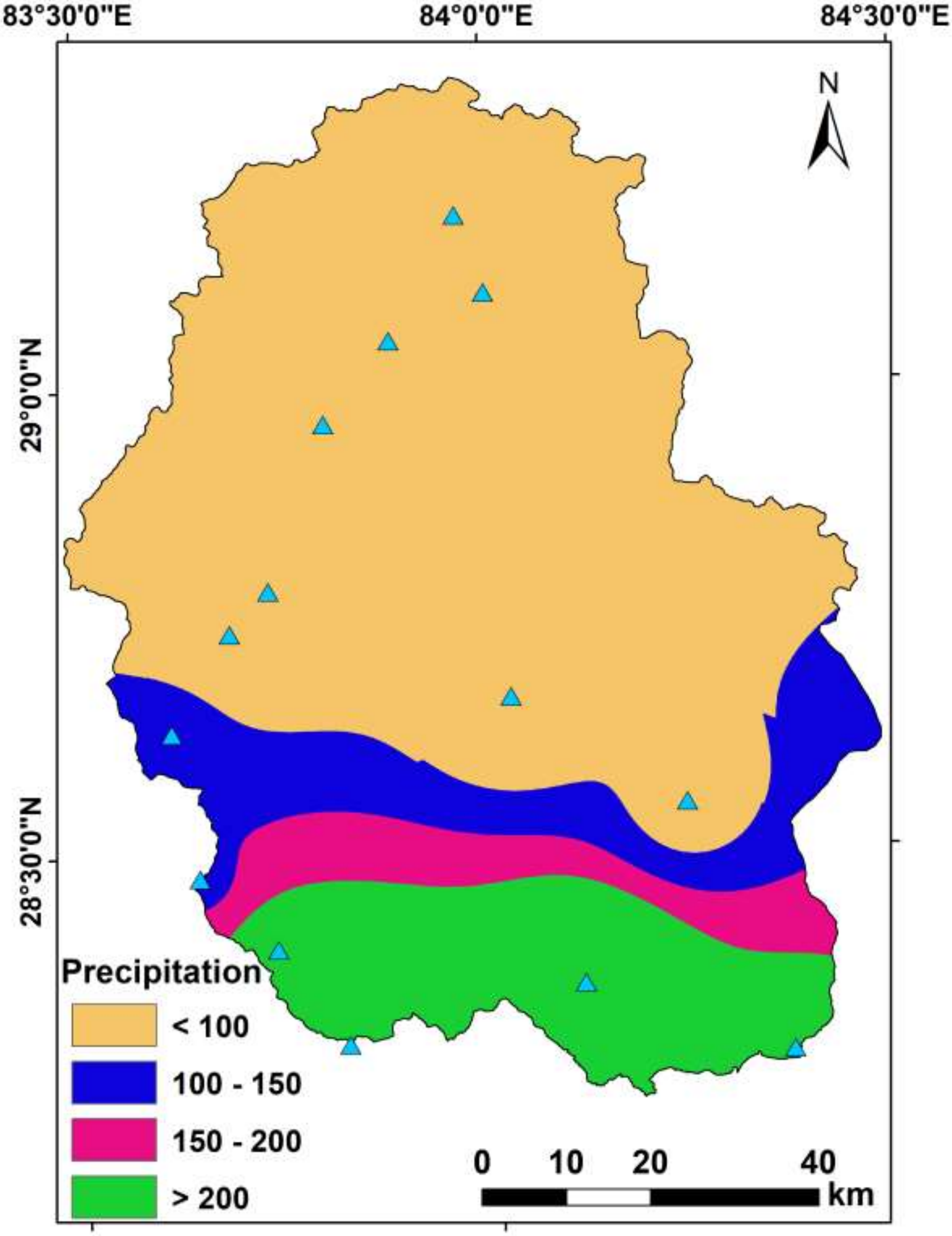

Figure 4.10 Precipitation map of ACA with each weather station represented by a blue triangle

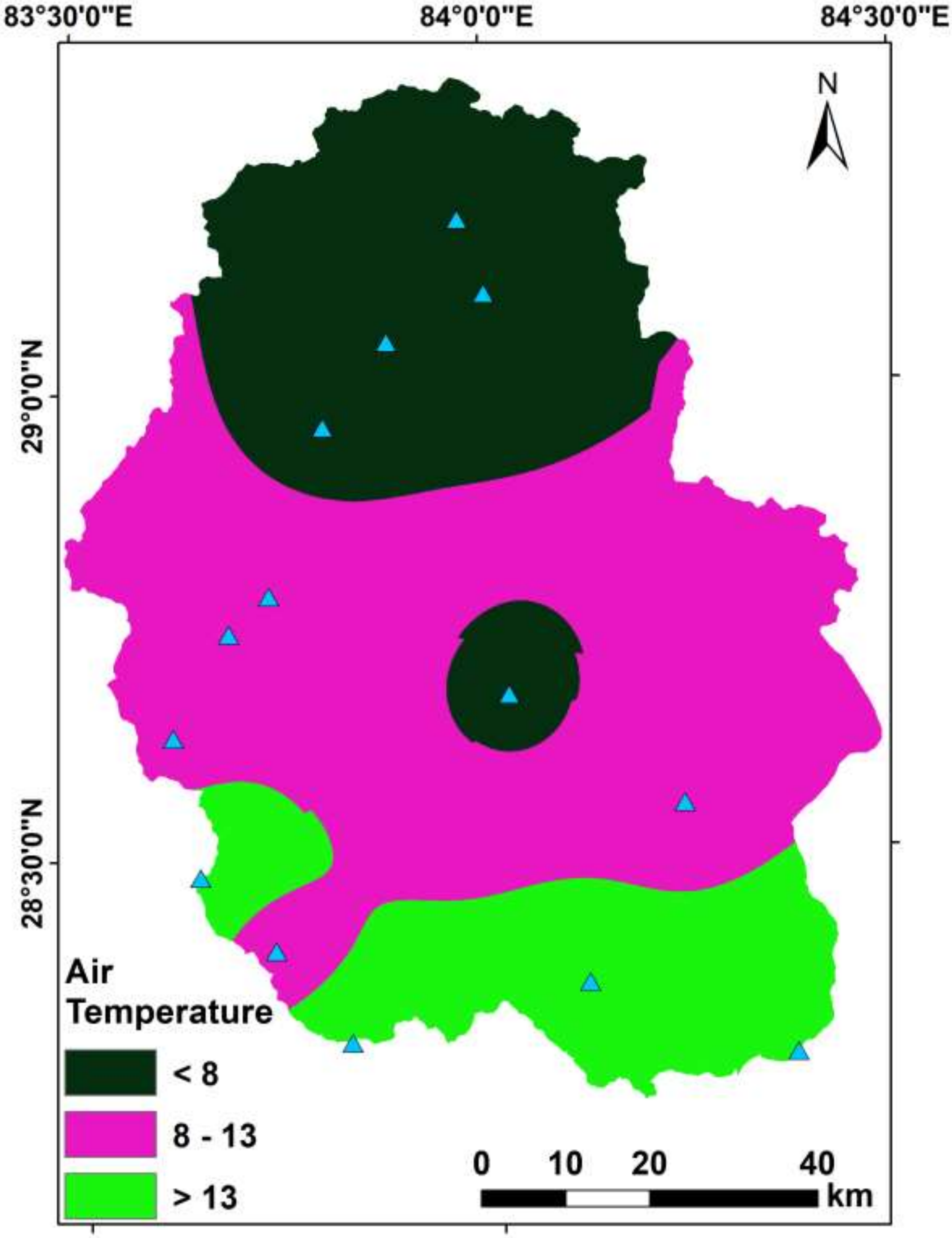

Figure 4.11 Temperature map of ACA with each weather station represented by a blue triangle

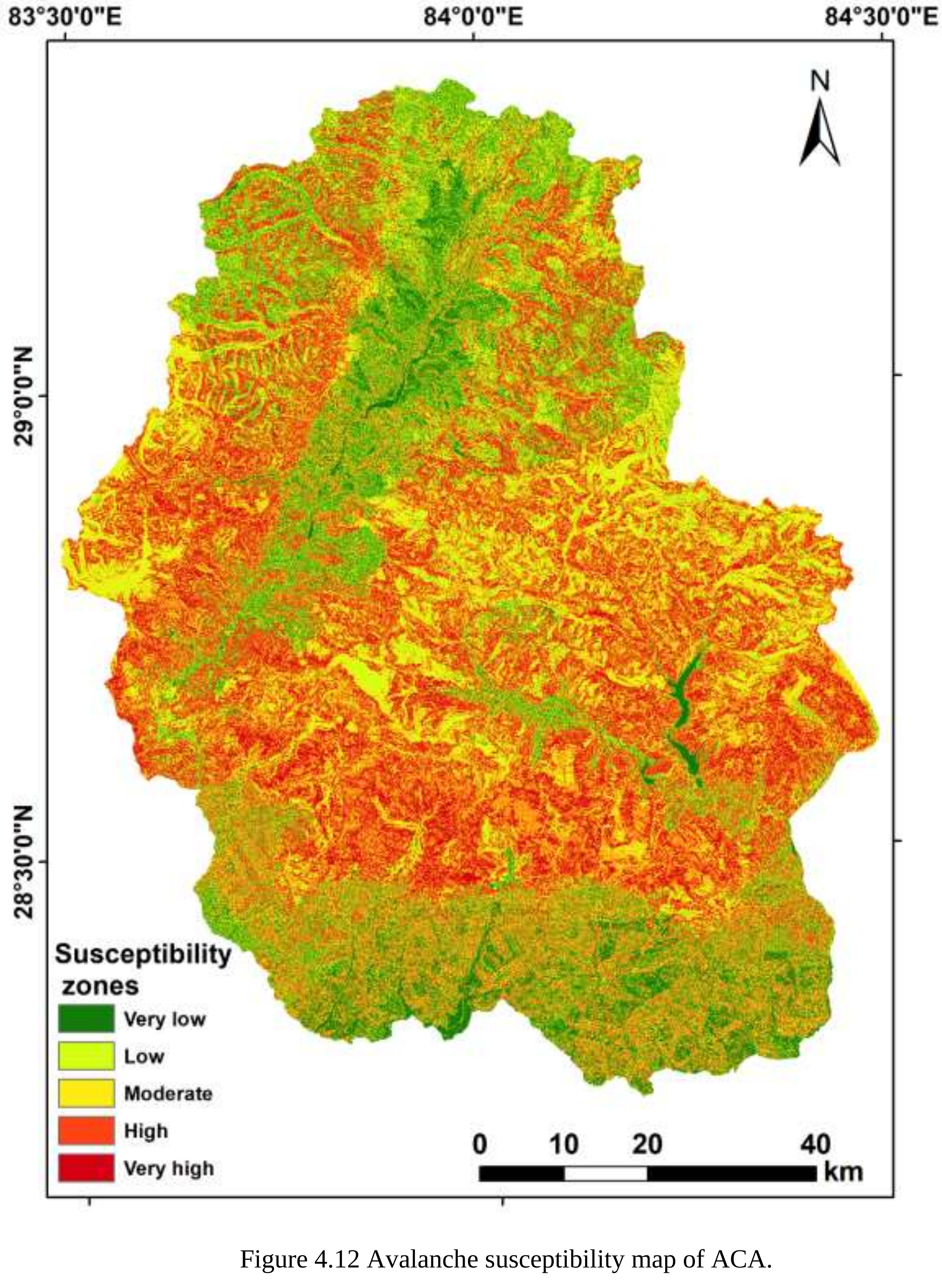

Figure 4.12 Avalanche susceptibility map of ACA.

Although the MCDA–AHP model provides great benefits concerning the complex decision problems and arrangement of spatial data, the determination of prediction rate/accuracy is also crucial for the validation of the model results. The validation process is performed to determine the prediction rate of the MCDA–AHP-based avalanche susceptibility map. A popular statistical assessment technique, the area under the ROC curve, is utilized in this process. This ROC-AUC method is one of the most popular methods for calculating the prediction rate (Yesilnacar and Topal 2005; Van Den Eeckhaut et al. 2006; Baeza et al. 2010). To generate the prediction rate curve or ROC curve, the cumulative percentage of observed or documented avalanche locations is plotted against the obtained ASI, and the area under a ROC curve value is calculated in Figure 4.13. An ideal situation or result would have an area under the curve equal to 1. The area under an ROC curve ranging from 0.5 to 1 is a good fit, and less than 0.5 indicates an irregular fit (Hanley and McNeil 1983). In this study, the value of the area under a ROC curve is calculated as 0.89. The validation results imply that the overall prediction rate of the avalanche susceptibility map is 89%, which means that the total avalanche pixels are appropriately categorized by the avalanche susceptibility mapping model and demonstrate acceptable agreement relating to the avalanche susceptibility map.

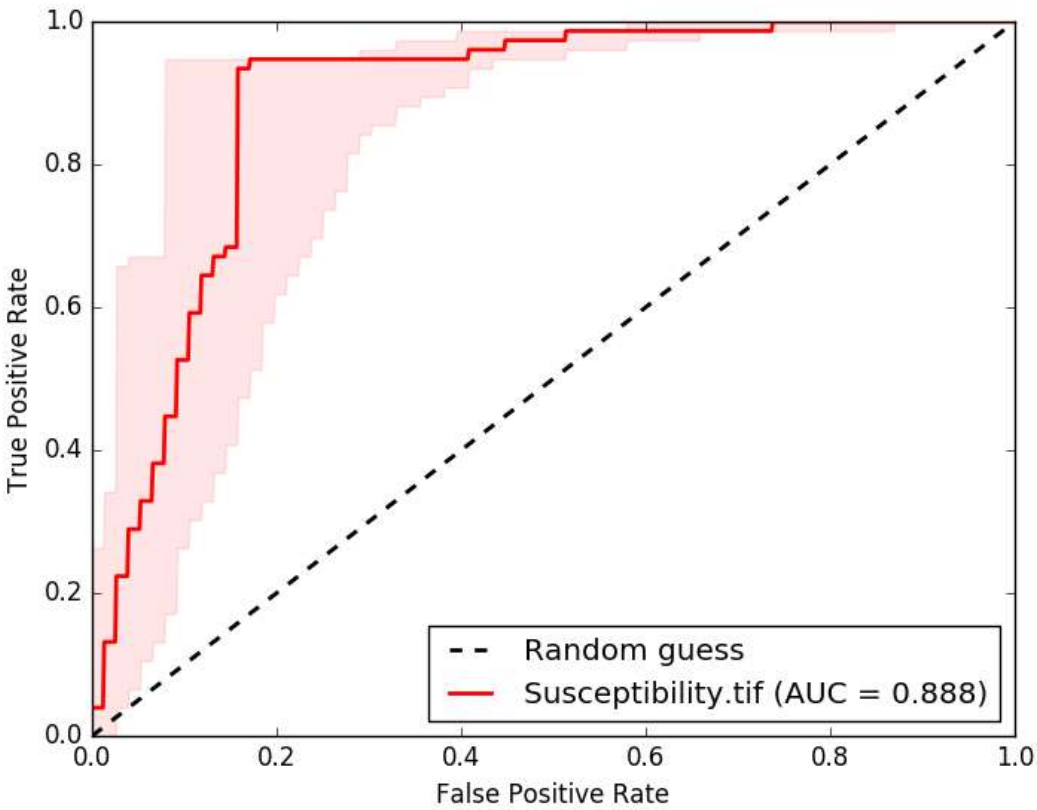

Figure 4.13 Validation of avalanche susceptibility map using the area under the ROC (ROC-AUC) curve analysis.

4.5 Conclusion

This chapter presents a multi-criteria Decision-based Analysis (MCDA) study to derive an avalanche susceptibility map incorporating crucial terrain and meteorological factors. Seven avalanche occurrence factors—slope, curvature, elevation, aspect, terrain roughness, ground cover, and lithology—were sourced from ASTER DEM V3, ESRI LULC, and the Nepal Tourism Board, respectively. Additionally, two meteorological factors—precipitation and air temperature—were sourced from the Department of Hydrology and Meteorology Nepal. These factors were selected for susceptibility mapping due to their availability and significant relevance to avalanche occurrences. However, future studies may benefit from considering other factors, such as more meteorological variables, including snow information, to enhance the accuracy of avalanche susceptibility mapping.

Using the natural jerk's method, the resulting susceptibility map was classified into five zones: very low, low, moderate, high, and very high. High and very high susceptibility zones collectively cover a total area of 36.9%, indicating the need for caution and thorough planning. Similarly, moderate susceptibility zones account for 39.7% of the region, while low and very low susceptibility zones encompass 27.2% of the ACA.

The derived avalanche susceptibility map was rigorously validated through ROC curve analysis, and it yielded a prediction rate of 89%. This high rate of accuracy indicates the map's reliability in identifying avalanche-prone areas and aligning with the documented avalanche locations. Such a reliable tool can significantly aid in disaster management and mitigation efforts.

Recommendations include using dynamic avalanche models to quantify risk and delineate run-out zones, which helps planners and engineers design effective mitigation measures and control structures. Similarly, the strategic planning of zone-specific mitigation measures is highly endorsed. It is strongly recommended that human activities in the high and very high susceptibility zones be strictly limited, with careful consideration for implementing necessary engineering avalanche control measures. A cautious approach to human activity is recommended in the moderate susceptibility zones and the potential adoption of engineering standards to mitigate risks.

Concisely, the susceptibility map derived from this study serves as a crucial foundation for disaster management. It is not just a theoretical concept, but a practical tool that can effectively minimize avalanche damage. By identifying avalanche-prone areas and accurately mapping susceptibility zones, this map equips decision-makers and planners with the necessary information to implement effective measures and mitigate these avalanche risks.

Chapter 5: Result 3- Analysis of avalanche hazards, community vulnerability and mitigation efforts in the ACA

5.1 Introduction

Mountainous regions harbor diverse biological and cultural entities while offering multiple ecosystem services essential to over half of humanity (Ives et al. 1997). However, these mountains are often perceived as fragile and hazardous terrains covered with various cryosphere such as permafrost, glaciers, snowcapped mountains, and other cryosphere (Tuladhar et al. 2021). These terrains are occupied mainly by economically and politically marginalized social groups (Jodha 1992). he lives and livelihood of the mountain population are closely linked with this cryosphere present in their surroundings. The water supplies from the melting glaciers serve as a continuous water supply for agriculture, pastoralism, drinking, hydropower generation, and recreation (Wester et al. 2019). Many mountainous communities rely on irrigation channels supplied by glaciers (Nüsser and Schmidt 2017).

Moreover, medicinal herbs and many aromatic plants regenerate, acquiring moisture from the cryosphere in the HMA. Similarly, snowcapped mountains have cultural significance and are regarded as their sacred place and deities' abode there (Allison 2015). Furthermore, the cryosphere plays a pivotal role in regulating microclimates, with its dynamics influenced by numerous factors like the onset and intensity of monsoons and general circulation patterns (Moors and Stoffel 2013). These dynamics, in turn, have cascading effects on adjacent ecosystems and livelihoods (Xu et al. 2009).

In recent decades, mountain communities in the Himalayan region have experienced significant changes in the existing cryosphere (Wang et al. 2019). The alarming reports from both "The Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC, 2014)" and the "Hindu Kush Himalayan Monitoring and Assessment Programme (HIMAP)" (Wester et al. 2019) indicate that temperature rise in the HKH surpasses the global average temperature increase. As a result, this rising temperature directly influences the glacier melt. Multiple studies show that glaciers are melting accelerated (Kayastha et al. 1999; Baral et al. 2014; Gurung et al. 2016; Acharya and Kayastha 2019) significantly decreasing the glacier's mass balance. Some studies suggest a reduction in the volume of annual snowfall and changes in seasonal snowfall patterns across the region (Paudel and Andersen 2011; Tuladhar et al. 2021) critically decreasing agricultural productivity.

Numerous studies suggest that mountain communities will bear the immediate and severe impacts of changes in the cryosphere (McDowell et al. 2019; Rasul et al. 2020). The rapid changes in the cryosphere increase the risk of numerous disasters, such as glacial lake outburst floods, snow, ice, rock avalanches, and landslides (Krishnan et al. 2019). These events not only damage property infrastructures but also claim the lives of the mountain population residing in the region (Watanbe and Rothacher 1996; Ashraf et al. 2012; Khanal et al. 2015; Thakuri et al. 2020), subsequently exacerbating the economic burdens and in many cases contributing to psychological trauma, mental stress and other health issues especially in vulnerable population like elderly, women and children and marginalized group (Ashraf et al. 2012; Mukherji et al. 2019).

Livelihoods in mountain areas are primarily dependent on natural resources (forest, pastures, land, and water) (Khan 2012) and primarily shaped by their access to natural resources, which include forest and pasture resources, land, and water. They appropriate them by applying indigenous knowledge and their experience interacting with the natural environment (Dasgupta 1997). In Nepal, people in the mountain population are heavily dependent upon tourism (Raya 2020; Sun and Watanabe 2021; Tuladhar et al. 2021), apart from tourism, livestock rearing, and medicinal herbs collections are among the major livelihood activities in the mountainous terrain of Nepal. However, the changing cryospheric system, such as changing snowfall patterns, growing incidence of hazards, and changes in temperature and precipitation, led to choosing tourism as a better option due to frequent disruption by untimely snowfall, avalanches, and other diversified livelihood options. A study in Langtang, Nepal, revealed that the locals feel that the avalanches have increased over the last decade and need urgent attention from the authorities (Tuladhar et al. 2021). ACA, the second biggest tourism destination after the Everest region, is also no exception in terms of increasing avalanche incidences. Many reports about avalanches adversely affecting the area's life, livelihood, and infrastructure. Hence, this section attempts to analyze the impacts of avalanches in the Annapurna Conservation Area (ACA).

5.2 Study Area

ABC Route (Area 1) and Kobang Area (Area 2) were considered for a detailed study by conducting a questionnaire survey. Area 1 lies in the Annapurna Rural Municipality of Kaski District, whereas Area 2 lies in the Thasang Rural Municipality of Mustang District. The study was conducted from the elevation range of 2491 m a.s.l to 4084 m a.s.l in Area 1, whereas in Area 2, the elevation ranges from 2522 m a.s.l. to 2762 m a.s.sl. Area 1 extends from the latitude of 28°28’ 00” to 28°34’ 00” and longitude of 83° 52’ 00” to 83° 56’ 00”. Similarly, Area 2 extends from the latitude 28° 40’ 00” to 28° 42’ 00” and the longitude of 83°36’ 00” to 83°37’ 00”. Area 1 is heavily glaciated. Area 2 also has glaciated surroundings; however, the settlements are in much lower elevations than Area 1.

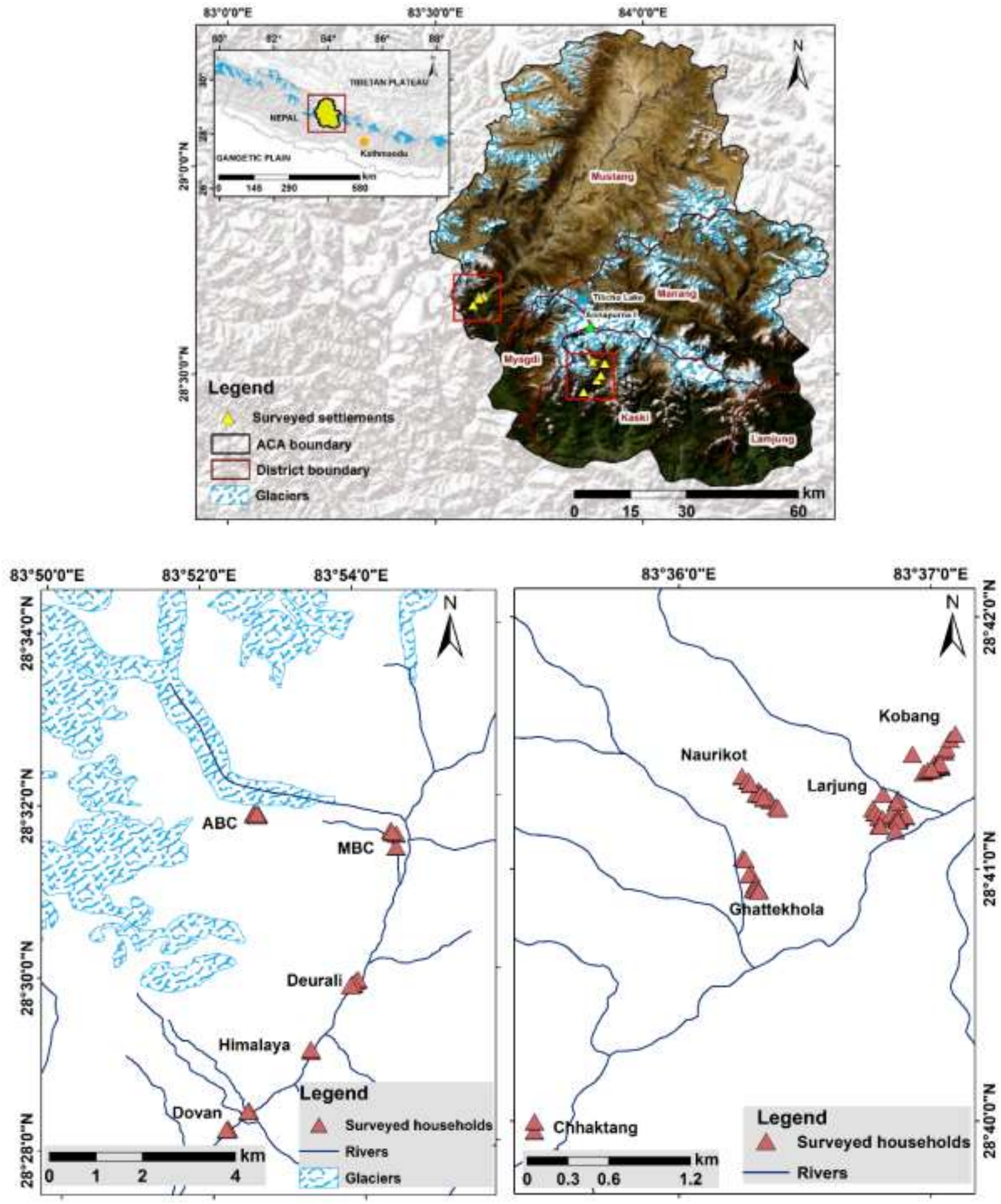

Figure 5.1 Location map of ACA route (left bottom) and Kobang Area (Right bottom) in the ACA

5.3 Methodology

The study was conducted in two areas in the Annapurna Conservation Area of Nepal. Table 5.1 and

Table 5.2 show information about the surveyed settlements and the households. The table shows detailed information about the villages investigated.

Table 5.1 Information of settlements in ABC Route

Name of settlement	Latitude (DD)	Longitude (DD)	Elevation (m a.s.l)	No of surveyed households	Household Number
ABC	28.530792	83.878104	4084.2	6	1 - 6
MBC	28.526592	83.906697	3656.8	5	7 - 11
Deurali	28.498193	83.899154	3156.7	5	12 - 16
Himalaya	28.484712	83.888735	2900	3	17 - 19
Dovan	28.469931	83.869991	2491	5	20 - 24

Table 5.2 Information of settlements in Kobang Area

Name of settlement	Latitude (DD)	Longitude (DD)	Elevation (m a.s.l)	No of surveyed households	Household number
Ghattekhola	28.682812	83.604626	2558.9	9	1 - 9
Naurikot	28.526592	83.906697	2762	18	10 - 26, 68
Larjung	28.686575	83.613496	2564.2	19	27 - 45
Kobang	28.690188	83.617268	2654.8	22	46 - 67
Chhaktang	28.469931	83.869991	2522	2	69 - 70

A questionnaire survey with 30 different questions focused on socioeconomic information, impacts of avalanches, prevention and mitigation efforts, and general information was collected to analyze the existing understanding of avalanche hazards and their efforts to mitigate or cope with this hazard. The questions in the questionnaire survey are in **ANNEXURE C.** Similarly, focus group discussions (FGDs) were conducted with relevant local stakeholders. In area 1, representatives from Annapurna Conservation Area (ACAP), Tourism Management Committee (TMC), Annapurna Rural Municipality (ARM), and Century Youth Club (CYC) were invited for focus group discussions. In contrast, Thasang Rural Municipality (TRM), Kobang Ward, and Conservation Area Management Committee (CAMC) were invited to Area 2.

5.4 Results

5.4.1 Area 1: ABC Route

All 24 households in the ABC are guesthouses, and the words household and guesthouse in this section refer to the same meaning. These guesthouses are open in Spring and Autumn every year and are mostly loaded with tourists. The following sections show the results of a questionnaire survey conducted there.

5.4.1.1 Exposure to avalanche hazards

5.4.1.1.1 ABC

A total of 36 people, predominantly men, have been exposed to the avalanche risks. Among them, 18 are migrant workers from Gorkha, and two are from the same district, Kaski. Additionally, 13 guesthouse owners regularly stay there, while three owners visit occasionally. Most of those exposed are aged between 18 and 60, comprising 33 individuals, while three are over 60.

5.4.1.1.2 MBC

In MBC, 26 people, mostly men, have been exposed to the avalanche risks. Among them, 17 are migrant workers from Gorkha District. Additionally, seven guesthouse owners regularly stay there, while two owners visit occasionally. All of those exposed are between 18 and 60 years of age.

5.4.1.1.3 Deurali

A total of 30 people, 29 men and a woman, have been exposed to the avalanche risks. Among them, 18 are migrant workers from Gorkha and Annapurna RM. Additionally, nine guesthouse owners regularly stay there, and two owners stay half a year (for each season). Most of those exposed are between 18 and 60, comprising 28 individuals, while one is over 60.

5.4.1.1.4 Himalaya

In the Himalaya, 14 people, 13 men and a woman, have been exposed to the avalanche risks. Among them, 10 are migrant workers from Gorkha District, Annapurna RM, and others. Additionally, three guesthouse owners regularly stay there, while one owner visits occasionally. Most of those exposed are between 18 and 60 years old, comprising 11 individuals, while two are below 18, and the age of 1 worker is unknown.

5.4.1.1.5 Dovan

Twenty-seven people, 25 men, and two women have been exposed to the avalanche risks. Among them, 11 are migrant workers from Gorkha District, Annapurna RM, and others.

Additionally, 13 guesthouse owners regularly stay there, while one owner visits occasionally and two owners stay sometimes. The majority of those exposed are aged between 18 and 60, comprising 27 individuals, while one is below 18 and the age of 1 worker is over 60.

5.4.1.2 Impacts of avalanches

5.4.1.2.1 ABC

Fortunately, there have been no human casualties among the respondents. However, it is essential to acknowledge that tourists and workers have tragically lost their lives on that route. Moreover, four respondents mentioned high impacts on tourism flow after major avalanche events, notably the avalanche in Deurali in January 2021, the ABC avalanche in April 2019 significantly affecting the successive trekking seasons.

5.4.1.2.2 MBC

There have been nine injuries caused by avalanches in Fishtail Guesthouse (H.N 8) in Spring 2013, whereas other guesthouses mentioned no human injuries. Moreover, four respondents mentioned high impacts on tourism flow after major avalanche events equal to or more than three times, notably the avalanche in Deurali in January 2021, the ABC avalanche in April 2019, and the MBC avalanche in 2009, significantly affecting the successive trekking season. In contrast, one respondent, Gurung Cooperative (H.N 10), mentioned only being affected heavily once regarding tourism flow after the Deurali avalanche in January 2021, as the respondent has been there for only ten years.

5.4.1.2.3 Deurali

Respondents from Deurali mentioned no human fatalities or injuries. 3 out of 5 respondents said that avalanches in several avalanche events damaged their guesthouses in 2003 and 2019, with one low level of impact just breaking the glass of the window from Dream Lodge & Restaurant (H.N 14) in 2003. (H.N 15) Moreover, H.N 16 was impacted at a medium level after the avalanche event 2019 destroyed their roof. Four respondents mentioned high impacts on tourism flow after major avalanche events equal to or more than three times, notably the avalanche in Deurali in January 2021, the ABC avalanche in April 2019, and the MBC avalanche in 2009, significantly affecting the successive trekking season. In contrast, one respondent, H.N 12, mentioned being affected lightly as the respondent is a new owner and has been there for just two years.

5.4.1.2.4 Himalaya

One minor injury was caused by avalanches in the Himalaya Guesthouse (H.N 18) in 1998, whereas other guesthouses mentioned no human injuries. The same guesthouse was impacted at a medium level in the spring of 2008, destroying the house's roof. Moreover, two respondents mentioned medium impacts on tourism flow after major avalanche events two times, notably the avalanche in Deurali in January 2021 and the ABC avalanche in April 2019, affecting the successive trekking season. In contrast, one respondent, Royal Family Guesthouse (H.N 17), mentioned not being affected by tourism flow as the respondent has been there for only two years.

5.4.1.2.5 Dovan

There have been no injuries in Dovan. However, two guesthouses, Annapurna Approach and Dovan G.H., were impacted at a high level in 1998, and the roofs of their guesthouses were destroyed. Moreover, three respondents mentioned medium impacts on tourism flow after major avalanche events three times, notably the avalanche in Deurali in January 2021 and the ABC avalanche in April 2019, affecting the successive trekking season. In contrast, two respondents mentioned not being affected highly in terms of tourism flow as the respondents, Greenland and Destination, have been there for only seven years. Prevention/mitigation efforts

5.4.1.2.6 ABC

All six guesthouses in ABC have taken steps to prevent avalanches by making a diversion dam with the support of the Tourism Management Committee (TMC) in the avalanche slope in ABC in 2021. According to their knowledge, four respondents mentioned no signs of government-led public awareness programs about avalanches, whereas two mentioned they do not know about public awareness programs. Additionally, 3 of them say there are no hazard maps, whereas three are unaware of any hazard maps for their region. Moreover, none of them know about the possibility of developing or putting efforts into developing avalanche early warning systems.

However, all guesthouses strongly agree that there is a strong community rapid response team and have sufficient emergency food supplies for 72 hours or more. While only four guesthouses expressed feeling unsafe from avalanches, the remaining two believe that they are safe as they are around 70m away from the significant avalanche slope and do not lie in the avalanche path, and both of them are new guesthouses.

They have all frequently practiced moving quickly to the nearest safe place, which usually takes them 1-3 minutes. This safe place is a room in Hotel Annapurna Sanctuary G.H., near Annapurna Glacier but at a safe distance from avalanche-prone slopes. Furthermore, all respondents stated that they often discuss avalanches and their impacts and plan where to meet in case of an avalanche event. The details are shown in Figure 5.2.

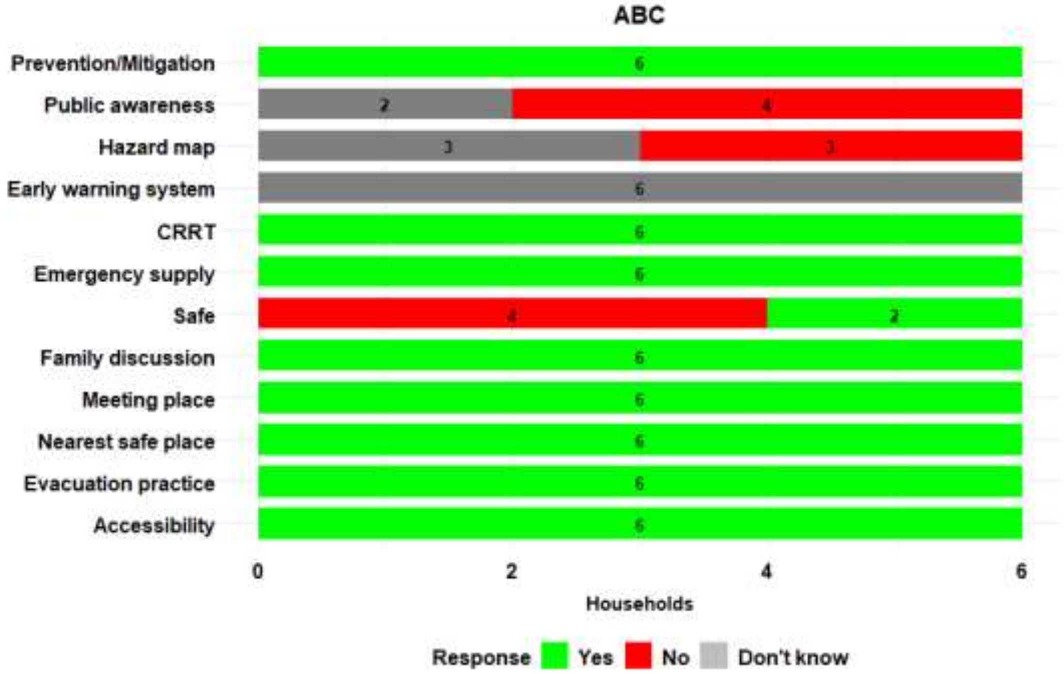

Figure 5.2 Summary of the prevention and mitigation efforts in ABC.

5.4.1.2.7 MBC

All five guesthouses in MBC have mentioned that they have always participated in warning tourists about the danger of avalanches whenever the weather is bad. They have taken steps to minimize the impacts of avalanches by advising them not to use the path often hit by avalanches and showing alternative paths. However, no structural prevention method has been applied. Among 5, three of the respondents mentioned the presence of government-led public awareness programs about avalanches. In contrast, one respondent feels there is no such program, while one does not know about it.

Additionally, three said they know the concept of avalanche hazard maps and feel their local authority has a preliminary hazard map showing a few locations prone to avalanches. In contrast, the other three said they do not have any regional hazard maps. All agreed that there is no possibility of developing or efforts to develop avalanche early warning systems.

However, all guesthouses strongly agree that there is a strong community rapid response team and have sufficient emergency food supplies for 72 hours or more. While only three guesthouses expressed feeling unsafe from avalanches, the remaining two believe that they are safe as the respondent of Gurung Cooperative (H.N 10) has not faced any major avalanche in his settlement area since his appointment there, and that is just ten years. In contrast, Gangapurna View Lodge and Restaurant (H.N 9) is comparatively in a very safe location and is not in the immediate vicinity of avalanche slopes.

They have all frequently practiced moving quickly to the nearest safe place, which usually takes 30 minutes to 2 hours. This safe place is Gangapurna View Lodge and Restaurant. A Respondent, H.N 10 in the MBC, mentioned that the safe location is inaccessible in case of heavy snowfall as it might take 2 hours whenever it is snowing heavily, and they have to make a way as snow blocks the path and path is not known. Additionally, all respondents mentioned that they often discuss avalanches and their impacts and plan where to meet in case of an avalanche event. Figure 5.3 shows the details of prevention/mitigation efforts of avalanches in MBC

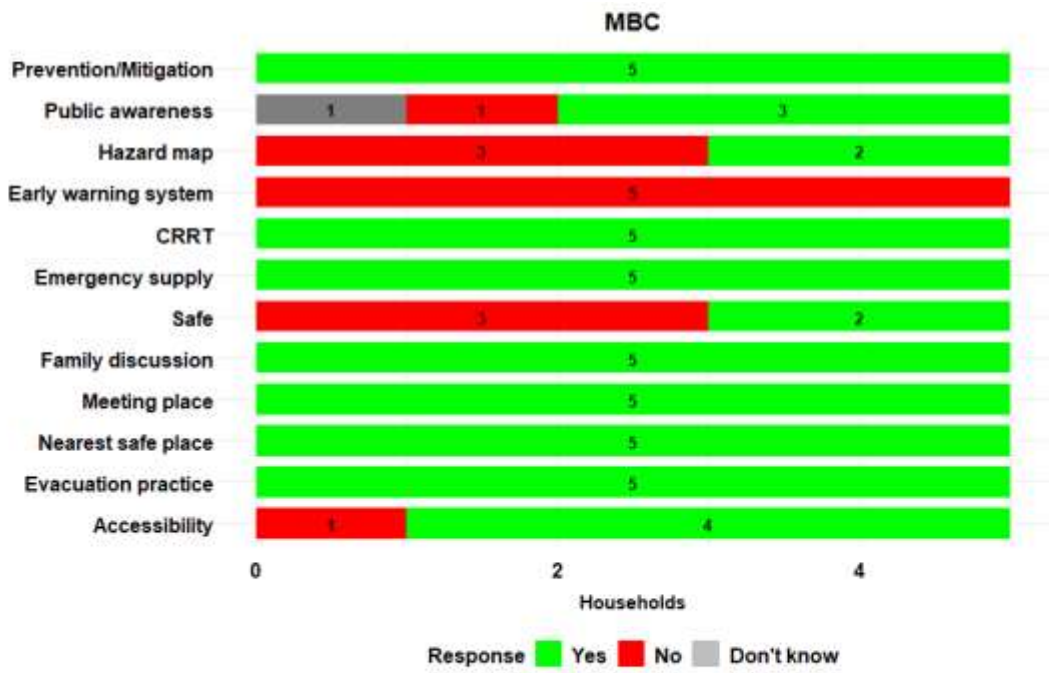

Figure 5.3 Summary of the prevention and mitigation efforts in MBC

5.4.1.2.8 Deurali

All five guesthouses have not taken any steps to prevent avalanches. According to their knowledge, four respondents mentioned there are no signs of any government-led public awareness programs about avalanches, whereas one mentioned there have been public awareness programs. Additionally, two said they know the concept of avalanche hazard maps and feel their local authority has a preliminary hazard map showing a few locations prone to avalanches. In contrast, the other two said they do not have any hazard maps. Two talked about the possibility of development or efforts in developing avalanche early warning systems. In contrast, one respondent feels no early warning system progression, and two mentioned they do not know about it.

However, all guesthouses strongly agree that there is a strong community rapid response team and sufficient emergency food supplies for 72 hours or more. All five guesthouses expressed feeling safe from avalanches. Hotel viewpoint (H.N 12) feels his location is very safe, and Deurali Guest House (H.N 3) feels the same, as he shifted his location from the prior location, which was very prone to avalanches.

They have all frequently practiced moving quickly to the nearest safe place, which usually takes less than 1 minute. This safe place is Room No. 6 in Dream Lodge and Restaurant (H.N 14). Furthermore, all respondents stated that they often discuss avalanches and their impacts and plan where to meet in case of an avalanche incident. Figure 5.4 shows the details of prevention/mitigation efforts of avalanches in Deurali.

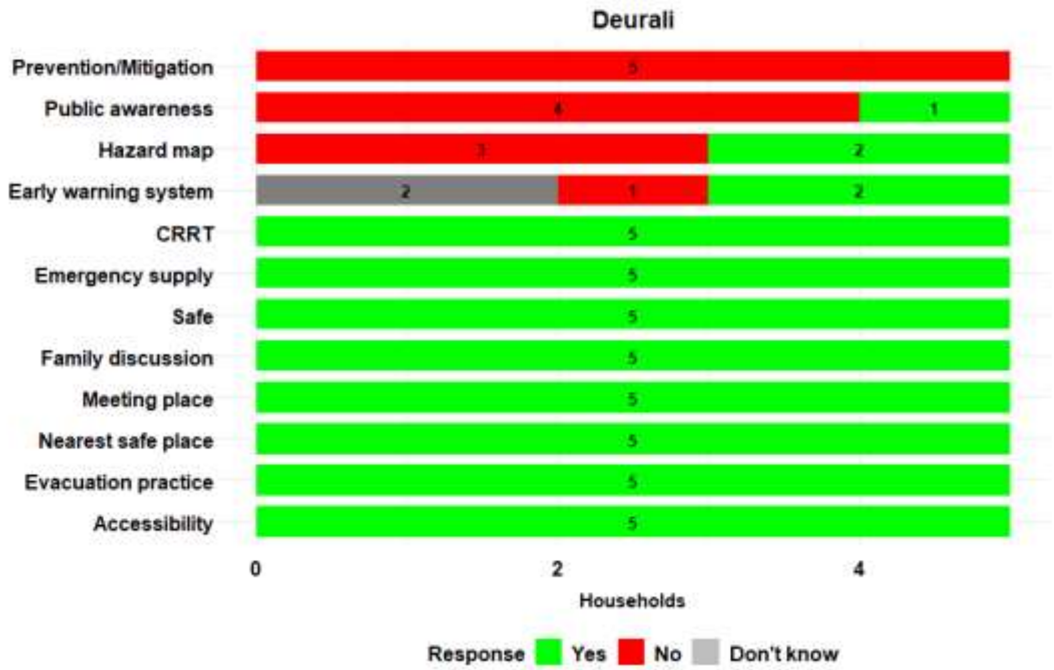

Figure 5.4 Summary of the prevention and mitigation efforts in Deurali

5.4.1.2.9 Himalaya

All three guesthouses have taken steps to prevent avalanches by constructing a retaining wall around 50 m above the guesthouse area. They all agreed that government-led public awareness programs about avalanches exist. They also said they do not know about an avalanche hazard map. All agreed that they do not know about the possibility of developing or putting efforts into developing avalanche early warning systems.

However, all guesthouses strongly agree that there is a strong community rapid response team and sufficient emergency food supplies for 72 hours or more. All of them expressed feeling safe from avalanches as they have retaining walls and also feel that nearby slopes receive less snowfall compared to earlier years. Due to rising temperatures, nearby slopes hold very little snow, and hence, the cases of avalanches have decreased in recent days.

They have all frequently practiced moving quickly to the nearest safe place, which usually takes less than 2 minutes. For all three respondents, the safe place is nearby. All respondents mentioned that they often discuss avalanches and their impacts and plan where to meet in case of an avalanche. Figure 5.5 shows the details of prevention/mitigation efforts of avalanches in Deurali.

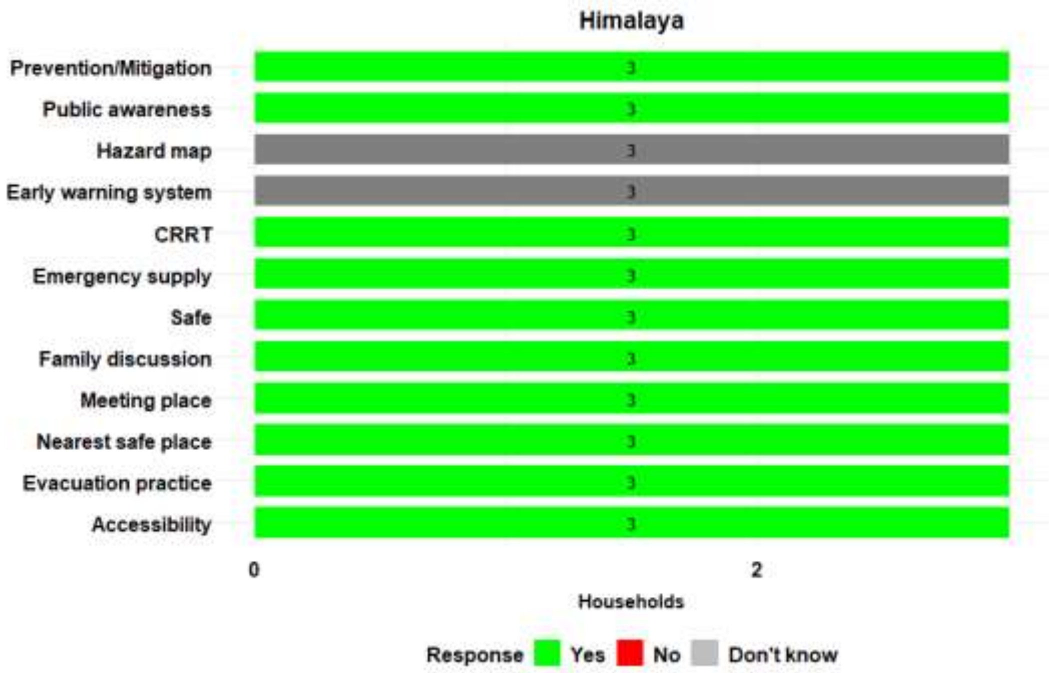

Figure 5.5 Summary of the prevention and mitigation efforts in Himalaya

5.4.1.2.10 Dovan

All five guesthouses have not taken steps to prevent avalanches. Three of them agreed about the presence of government-led public awareness programs about avalanches. In contrast, one feels there is no public awareness program, and one does not know about such programs. Additionally, 4 of them say they feel there is no concept of an avalanche hazard map in their area, whereas 1 of the respondents says he does not know about any hazard map.

Moreover, four respondents feel there is no early warning system progression, and one feels they do not know about it.

However, all guesthouses strongly agree that there is a strong community rapid response team and have sufficient emergency food supplies for 72 hours or more. All of them expressed feeling safe.

They have all frequently practiced moving quickly to the nearest safe place, which usually takes less than 2 minutes. Furthermore, only two respondents (Destination Guest House (H.N 21) and Greenland Guest House (22)) discussed avalanches and their impacts on their staff and family. In contrast, the other three guesthouses disregarded the discussion because now they feel their area is comparatively safe. Similarly, two guesthouses discuss the meeting place in case of avalanche emergencies. Figure 5.6 shows the details of prevention/mitigation efforts of avalanches in Deurali.

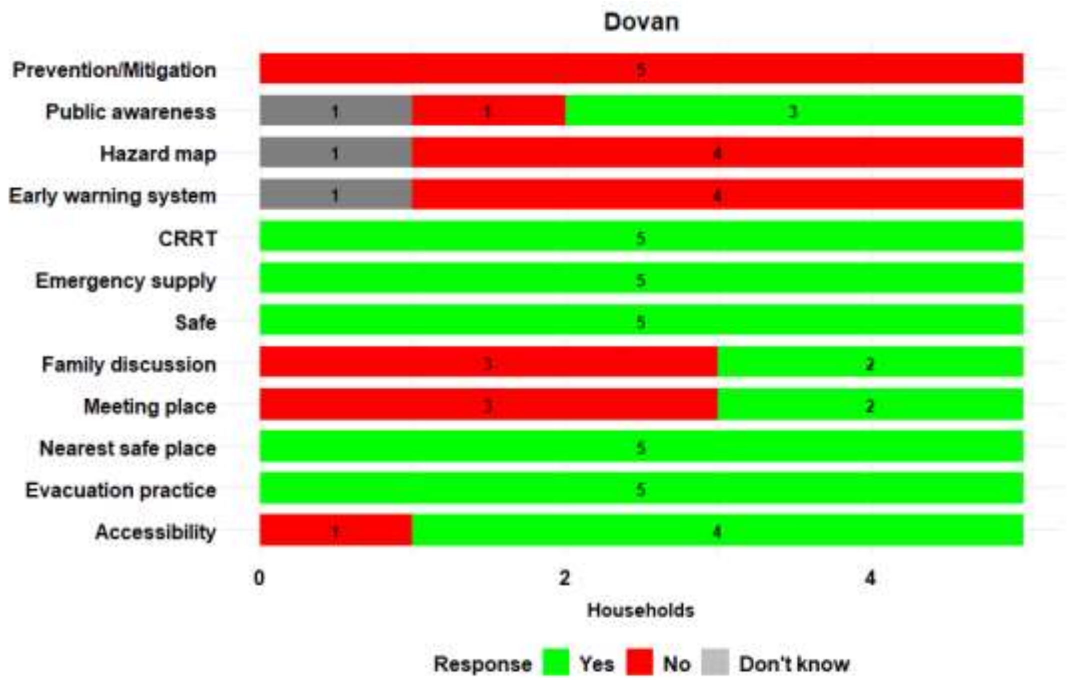

Figure 5.6 Summary of the prevention/mitigation efforts in Dovan

5.4.2 Area 2: Kobang Area

5.4.2.1 Exposure to avalanche hazards

5.4.2.1.1 Ghattekhola

Forty-one people are exposed to the avalanche risks, with around an equal percentage of males (51%) and females (49%). Out of the total population, 12 are involved in agricultural activities, two are involved in services (Nursing and Cheese factory clerk), four are involved in foreign employment/studies, two are in business, mainly hotels, and 13 are students. Six are in others (retired, homemaker, herder, driver, and contractor), 1 is unemployed, and the other 1 is a kid. Around 83% of the total population constantly stays there with more exposure to avalanches compared to the other seven people who are primarily outside of the Ghattekhola either for foreign employment (4), study (2), or business (1). This shows that people involved in agricultural activities (12) and students (11) are highly exposed to the risk of avalanches, comprising almost 67.6% of the population that is constantly staying. The exposed population based on age group is 1, 13, 9, 15, and 3 for the <5 years old, 5-18 years old, 18-30 years old, 30-60 years, and over 60 years old, respectively. Five people aged between 18 and 60 are outside the Ghattekhola for foreign employment and business, and two people between 5 and 18 are outside Pokhara as students.

5.4.2.1.2 Naurikot

Seventy-eight people are exposed to the risks of avalanches, with 48.7% of males and 51.3% of women. Out of the total population, 31 people are involved in agricultural activities like livestock rearing or agriculture, four are involved in services like bank and cottage industry, 6 in foreign employment, 8 in the hotel business, 13 are students, and six are in others (retired, caretaker), and 1 is kid, and four people are disabled. Around 87.2% of people constantly stay there with more exposure to avalanches compared to the other ten people who are outside of Naurikot for foreign employment (6) and study (1), hotel business (2), and service (1). These figures show that people involved in agricultural activities and students are highly exposed to avalanche risks, comprising 63.2% of the constantly staying population. The exposed population based on age group is 1, 9, 21, 35, and 12 for <5 years old, 5-18 years old, 18-30 years old, 30-60 years and over 60 years old, respectively.

5.4.2.1.3 Larjung

Eighty-three people are exposed to avalanche risks, with 51.8% of males and 48.2% of women. Out of the total surveyed population, 22 people are involved in agricultural activities like livestock rearing or agriculture, four people are teachers at nearby schools, four are involved in services like bank and office jobs, 5 in foreign employment, 4 in the hotel business, 23 are students, and 15 are in others (retired, herder, tailoring, daily wagers), and 4 is a kid, and two people are disabled. Around 64.1% of people constantly stay there with more exposure to avalanches compared to other 19 people who are outside of Larjung for foreign employment (5) and study (4), service (3), teacher (1), retired (1), others (4) and kid (1). These figures show that people involved in agricultural activities and students are highly exposed to avalanche risks, comprising 77.1% of the constantly staying population. The exposed population based on age group is 7, 18, 14, 36, and 8 for the <5 years old, 5-18 years old, 18-30 years old, 30-60 years and over 60 years old, respectively.

5.4.2.1.4 Kobang

One hundred people are exposed to avalanche risks, with 46% male and 54% women. Out of the surveyed total population, 43 people are involved in agricultural activities like livestock rearing or agriculture, two people are teachers at nearby schools, four are involved in services like bank and office jobs, 2 in foreign employment, 1 in the hotel business, 30 are students, and ten are in others (retired, herders, witchdoctor, daily wagers), and 6 is a kid, and two people are disabled. Around 80% of people constantly stay there with more exposure to avalanches compared to the other 20 people who are outside of Kobang for foreign employment (2) and study (13), service (2), and others (2). These figures show that people involved in agricultural activities and students are highly exposed to avalanche risks, comprising 56% of the constantly staying population. The exposed population based on age group is 8, 19, 34, 30, and 5 for <5 years old, 5-18 years old, 18-30 years old, 30-60 years and over 60 years old, respectively.

5.4.2.1.5 Chhaktang

A total of 10 people are exposed to avalanche risks, with 72.7% of males and 27.3% of women. Out of the total population, one person is involved in agricultural activities like livestock rearing or agriculture, three are in the hotel business, 4 are students, and two are in others (herders). Around 63.6% of people constantly stay there with more exposure to avalanches than the other four people outside Chhaktang for study. The exposed population based on age group is 0, 4, 1, 6, and 0 for the <5 years old, 5-18 years old, 18-30 years old, 30-60 years, and over 60 years old, respectively.

5.4.2.2 Impacts of avalanches

5.4.2.2.1 Ghattekhola

In Ghattekhola, respondents have endured the impacts of avalanches in many ways, ranging from damage to homes to sheds, animal casualty, agricultural land affected, and even deaths. Seven households were damaged at a low level due to an avalanche from Manapathi, an event in November 2021. All houses were painted with snow, ice, and debris mixed with avalanche debris, leaving many of them to spend days cleaning the walls and verandas of their houses and repainting. Similarly, a family member of H.N 8 lost her life due to an avalanche in November 1997. Moreover, 0.16 ha of corn and beans of H.N.1 were destroyed due to the same avalanche in November 1997. Similarly, H.N.8 also endured the loss of 27 yaks and the loss of a shed in a 1990 avalanche in the yak herding area, Muli.

5.4.2.2.2 Naurikot

Households in Naurikot have suffered several times in terms of damage to homes, animal casualties, agricultural land affected, and even deaths. In total, 16 households were damaged at a low level, and one house was damaged at a moderate level. In moderate level damage, the roof of the H.N 12 was destroyed, avalanche debris filled the house, and the walls cracked due to an avalanche from the Manapathi event in November 2021. All 17 houses were painted with snow, ice, and debris mixed with avalanche debris, leaving many of them to spend days cleaning and repainting the walls and verandas of their houses. Similarly, two people died due to the avalanche in 1995. Moreover, 109 animals were killed due to avalanches, and mostly yaks, 1.17 ha worth of corn, and beans were destroyed due to the same avalanche in Nov 1997.

5.4.2.2.3 Larjung

Similarly, households in Larjung have also suffered several damaged homes, damaged sheds, animal casualties, agricultural land, and even deaths. In total, 19 households were damaged at low levels due to an avalanche from Manapathi event in November 2021. All 19 houses were painted by the snow, ice, and debris mixed with avalanche debris, leaving many of them to spend days cleaning and repainting the walls and verandas of their houses. Similarly, one person was injured due to an avalanche in November 2021. Moreover, 44 animals were killed due to avalanches, and mostly yaks and two sheds were destroyed by the avalanche.

5.4.2.2.4 Kobang

Households in Kobang have suffered several times in terms of damage to homes and sheds, animal casualty, agricultural land affected, and even deaths. Out of 22 households, 15 mentioned having low-level damage to their homes due to an avalanche from the Manapathi event in November 2021. All 15 houses were painted with snow, ice, and debris mixed with avalanche debris, leaving many of them to spend days cleaning and repainting the walls and verandas of their houses. Similarly, three people were injured in the same event in November 2021. 60 animals were killed due to avalanches, and mostly yaks 0.5 ha worth of corn and beans were destroyed due to the same avalanche in in 1997

5.4.2.2.5 Chhaktang

Households in Chhaktang have suffered similarly to other places in the Kobang Area. Out of 2 households, one mentioned having low-level damage to their homes due to an avalanche from the Manapathi event in November 2021. Moreover, two animals (oxen) were killed in an avalanche in 2022.

5.4.2.3 Prevention and mitigation efforts of Avalanches

5.4.2.3.1 Ghattekhola

The summary of prevention/mitigation efforts is shown in Figure 5.7. In Ghattekhola, only one respondent mentioned adopting prevention/mitigation measures to cope with the avalanches. H.N. 8 mentioned relocating to a slightly safer location in Muli itself after the avalanche incident of 1997. Muli is infamous for being unsafe, but they are not left with choices as they cannot enter other herding regions due to their community setups with their allocated areas for herding. Public awareness programs being conducted by local authorities are felt by only two households, while seven households either did not see them conducted or did not have any idea. Similarly, the idea of hazard map development is either unknown or they feel it is not happening.

Similarly, the idea of an early warning system also seems either unknown or needs to be added by all the respondents of Ghattekhola. All nine respondents agreed about not having the CRRT in their locality. However, they all agreed to have emergency food supplies for more than 72 hours.

Regarding the question about feeling safe, 8 out of 9 mentioned their place is very unsafe regarding avalanche hazards. Eight respondents often had family discussions about avalanches and often talked about the meeting place. All of them said that the nearest safe place is Nakung Forest. They all mentioned regularly using the route and being accessible to them, but this is not exactly doing evacuation practice (here in this study, we considered regular use of that route as evacuation practice, as they have used the same route many times whenever avalanches occur in their area).

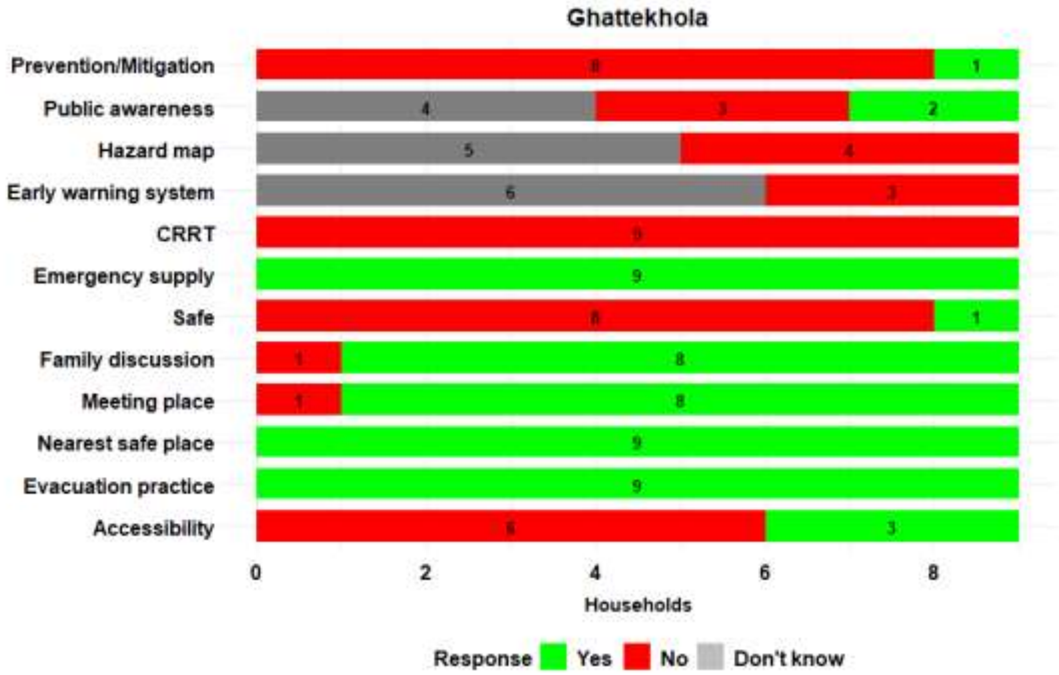

Figure 5.7 Summary of prevention/mitigation efforts in Ghattekhola.

5.4.2.3.2 Naurikot

The summary of prevention/mitigation efforts is shown in Figure 5.8. In Naurikot, 16 respondents mentioned not doing anything for prevention and mitigation. However, two of the respondents did something: relocating their houses to slightly safer locations (in Chhaktang). Three respondents have acknowledged the programs regarding public awareness. In comparison, nine respondents feel there are no such programs, and six have yet to learn about the public awareness schemes for avalanches. Similarly, 12 respondents have yet to learn about the hazard maps being developed by the local authorities, and 6 of them said they do not have any avalanche hazard map of the region. Regarding early warning systems, 2 of them said there were some talks about early warning systems. However, nine respondents did not have any idea about early warning schemes, and seven respondents felt there were no early warning schemes for avalanches.

Sixteen respondents felt they do not have any organized CRRT in their region, while two felt they have CRRT based on school or the Red Cross. Fortunately, all respondents have sufficient emergency food supplies in case of any hazards. In total, only seven households felt safe, while the remaining 11 households felt very unsafe. The feeling of safety has different definitions for the people there. They felt their homes were the safest among any other nearby places. It is like having no choice and considering the home a very safe place for them. Fifteen households always have family discussions, while three do not feel the necessity of discussing the avalanches. 11 households also mentioned discussing the meeting place in case of any avalanche events. Only four households out of 18 mentioned having the nearest safe place, and the nearest safe place is Thasang Village Resort. The structure of Thasang Village Resort is very Robust and lies far from other households in the village. All four households agreed on the regular evacuation practice and the nearest safe place accessible to them.

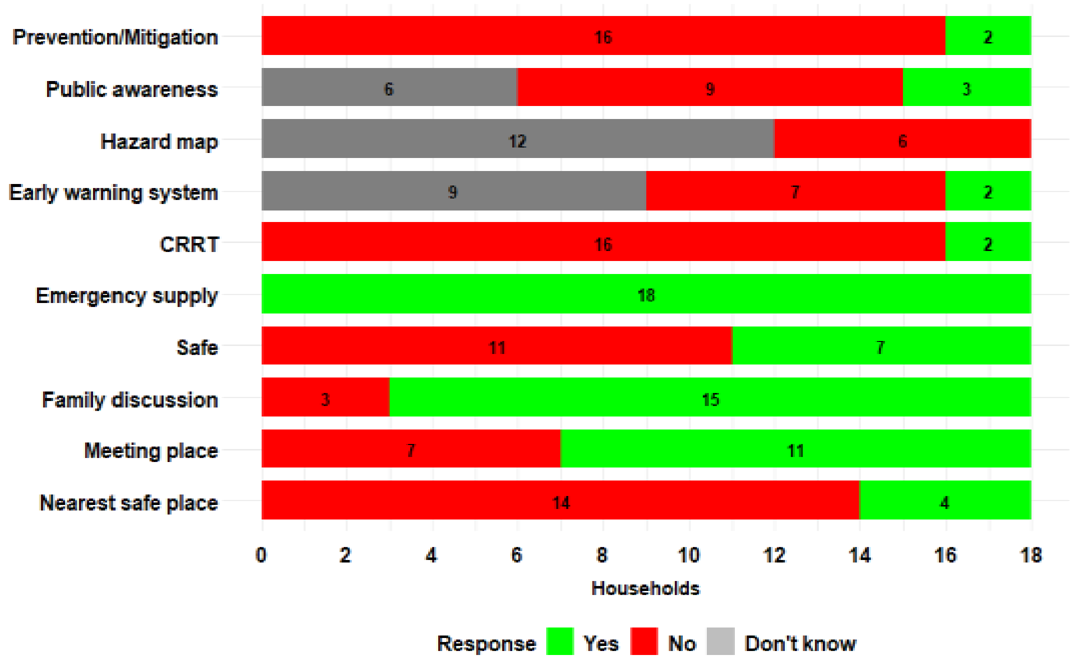

Figure 5.8 Summary of the prevention/mitigation efforts in Naurikot.

5.4.2.3.3 Larjung

The summary of prevention/mitigation efforts is shown in Figure 5.8. In Larjung, all 19 households mentioned not employing any prevention/mitigation efforts for avalanche hazard impacts. Regarding public awareness programs by the local authority, three households mentioned having some awareness programs regarding the avalanche. In comparison, 12 households felt there were no such programs, and four households did not know anything regarding the public awareness programs. Similarly, all households felt that they did not have any avalanche hazard map, and 5 of them did not know about the existence of any hazard map for their region. Only one household mentioned the knowledge of the early warning system scheme discussed by the local authority. At the same time, 6 of them do not know about their existence or their future development plans, and 12 feel they do not have any such provision related to the avalanche early warning system. Similarly, one household mentioned the existence of CRRT, while the other 18 either did not know about this or they feel they do not have any CRRT. However, all Larjung households have sufficient food supply in case of emergency.

Only two households out of 19 felt safe at home. Eighteen households often discussed avalanches, whereas only 15 discussed the meeting place. Twelve households mentioned having the nearest safe place in case of an avalanche event. The place is Bagar. All 12 households mentioned having regular evacuation, whereas only 11 households mentioned being accessible to their family members.

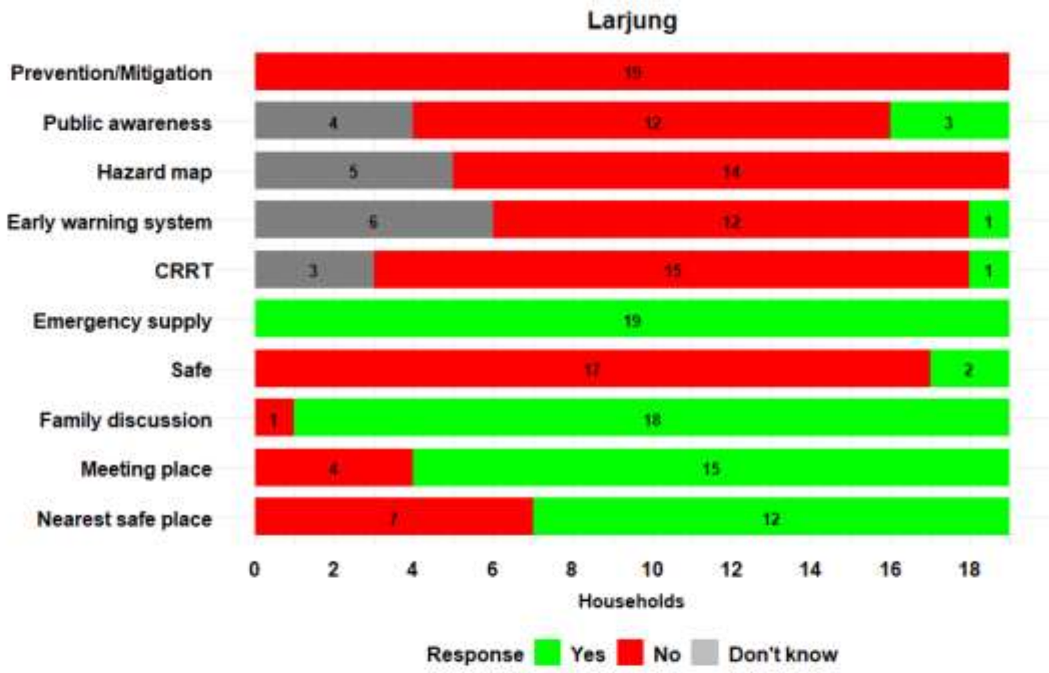

Figure 5.9 Summary of the prevention/mitigation efforts in Larjung.

5.4.2.3.4 Kobang

Figure 5.10 shows the summary of prevention and mitigation efforts in Kobang. In Kobang, all 22 households mentioned not having any prevention/mitigation mechanism for avalanche events. Regarding public awareness by the local authority, only five households mentioned having some public awareness programs. However, seven households felt they did not have any such programs, and ten households did not have any information related to this.

Two households mentioned the presence of avalanche hazard maps of their region. 6 households felt that their location did not have any hazard map, whereas 14 households did not have any about the presence of a hazard map. Similarly, at least one household was aware of the talks of an early warning system. However, the remaining ten responded that they had no EWS or future developments, and 11 responded that they had no idea about this. Similarly, two households mentioned the presence of CRRT, but 20 households responded that they did not have any CRRT. Similar to other settlements, they also have enough food supply in case of emergency.

Moreover, only six households mentioned their house as the safest place, but the remaining 16 responded that they felt unsafe as an avalanche could hit them anytime. Out of 22, 18 households mentioned having regular family discussions. Similarly, 13 households often discuss the meeting place, and 18 acknowledge having the nearest safe place in their area.

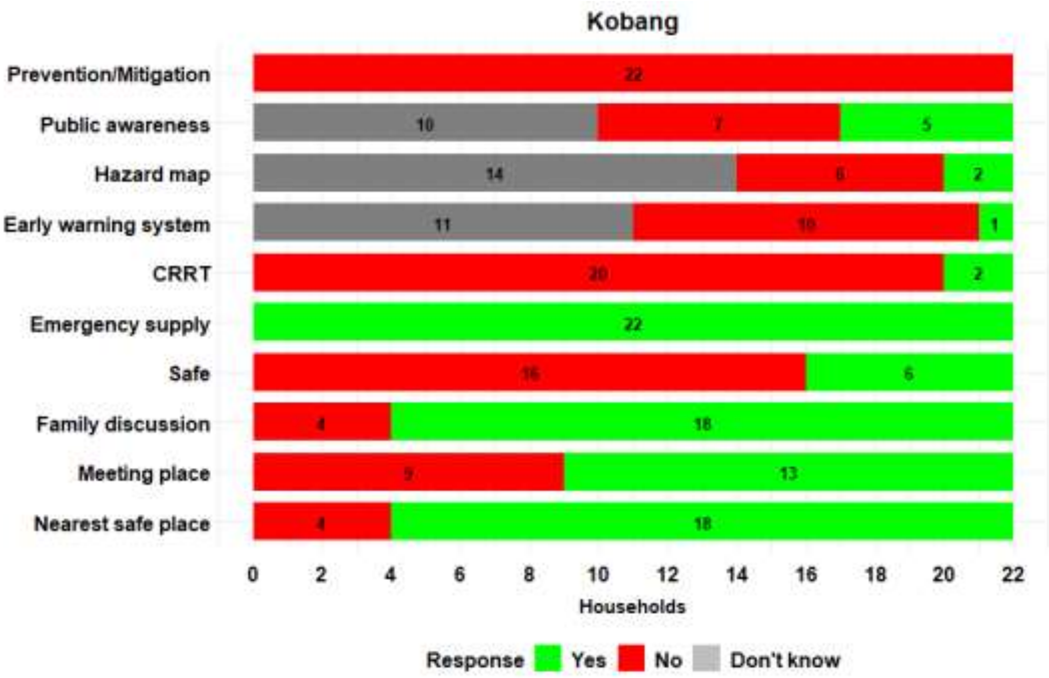

Figure 5.10 Summary of the prevention/mitigation efforts in Kobang.

5.4.2.3.5 Chhaktang

Only two households were studied in Chhaktang, as the other houses were on the other side of the river. Only two houses were on the roadside and at the bottom of avalanching slopes. One household mentioned employing prevention/mitigation efforts, while the other one mentioned not doing anything.

One household felt the local authority was not conducting public awareness programs, while the other did not know about this. There are similar statistics for the hazard map and early warning system in the Chhaktang. The household agreed not to have any CRRT in their locality. Both of them agreed to have an emergency food supply. One household felt safe at home. Both households agreed on having regular family discussions regarding avalanches, discussing the meeting place, the presence of the nearest safe place, practicing evacuation, and accessibility to the nearest safe place.

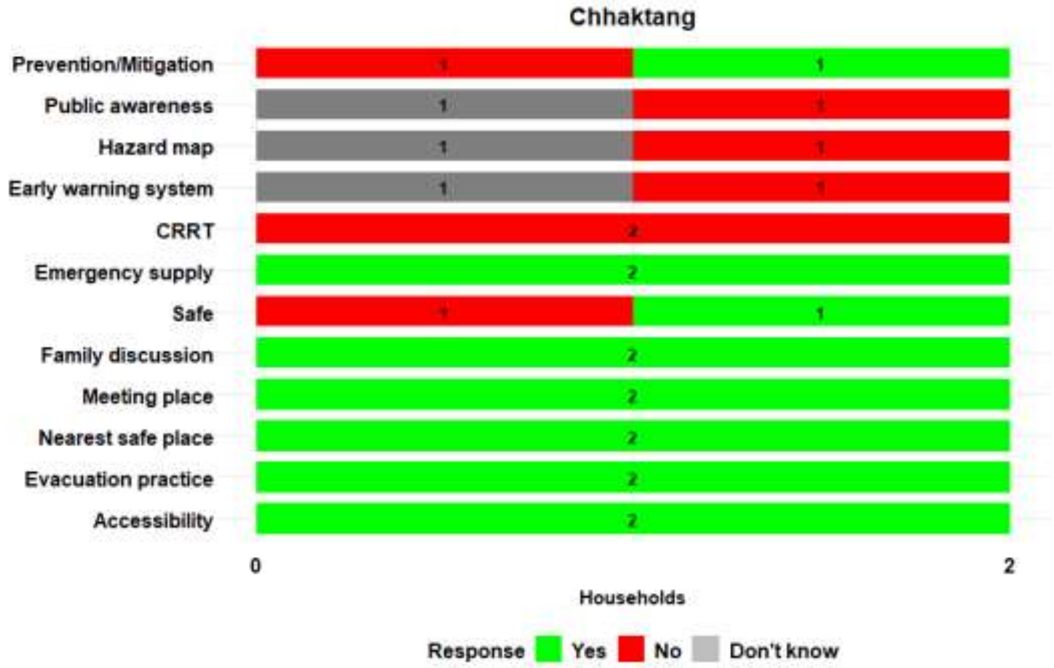

Figure 5.11 Summary of the prevention/mitigation efforts in Chhaktang

5.4.3 Existing disaster management strategies

5.4.3.1 ABC Route (Area 1)

Focus Group Discussion with Century Youth Club (CYC), Annapurna Rural Municipality (ARM), Ward office, NTNC-Annapurna Conservation Area Project (ACAP), and Tourism Management Committee (TMC) in the ABC route revealed that the government channel had employed no concrete mechanism have been carried out in order to prevent/mitigate the avalanches. However, local communities in Area 1, together with the support of TMC, built a diversion dam in the avalanche slope of ABC in 2021. Similarly, a retention wall was built in Himalaya by the guesthouse owners in the Himalaya. In both locations, they faced frequent avalanche devastation, so they used their own money to build the control structures. TMC also has strict rules for the opening and closing of the trekking season, ensuring the safety of tourists and the local population, mainly in winter.

Similarly, TMC has been actively involved in making alternative routes in necessary places, especially in Deurali; the usual trekking route in Deurali is very prone to avalanche risks. Hence, they opened an alternative path that takes slightly longer. NTNC-ACAP has also placed signboards where avalanches often occur, mainly in Deurali (Figure 5.12) . CYC, on the other hand, actively participates in evacuation and rescue operations during avalanche incidences. The local government, Annapurna Rural Municipality (ARM) doesn't have a sufficient budget to be actively involved in implementing avalanche prevention/mitigation measures leading to concrete plans apart from public awareness campaigns, as they have relied on the district disaster management committee of Kaski, which is not directly implementing any programs to cope up with existing avalanche risks.

Figure 5.12 Photograph after FGD with local stakeholders (A), Warning signs installed by ACAP (B) in ABC Route (Photo: Paru Gurung, May 2023)

5.4.3.2 Kobang Area (Area 2)

The focus group discussions with Thasang Rural Municipality (TRM), Ward office, Conservation Area Management Committee-Annapurna Conservation Area Project (CAMC-ACAP)), Shree Jana Adarsha Aamar Singh Secondary School revealed that there are no robust mechanisms for dealing with disasters like avalanches. More attention should be given to avalanche hazard and their consequences. Very few temporary programs for compensating victims immediately after avalanche events are the common practice of disaster management strategy there. The insurance company covered the loss of the yak, and the Veterinary Hospital and Animal Service Expert Office also compensated with NRs 10,000 per yak for the loss of livestock. Similarly, CAMC compensated the people with NRs 1000. Apart from compensating, no other disaster management strategies were implemented. Similarly, the School mentioned conducting public awareness campaigns about avalanches through plays. However, the local government, TRM, also does not have concrete plans, particularly regarding avalanche hazard risk management, and similar to ARM, it relies on Mustang's district disaster management committee.

Figure 5.13 FGD in Kobang Area (Photo: Harsha Thakuri, May 2023)

5.5 Conclusion

This chapter comprehensively overviews avalanche hazard scenarios within the study area. It mainly focuses on the population exposed to avalanches, impacts of avalanches, and existing avalanche prevention and mitigation measures in ABC Route (Area 1) and Kobang Area (Area 2). The avalanche is a concerning hazard in both locations that risks their life, livelihoods, and infrastructure. A questionnaire survey with 30 questions was conducted at both areas through face-to-face interviews, and focus group discussions were carried out at both areas to understand the existing disaster management strategies.

A total population of 133 from 24 households is alarmingly exposed to the risk of avalanches on the ABC Route. In contrast, a sample population of 313 from 70 households in the Kobang Area expressed their fear of being in danger of avalanche hazards. The majority, 97%, are men in ABC Route, making them particularly vulnerable to avalanche hazards. However, in Mustang, the exposed population in terms of gender is almost equal (50%). In both locations, the population aged between 18 and 60 is more exposed to the risk of avalanches, with a staggering percentage in ABC Route (92%) and a significant percentage in (64.2%).

In ABC Route, 62.5% out of 24 households claimed that their households were damaged by avalanches at some point. In contrast, in Mustang, 82.9% of households claimed that their houses were damaged due to avalanches—no human casualties in ABC Route but three deaths in Mustang. ABC also sustained ten injuries, and respondents in Kobang claimed six injuries. ABC is severely affected in terms of tourism flow, whereas Mustang is affected in terms of agricultural activities.

It is crucial to note that prevention and mitigation efforts in both areas are insufficient and alarmingly non-existent. However, ABC Route is slightly more aware of the situation and is making personal contributions to sustain its livelihood. It is concerning to find that the relevant stakeholders pay minimal attention to minimizing the risks posed by avalanches, leaving the population and infrastructure vulnerable.

ACA is one of the nation's major tourism hubs, and the tourism industry is the major source of income. Avalanches affect the lives and livelihoods of the local population in both areas, subsequently impacting the country's revenue. The relevant authority should consider it seriously and plan and design policies and control measures to minimize the damage caused by avalanches.

Chapter 6: General discussion

6.1 Avalanche incidents and impacts in the HMA

Comprehensive records of observed avalanches in HMA are gathered, including those that did not have any notable impact on livelihoods or infrastructure and information on impacts for those that did. Until the 2010s, rarely more than one event was recorded every 2 years in individual mountain ranges, which increased to more than four per year in the Pamir and more than one in the Hindu Kush Figure 3.5, largely due to the commencement of a dedicated avalanche monitoring program. Records also increased elsewhere, but it is impossible to say whether an increase in avalanche activity, an increased exposure, or simply an increase in reporting (e.g., the advent of social media resulting in more coverage in the local news) is responsible. records show that relying solely on peer-reviewed publications would result in a considerable underestimation of events, capturing only 6% of all avalanches and 23% of all recorded fatalities. Relying on various news sources, which, however, often have conflicting documentation of what happened, requiring a lot of cross-checking work and technical reports by agencies operating in hazard management in the region, proves essential.

Total fatalities in the region since the early 1970s end up at an average of 62 people killed each year, or 74 when we include deaths during mountaineering. Records in the Alps, an area considerably smaller and less populated than HMA, show ∼100 people per year who lost their lives between 1937 and 2015 (Techel and Schweizer 2017). However, while in the Alps, between 72% and 97% of deaths are related to mountaineering or recreation, this number is reversed in HMA (15%) and becomes even smaller (10%) when we consider that porters and guides died during work rather than recreation. In Switzerland, avalanche victims between 1946 and 2015 made up 37% of all natural hazard fatalities, more than any other. For HMA, insufficient comprehensive data exist for other hazards to make such a comparison. However, data from GLOFs suggest a considerably lower number of deaths (907, excluding the Kedarnath event) for a much longer period (1833–2022) for the same region (Steiner and Shrestha 2022). Landslides claim a lot more deaths in monsoon-dominated India (∼5000 between 1998 and 2018 excluding the Kedarnath event; Martha et al. 2021) and Nepal (2179 between 1978 and 2005; Petley et al. (2007). Records for countries entirely in HMA suggest 67 deaths in Afghanistan, 50 in Bhutan, 809 in Nepal and 75 in Tajikistan between 2004 and 2010 (Petley 2012). The relative lack of recreational sports in the avalanche-prone territory in the region, therefore, makes avalanches relatively less deadly than in the Alps and also much less deadly than landslides in the region but considerably more than GLOFs, a high mountain hazard that has received relatively more attention in the literature (Emmer et al. 2022).

The data suggest that 564 people died in avalanches while mountaineering in HMA, 191 (34%) of whom were hired personnel like guides and porters. This emphasizes the danger of the job, which is perceived as an important opportunity for some regions, especially in Nepal. An earlier study found slightly more fatalities for HMA (616), stemming from undocumented sources beyond peaks above 8000 m (McClung 2016).

Previous work in North America (Schauer et al. 2021), northern Europe (Fitzharris and Bakkehøi 1986; Hancock et al. 2021), and the Alps (Jomelli et al. 2007) has shown the potential of investigating precursor meteorological data for avalanche prediction using avalanche databases. In HMA, such forecasting only exists in the Indian western Himalaya. The present database would allow for a first analysis of such links. So far, an inventory of avalanches without significant recorded impacts for countries other than Afghanistan is missing so far to make such an analysis robust. With such monitoring efforts being highly labor intensive and not possible for past events, the potential of remote sensing data would need to be further exploited, so far only done for limited areas in the region (Eckerstorfer and Grahn 2021; Caiserman et al. 2022). Satellite imagery can scale up avalanche monitoring, mainly thanks to the availability of numerous satellite datasets, both optical and radar. Due to the challenging nature of interpreting radar data for different avalanches (Eckerstorfer et al. 2016; Eckerstorfer and Grahn 2021), databases relying on field observations will be necessary for validation. Combining the available events database with past regional climate data would allow one to understand the climatology of avalanches in HMA better, an approach already employed in the Alps (Eckert et al. 2010). This could allow for a better understanding of the link between a changing climate and the occurrence of avalanches, which so far only been investigated for a field site in India (Ballesteros-Cánovas et al. 2018) and one in China (Hao et al. 2023). More recently, distributed datasets on a number of variables including snow cover (Muhammad and Thapa 2021), snow depth (Lievens et al. 2019), snow water equivalent (Smith and Bookhagen 2018; Liu et al. 2021) and, locally, refreezing within the snowpack (Veldhuijsen et al. 2021) have become available. Such data could be combined with records of avalanche events to investigate favorable conditions for avalanche occurrence, ideally in combination with more comprehensive assessments aided by remote sensing.

6.2 Application of GIS and AHP in avalanche hazard susceptibility mapping

The GIS-based MCDA technique was applied to develop an avalanche hazard susceptibility map of the Annapurna Conservation Area. AHP was chosen over a wide variety of MCDA techniques due to its proven efficiency in integrating diverse datasets, ease of obtaining weights for many criteria, and improvement in decision-making processes. It has been widely used and accepted in the field of natural hazards (Selcuk 2013).

The susceptibility map with five zones was derived using the jerk method in a GIS environment. The jerk classification method can determine the best arrangement of values into classes by iteratively comparing the sums of the squared difference between observed values within each class and class means (Jenks 1967). Additionally, expert judgment and literature were incorporated to determine the weight distribution for each factor criterion.

The resulting susceptibility map identifies high and very high susceptibility areas concentrated along the Annapurna range within the ACA. More avalanche susceptibility is observed in the ACA's Middle Eastern and Western areas. These zones pose significant risks to nearby settlements, including ABC, MBC, Deurali, and Himalaya, where recurring fatal and non-fatal avalanche incidents are reported, particularly during winter, pre-monsoon, and post-monsoon seasons.

Snow avalanches are frequent in mountainous regions and are influenced by meteorological conditions, terrain features, and snowpack properties. However, due to data constraints, our analysis focused solely on terrain and meteorological factors. We utilized ASTER DEM V3 data to derive terrain parameters relevant to avalanche formation. ALOS PALSAR DEM 12.5 m, with its higher resolution, was initially considered for the study. However, it was unavailable for the study area and could not be used. As a result, the susceptibility map was developed using other DEMs, including NASADEM and Copernicus DEM. Ultimately, the best results were achieved with ASTER DEM. While higher-resolution data could have Improved the accuracy, it also posed the risk of detecting more avalanches (Bühler et al. 2013). Moreover, air temperature data were only available for three stations, necessitating temperature lapse rates to estimate the air temperatures at other remaining stations across the study area. The mean annual temperature lapse rate of -5.2°C/km (Kattel et al. 2013) was applied to derive temperature datasets for all remaining weather stations in the ACA from 1992 to 2022.

During the avalanche inventory map preparation, field visits were conducted to identify avalanche locations. Despite the challenges posed by inaccessible terrain, we meticulously recorded GPS coordinates at each area and cross-verified them against runout zones. Moreover, Google Earth was utilized to improve the accuracy of location data.

Overall, the development of the avalanche susceptibility map for the ACA represents a significant advancement in hazard assessment and risk management. This study not only sets the foundation for future research endeavors but also inspires and motivates the scientific community to refine susceptibility mapping methodologies and enhance community resilience to avalanche hazards.

6.3 Avalanche occurrences and meteorological conditions

Precipitation is crucial in avalanche forecasting, especially for predicting large, catastrophic avalanches. Studies show that about 1 meter of new snow during a storm can trigger extreme avalanches, while 30-50 cm of new snow is critical for naturally occurring avalanches (Föhn et al. 2002). Ancey (2001) suggests that a snow accumulation threshold of 30 cm d^{-1} results in widespread avalanching in the European Alps.

However, new snow depth alone does not entirely predict avalanche activity, as the probability of multiple avalanche paths releasing under these conditions is often less than 50% (Schaer 1995). The rate of snowfall during storms is also significant; if snow accumulates rapidly (≥2.5 cm/h), the weak layer beneath may not strengthen quickly enough, raising the avalanche risk (Schweizer and Föhn 1996).

A study in Davos, Switzerland conducted to analyze the relationship between new snow depth over three-day storm periods and the verified degree of avalanche danger, using the five-degree unified European danger scale, using 1512 observations, the Spearman rank-order correlation coefficient between the three-day sum of new snow depth and the avalanche danger degree was 0.58 indicating a moderate positive correlation, with a significance level of $p < 0.001$(Schweizer and Föhn 1996).

In the Tibetan Plateau region, Hao et al. (2018) found avalanche release prevalent when precipitation was >20.4 mm during a single storm period during the study period from November 2011 to April 2017. Heavy snow precipitation followed by rising temperatures within 3 d and daily mean temperature approaching 0.5°C the next day tends to increase the risk of avalanches in late February to mid-March in the region. Similarly, avalanches were generally recorded when mean daily temperatures were between 2 and 0°C, with successive heavy snowfalls, or when mean monthly air temperatures are above −3°C in the same region (Wang 1988).

Similarly, in the western Himalaya, an accumulation of more than 1.5 m during snowstorms, resulted in numerous avalanches (Sharma and Ganju 2000).

In ACA, precipitation data from two nearby weather stations, Sikles (1820 m a.s.l.) and Lumle (1740 m a.s.l.), situated relatively close to Deurali on the ABC Route where an avalanche occurred on January 17, 2020, showed significant precipitation levels: 49.3 mm in Sikles and 45.5 mm in Lumle, as shown in Figure 6.1. This substantial precipitation supports the occurrence of avalanches, similar to incidents observed in other regions.

Snowstorms between 13 October and 15 October 2014 led to catastrophe in the trekking trails of the Annapurna region and was the deadliest year in the history of mountaineering and trekking in Manang and Mustang. In total 43 people lost their lives in this specific event (Neckel et al. 2015; Oz et al. 2016; Raya 2020; Thakuri et al. 2020). This specific event was associated with tropical cyclone Hudhud which reached Nepal on 12 October 2014. During Cyclone Hudhud (October 13-15), a sudden increase in snow height was recorded, peaking on October 15 with snow accumulation reaching up to 0.37 meters (Neckel et al. 2015). The frequency of such extreme events is increasing due to changes in global climate phenomena. So, people should always look after the weather forecast and prepare themselves while planning for such adventurous treks and climbing.

In the last four decades, experiencing elevation dependent warming means the mountainous region is warming more compared to the southern plains of the country. The temperature trend of Nepal shows the Maximum air temperature has increased by 0.045°C/yr and the minimum temperature by 0.009°C/yr from 1976 to 2015 (Thakuri et al. 2019). According to Global Climate Risk Index (GCRI), Nepal is one of the most susceptible countries to climate risk based on impacts of meteorological events to socio-economic losses and human fatalities (Eckstein et al. 2021).

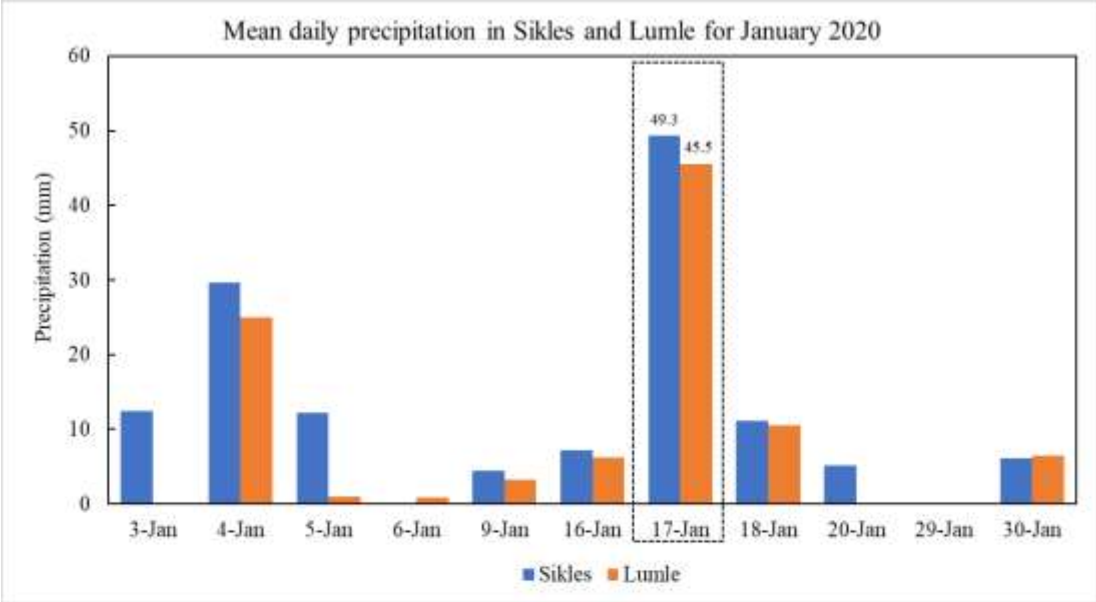

Figure 6.1 Mean daily precipitation in Sikles and Lumle for January 2020

6.4 Sensitivity Analysis of susceptibility map

The sensitivity of the derived susceptibility map of the ACA to changes in precipitation and air temperature was conducted using meteorological datasets from 1993-2022. Precipitation was altered by ±10% and ±20%, whereas ±1°C and ±2°C were altered for the air temperature. These trends could change the avalanche susceptibility zones of the ACA.

Table 6.1shows the results of sensitivity tests. Massive alteration in the area coverage of susceptible zones was not observed, as terrain parameters were given with more weight than meteorological parameters. However, despite the low weight of meteorological factors, the observed alterations confirm their crucial role in predicting and forecasting avalanches (Singh et al. 2005; Dreier et al. 2016; Yariyan et al. 2022). An analysis of air temperature trends from 1985 to 2016 at the Jomsom station showed an annual increase of 0.067°C for the mean maximum temperature, 0.0369°C for the mean minimum temperature, and 0.0217°C for the mean average temperature, indicating a rising temperature trend over the period in the ACA.

Similarly, the annual precipitation trend in the Jomsom area has shown an increase of 3.1823 mm/year over the same period. Jomsom Weather Station is one of the nearest weather stations to Kobang, ACA (Adhikari et al. 2020). These trends could change the avalanche susceptibility zones of the ACA.

Table 6.1 Sensitivity test of susceptibility map to changes in precipitation and air temperature

Meteorological parameter	Change	Susceptibility zones				
		Very Low (%)	Low (%)	Moderate (%)	High (%)	Very high (%)
Precipitation (%)	-20	18.19	25.60	22.40	20.20	13.60
	-10	17.43	24.90	22.60	20.30	14.90
	0	15.70	24.00	23.30	21.30	15.60
	10	12.01	24.10	25.30	22.10	16.50
	20	10.90	23.60	26.00	22.40	17.10
Air temperature (°C)	-2	13.98	22.99	24.09	21.93	17.01
	-1	12.37	23.65	25.08	22.17	16.73
	0	15.70	24.00	23.30	21.30	15.60
	1	14.69	25.52	25.11	20.34	14.33
	2	11.65	28.11	26.96	20.05	13.24

6.4.1 Sensitivity test to precipitation change

The sensitivity test results reveal that changes in precipitation considerably impact the distribution of susceptibility zones. Higher precipitation tends to reduce the areas categorized as very low and low susceptibility while expanding the areas of very high susceptibility. High susceptibility zones remain relatively stable (Figure 6.2). These findings suggest that increased precipitation may heighten the risks of avalanche hazards, necessitating enhanced risk management and mitigation strategies to address the shifting susceptibility patterns. Several studies also show that avalanche activities increased with increased precipitation (Jomelli et al. 2007; Laute and Beylich 2018). Similarly, Shrestha et al. (2012) observed that the average annual precipitation in the Himalayan region increased by 163 mm between 1982 and 2006, showing an increasing trend.

As precipitation increases, the area coverage of very low susceptibility zones decreases significantly. At -20% precipitation, the area coverage is 18.2%, but it reduces to 10.9% at +20% precipitation, while the reference area coverage is 15.7%. This suggests that increased precipitation leads to a reduction in very low susceptibility areas.

Similarly, low susceptibility zones exhibit a slight downward trend with increasing precipitation. The coverage is approximately 26% at -20% precipitation and falls to 23.6% at

+20% precipitation, while the reference area coverage is 24.0%. This indicates a moderate sensitivity of low susceptibility zones to changes in precipitation.

Moderate susceptibility zones exhibit a slight increasing trend across the range of precipitation changes. At -20% precipitation, the area coverage is 22.4%, increasing to 26.0% at +20% precipitation, while the reference area coverage is 23.3%. This suggests that increased precipitation leads to an increase in moderate susceptibility areas.

The area coverage of high susceptibility zones shows a slight increasing trend with increasing precipitation. At -20% precipitation, it is 20.2% and increases to approximately 22.4% at +20% precipitation, while the reference area coverage is 21.3%. This indicates that high susceptibility zones are not significantly impacted by variations in precipitation.

The area coverage of very high susceptibility zones increases notably with increasing precipitation. At -20% precipitation, the area coverage is around 13.6%, rising to about 17.1% at +20% precipitation, while the reference area coverage is 15.6%. This indicates a significant increase in very high susceptibility areas as precipitation rises

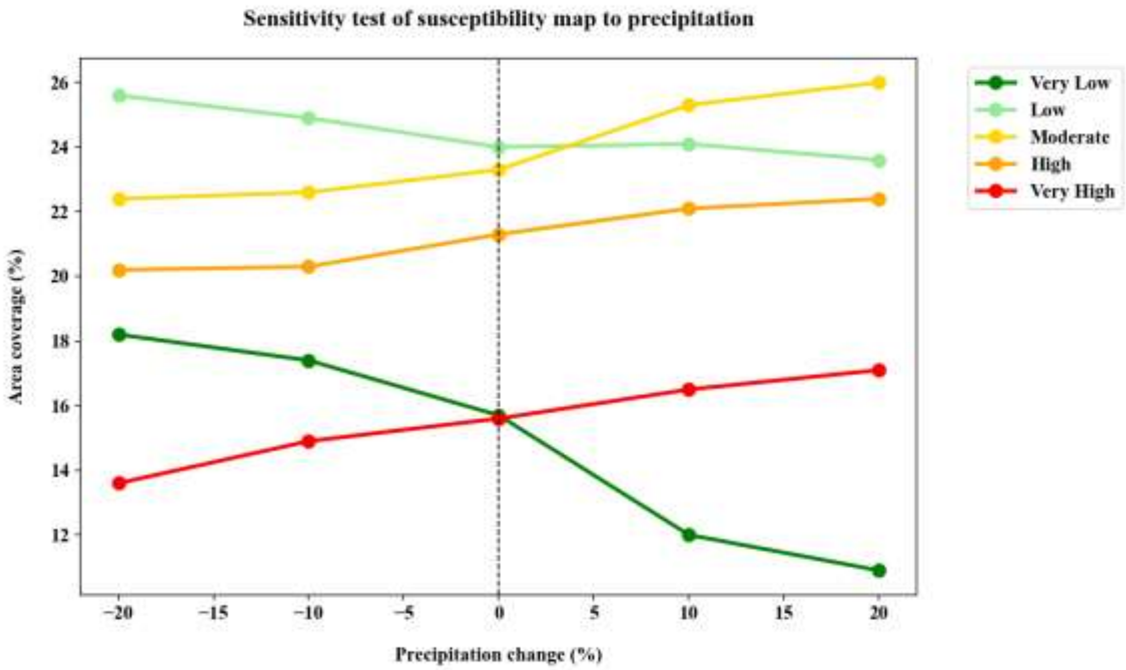

Figure 6.2 Sensitivity test of susceptibility map to precipitation

6.4.2 Sensitivity test to air temperature change

The sensitivity test results indicate that changes in air temperature moderately impact susceptibility zone distribution. Higher air temperatures lead to a decrease in very low, high, and very high susceptibility areas, while areas categorized as low and moderate susceptibility areas show an increase (Figure 6.3). These findings imply that rising temperatures may shift the susceptibility profile of the region, potentially decreasing high risk areas but increasing the prevalence of moderate and low-risk zones. In general, air temperature plays a vital role in snowpack stability, and resulting in weak layer formation (Ancey 2001; McClung and Schaerer 2006) and wet avalanches (Ballesteros-Cánovas et al. 2018).

As air temperature increases, the area coverage of very low susceptibility zones decreases. At -2.0°C, the area coverage is around 14%, but it decreases to 11.6% at +2.0°C, while the reference area coverage is 15.7%. This indicates that higher air temperatures lead to a reduction in very low susceptibility areas.

The area coverage of low susceptibility zones shows a slight increasing trend with rising air temperature. The coverage is approximately 23% at -2.0°C and increases to 28.2% at +2.0°C, while the reference area coverage is 24.0%. This suggests that low susceptibility zones become more prevalent with higher air temperatures.

The area coverage of moderate susceptibility zones alters slightly but shows a general increasing trend with rising air temperature. It is 24.1% at -2.0°C and reaches approximately 27.0% at +2.0°C, while the reference area coverage is 23.3%. This indicates that moderate susceptibility zones are relatively stable but slightly increase with higher temperatures.

The area coverage of high susceptibility zones fluctuates minimally but shows a general decreasing trend with rising air temperature. It is around 22% at -2.0°C and decreases to approximately 20.5% at +2.0°C, while the reference area coverage is 21.3%.

The area coverage of very high susceptibility zones decreases notably with increasing air temperature. At -2.0°C, the coverage is around 17%, but it decreases to about 13.0% at +2.0°C, while the reference area coverage is 15.6%. This indicates a significant reduction in very high susceptibility areas as air temperatures increase.

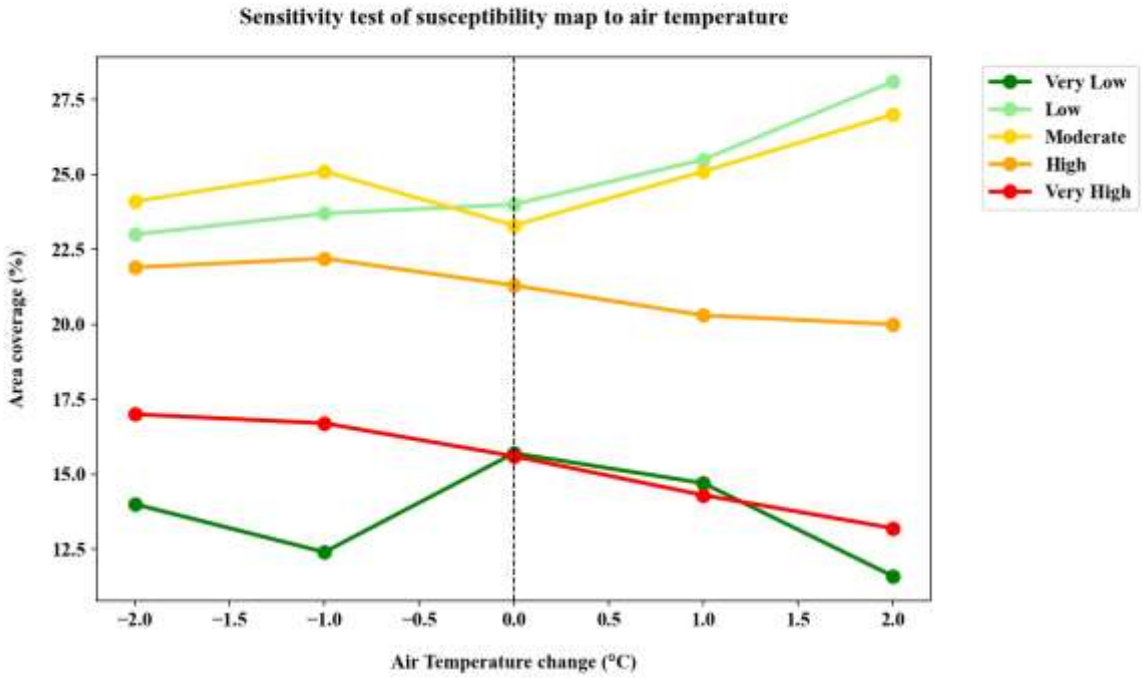

Figure 6.3 Sensitivity test of susceptibility map to air temperature

6.5 Avalanche susceptibility and infrastructure in ACA

The Annapurna Conservation Area was the most visited destination by foreign tourists in 2023, attracting 107,880 visitors. This made it the top-ranked protected area out of 20 in Nepal for that year (GoN 2024). Figure 6.4 shows the dense network of different tourism activities routes and infrastructure in the ACA. The Annapurna Conservation Area (ACA) offers at least 25 trekking trails, 29 climbing trails, and a Great Himalayan trail, attracting thousands of visitors annually. Famous trekking trails such as Tilicho trek, Annapurna Circuit, Annapurna Base Camp, Dhaulagiri Main Trek, and Ghorepani Poonhill and climbing trails such as Annapurna South, Annapurna II, Dhaulagiri, Gangapurna, Pisang and Hiuchuli are there in the ACA. These trekking, climbing, and Great Himalayan trail routes cross multiple susceptibility zones, exposing trekkers to different levels of avalanche hazard risk. Routes passing through high and very high susceptibility zones require regular maintenance and the implementation of safety measures, such as clear signage, hazard warnings, and emergency response protocols (McClung and Schaerer 2006). Warning signs regarding avalanches can be seen in some trekking areas of ACA, as shown in Figure 5.12 (B).

Roads are crucial in connecting settlements and facilitating the movement of goods and people. The road networks on the map intersect several high-risk zones. Ensuring these roads are resilient to natural hazards is important; it is essential for maintaining accessibility and safety, particularly during adverse weather conditions. This underscores the significant role of stakeholders in this aspect.

The ACA is renowned for its peaks, attracting many adventure seekers aiming to summit them. This area includes numerous peaks, including Annapurna I, which stands 8,091 meters above sea level. Himalayan trails and mountain climbing routes are popular among climbers and adventure tourists. However, their passage through high and very high susceptibility zones throughout the ACA highlights the need for enhanced safety measures to minimize avalanche damage. Providing climbers with current information on trail conditions and potential hazards can significantly reduce risks.

These routes are vital for local transportation and tourism, which are significant economic activities in this area. Enhancing the safety and resilience of these routes benefits residents and visitors and promotes the sustainable development of the tourism industry in the ACA.

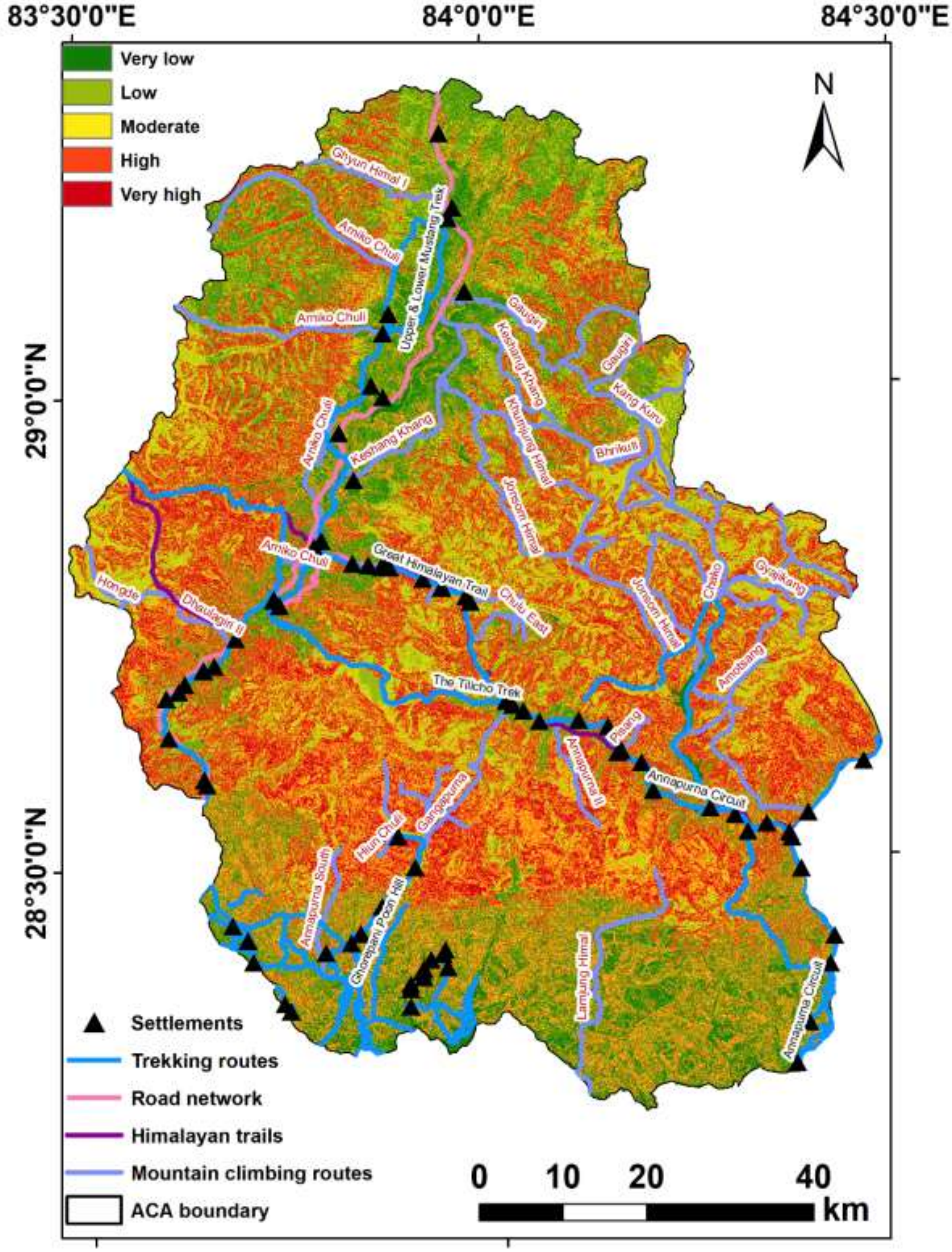

Figure 6.4 Distribution of different routes throughout the susceptibility zones of the ACA

6.6 Avalanche susceptibility, settlements, and safe locations in surveyed areas

Figure 6.4 shows that a large portion of the region is covered by high and very high susceptibility zones, particularly in the central and southern parts. Many settlements are located within or near these high-risk zones, increasing their exposure to avalanche hazards. Settlements such as Kobnag, Larjung, Pisang, Manang, ABC, and Deurali have significant risks of avalanches, and incidents of avalanches are frequently reported near these settlements.

It is important to note that settlements along the central axis of the map, stretching from the northernmost to the southernmost parts, are predominantly in high to very high susceptibility zones. This highlights the urgent need for focused risk mitigation strategies, such as infrastructure reinforcement, community preparedness programs, and the establishment of early warning systems. On a positive note, some settlements in the northern and southern extremities of the map are in low and very low susceptibility zones, suggesting relatively safer areas that could serve as potential evacuation sites during emergencies, providing a reassuring aspect of the preparedness.

In Figure 6.6 (B), the distribution indicates that a significant portion of the population is at risk from avalanche hazards. Specific areas like Naurikot, Ghantekhola, Larjung, and Kobang have clusters of households in moderate to high-risk zones, emphasizing the need for risk mitigation and preparedness strategies. Similarly, almost all guesthouses on the ABC route (Figure 6.6 (A)) are in moderate to high-risk zones, with ABC being highly susceptible to avalanche hazards. Avalanches destroyed ABC on April 12, 2019, and subsequently rebuilt. Deurali, located in high and very high avalanche-susceptible zones, was severely affected by an avalanche in January 2020, although guesthouses were not impacted. Himalaya has a history of frequent avalanche occurrences. Dovan, while also having a history of avalanches, has yet to experience recent incidents due to reduced snowfall; even though the terrain features are suitable research suggests similar claims about climate change and rising temperatures reducing avalanches due to less snow accumulation.

The identification of safe locations was primarily based on the experience of local residents without the backing of scientific research. In the Kobang area (Area 2) as shown in Figure 6.6 (B), these safe locations are predominantly in low and very low zones. For instance, the safe location near Kobang is in a low susceptibility zone, suggesting it can serve as a reliable evacuation point for the surrounding community. However, it is crucial to note that these safe locations may not be entirely safe due to mixed terrain features that alter avalanche flow paths, such as in Ghatekhola, where the safe location spans both low and high susceptibility zones.

On the ABC route, safe locations are mostly rooms in guesthouses that are not in the direct path of avalanche slopes. These are the only available options, as the surrounding area is highly glaciated and offers no other safe refuge. This underscores the critical need for extensive field-based research to identify and confirm safe locations, enhancing the community's safety and providing a thorough risk assessment.

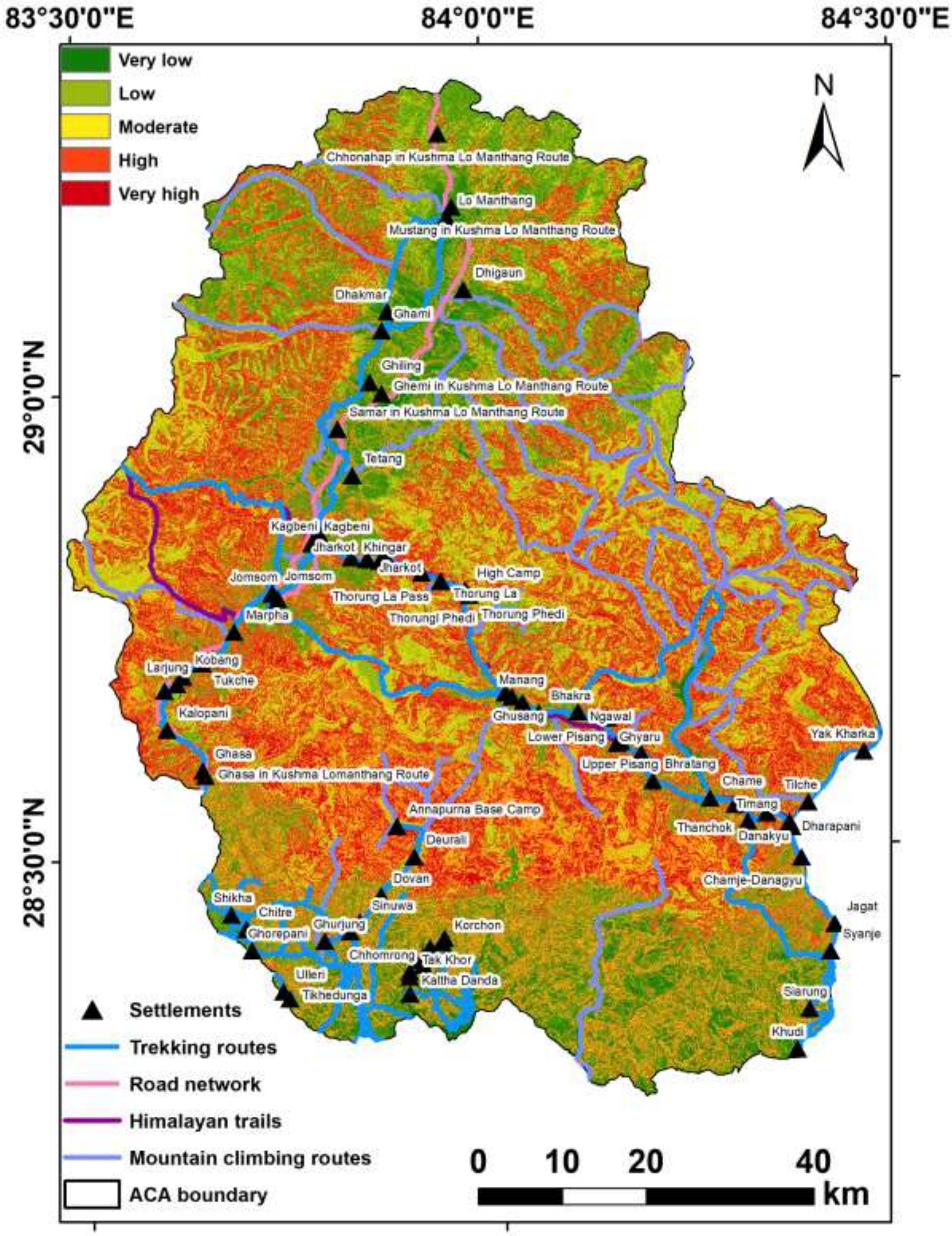

Figure 6.5 Distribution of settlements throughout the susceptibility zones of the ACA

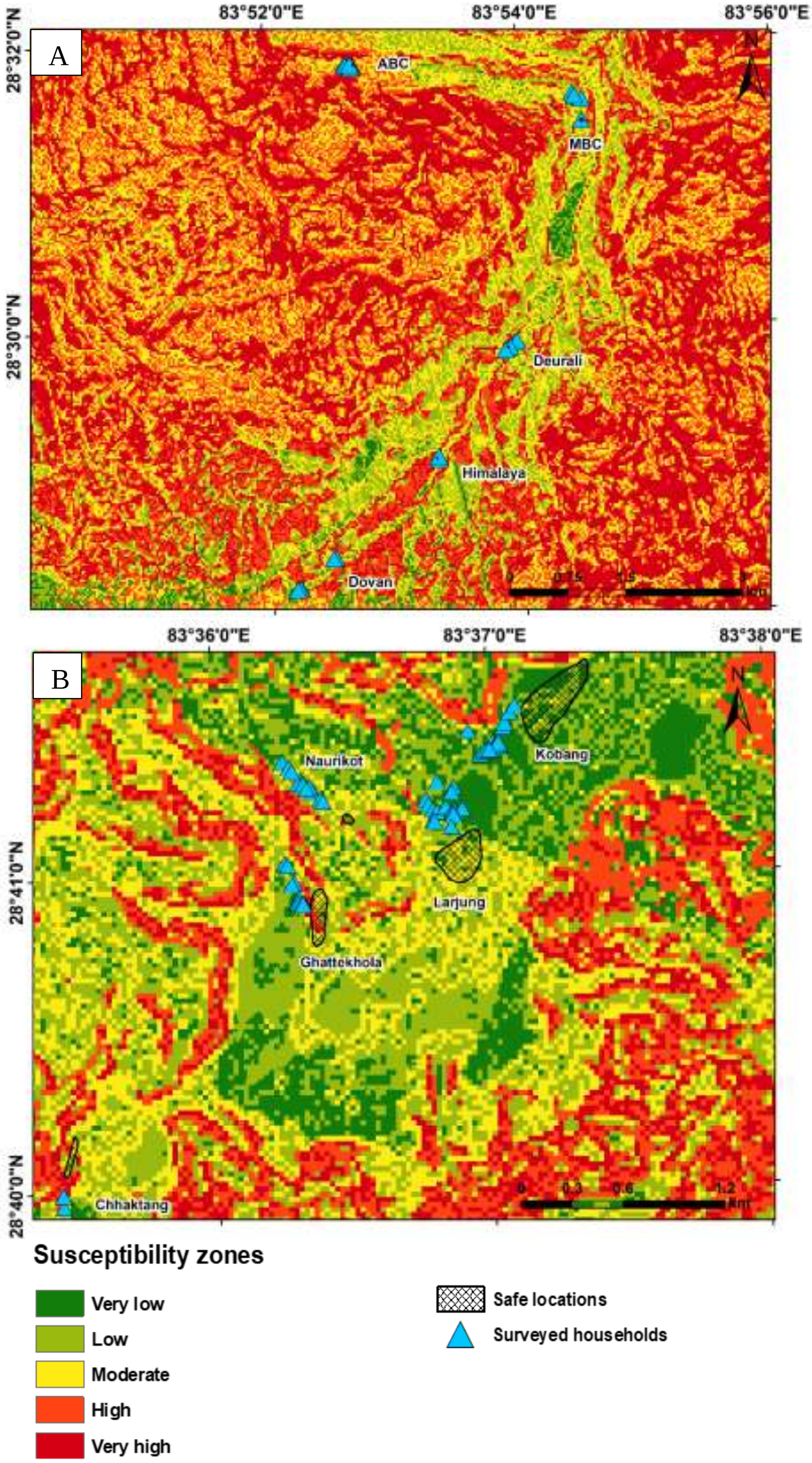

Figure 6.6 Settlements and safe locations on susceptibility map of ACA, ABC Route (A), Kobang Area (B)

6.7 Tourism and avalanches in the ACA

Tourism is a significant contributor to Nepal's gross domestic product (GDP). According to the Government of Nepal, direct earnings from tourism amounted to 77.80 billion Nepali Rupees (approximately US$580 million) in the fiscal year 2018/19, representing 2.2% of the GDP (GoN 2019).

In recent decades, international and domestic tourists have frequently visited the famous destinations in the Annapurna Conservation Area (ACA). The UNDP (2016) report revealed that over 900 international and about 1,000 domestic visitors traverse the popular Sikles trekking route annually, contributing over $5,000 to the local economy. The local hotels and lodges, with their annual contribution of more than $15,000, further foster the region's economic activity. 9 tourist information centers are in operation in the ACA, managed by the National Trust for Nature Conservation (NTNC) in the Annapurna Conservation Area Project (ACAP) (NTNC 2022) for convenience.

Nepal's tourism history dates back to the 1950s when foreign mountaineers began visiting the country for various summits (Dhananjay, 2022). Over the years, domestic tourists have also started exploring the diverse tourist destinations in Nepal, significantly contributing to the local economy (Baniya and Paudel 2016; Basnyat et al. 2020).

However, this increased tourism has exposed more people, both domestic and international, to avalanche hazards. Many domestic tourists lack the experience with mountain hazards that tourists from Europe, Canada, and Japan typically possess. Consequently, domestic tourists are generally less prepared and alert to these dangers compared to international tourists. Despite this, only a few domestic tourists have been directly affected by avalanches, as they usually trek seasonally, heed local advice, and often avoid the more challenging and inaccessible terrains where mountain hazards are more prevalent (Baniya and Paudel 2016).

Tragic incidents suggest the dangers of avalanches in the region. On January 17, 2020, an avalanche claimed the lives of four Korean climbers and three Nepali guides. Similarly, on October 10, 2018, an avalanche on Mt. Gurja resulted in nine deaths, including that of a renowned South Korean climber (Thakuri et al. 2020). The famous 8000-meter peaks, Dhaulagiri and Annapurna, also have infamous records of avalanche incidents. In Dhaulagiri, 18 out of 42 casualties in 16 avalanche incidents were hired personnel, while in Annapurna I, 13 out of 41 casualties in 19 incidents were local hires.

Although avalanches do not frequently kill domestic tourists, the local guides and porters from Nepal often lose their lives. This is sometimes due to a lack of weather knowledge but often because international clients insist on continuing their treks despite poor weather conditions, as seen in the Deurali January 17, 2020 incident. These local workers understand the dangers of avalanches but take these risks to earn their livelihood.

6.8 Exposure and impacts of avalanches in ACA

Avalanche risk refers to the probability of harm arising from the interaction between avalanche hazards and specific elements at risk. This risk assessment considers both the element's exposure and susceptibility to the avalanche hazard. Avalanche hazard describes the potential danger posed by avalanches and is determined by both the likelihood of triggering an avalanche and the resulting magnitude of its destructive force. It is important to note that avalanche hazard exists independently of any assets or individuals at risk. Hazard does not threaten individuals who are not exposed to it (Hein et al. 2003; Statham 2008). Exposure refers to the location and duration for which an element at risk is situated within the terrain. The exposure component of risk is a crucial consideration for controlling the risk of avalanches. Even during periods of high avalanche hazard, a simple reduction in exposure will reduce the risk (Stethem et al. 2003). This section analyzes people's exposure to avalanche hazards based on age, gender, residency in two areas in ACA.

Figure 6.7 and Figure 6.9 highlight distinct gender distributions across ABC Route and Kobang Area. ABC Route exhibits a pronounced gender disparity, with males constituting 97% of the population and females only 3%. This skew suggests that males predominantly engage in guesthouse businesses, which is the main livelihood of this area, indicating male-dominated workforce. In contrast, Kobang Area shows a nearly equal distribution between males and females, with 49.84% males and 50.16% females. This balance depicts a diverse community with multiple livelihoods, reflecting a more residential or family-oriented setting.

Age demographics also differ significantly between these two areas. ABC Route primarily attracts adults or a working-age population within the 30-60 age bracket, confirming at job opportunities that appeal and retain this age group, while less accommodating conditions for younger and older demographics due to unavailability of basic necessities. Conversely, in Kobang Area, broad age distribution, including a significant proportion of both very young and elderly residents, indicative of an environment with facilities and a lifestyle supporting all age groups.

Furthermore, the impact of avalanches also varies markedly between the two areas. In ABC Route, avalanches mostly affect the tourism sector, with some repercussions such as damage to guesthouses (15) and human injuries (10). Conversely, Kobang experiences a broader range of avalanche impacts, including considerable damage to houses (69), human fatalities (3), injuries (6), animal deaths (249), crop damage (1.58 hectares), and destruction to animal sheds (4 incidents). These figures demonstrate that Kobang's diverse livelihood patterns are consistently and severely affected by avalanche activities, pointing the need for targeted disaster management, support systems and response strategies in the area. Study based on case material from 50 households in the settlements of Phalyak and Dhakarjong in Kagbeni VDC, Mustang district near the same area, collected between 2013 and 2015, shows that households in these settlements have diversified their livelihood options. Previously dominated by agriculture and livestock raising, they have now expanded to include apple farming (for cash income), vegetable farming, external migration, and tourism-based activities in response to various shocks and stresses (Fort 2015).

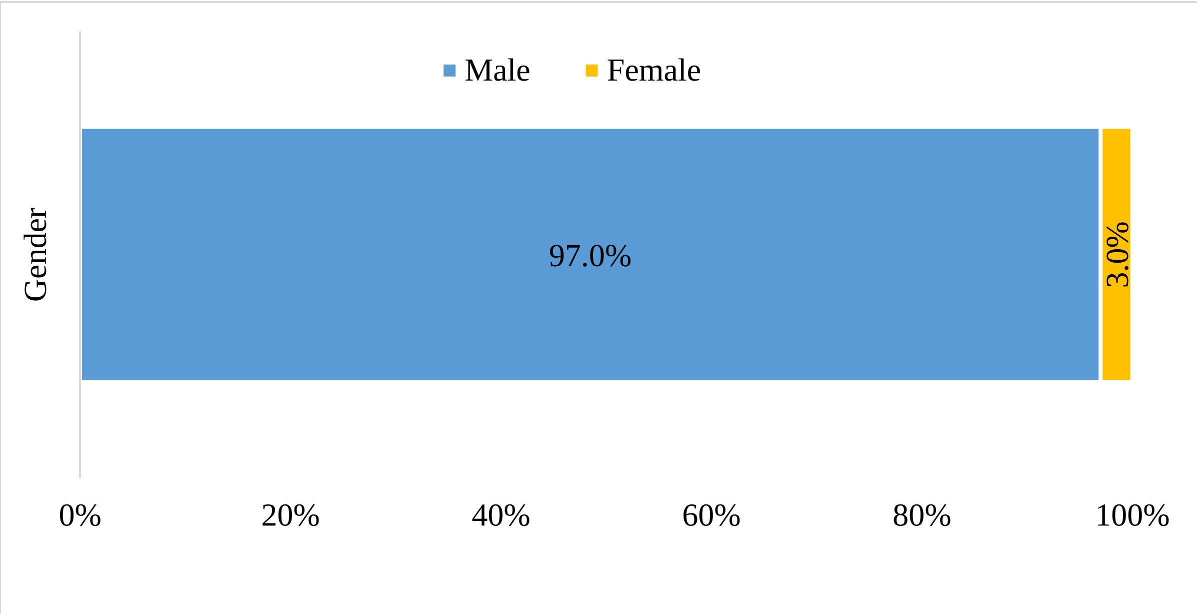

Figure 6.7 Gender-based distribution of exposed population in ABC Route

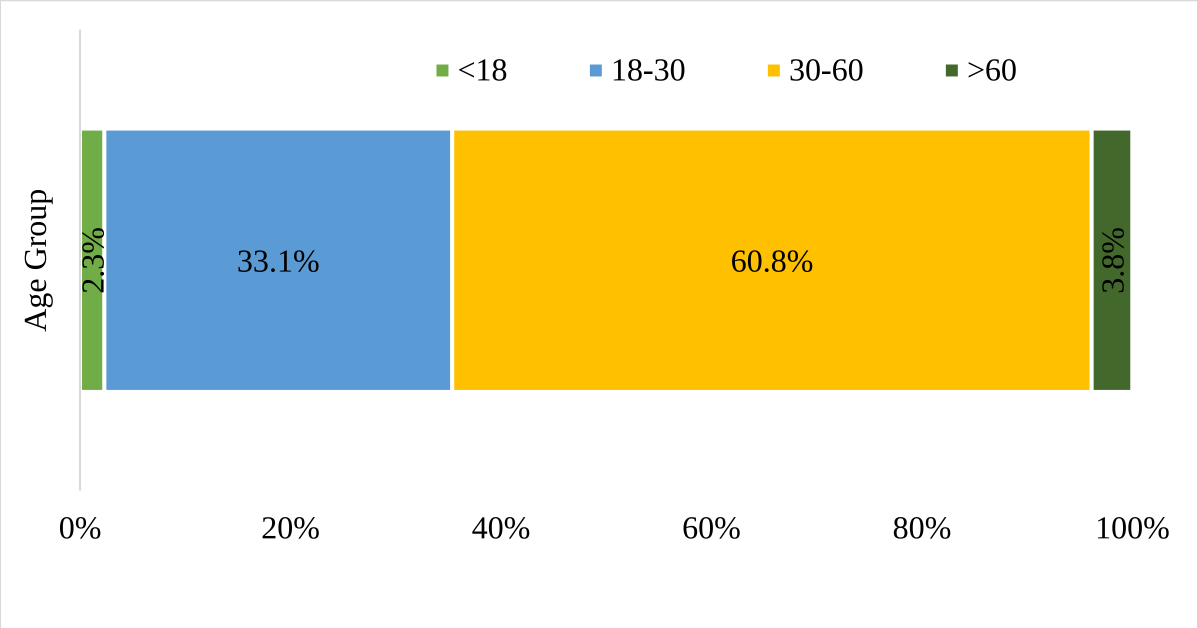

Figure 6.8 Age-based distribution of exposed population of ABC Route

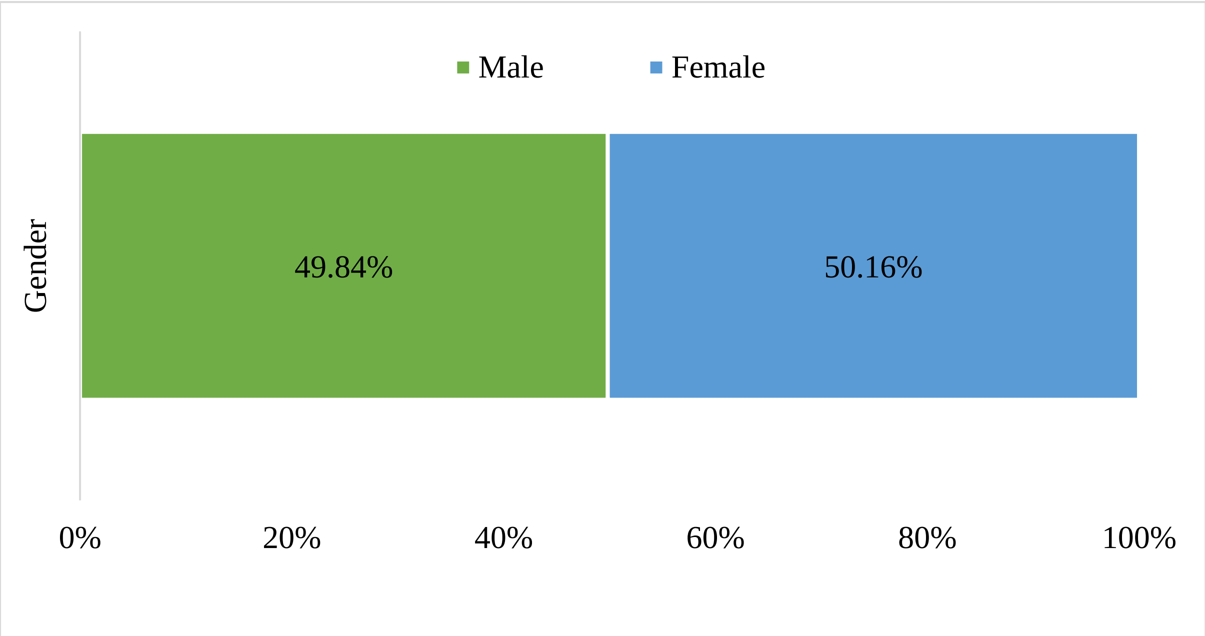

Figure 6.9 Gender-based distribution of exposed population in Kobang Area

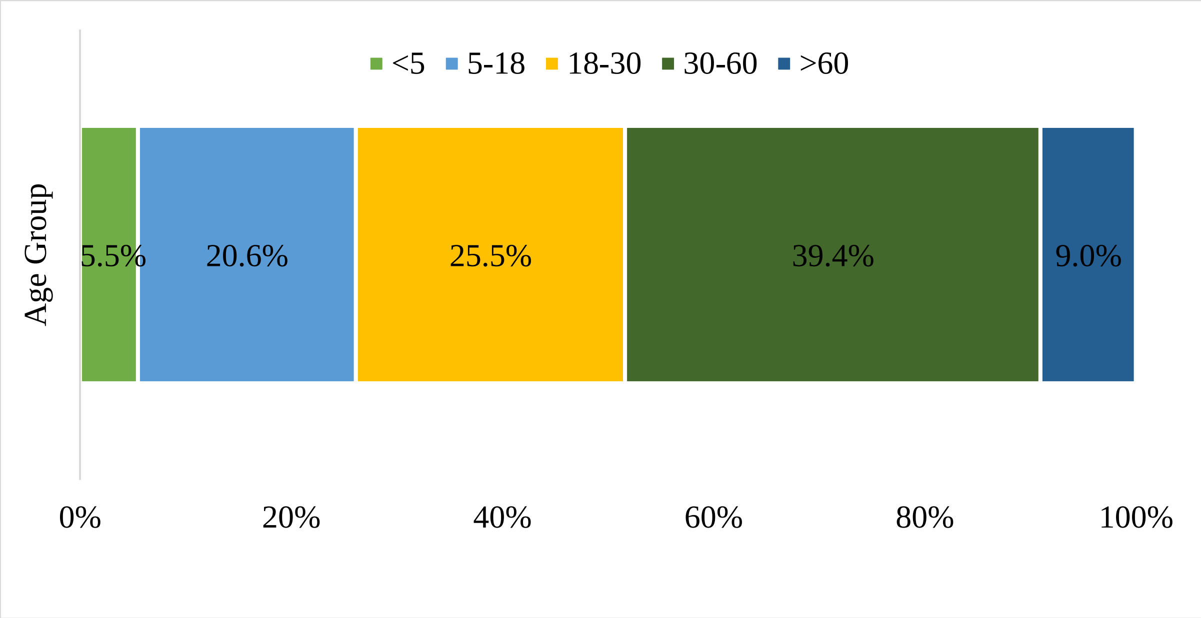

Figure 6.10 Age-based distribution of exposed population in Kobang Area

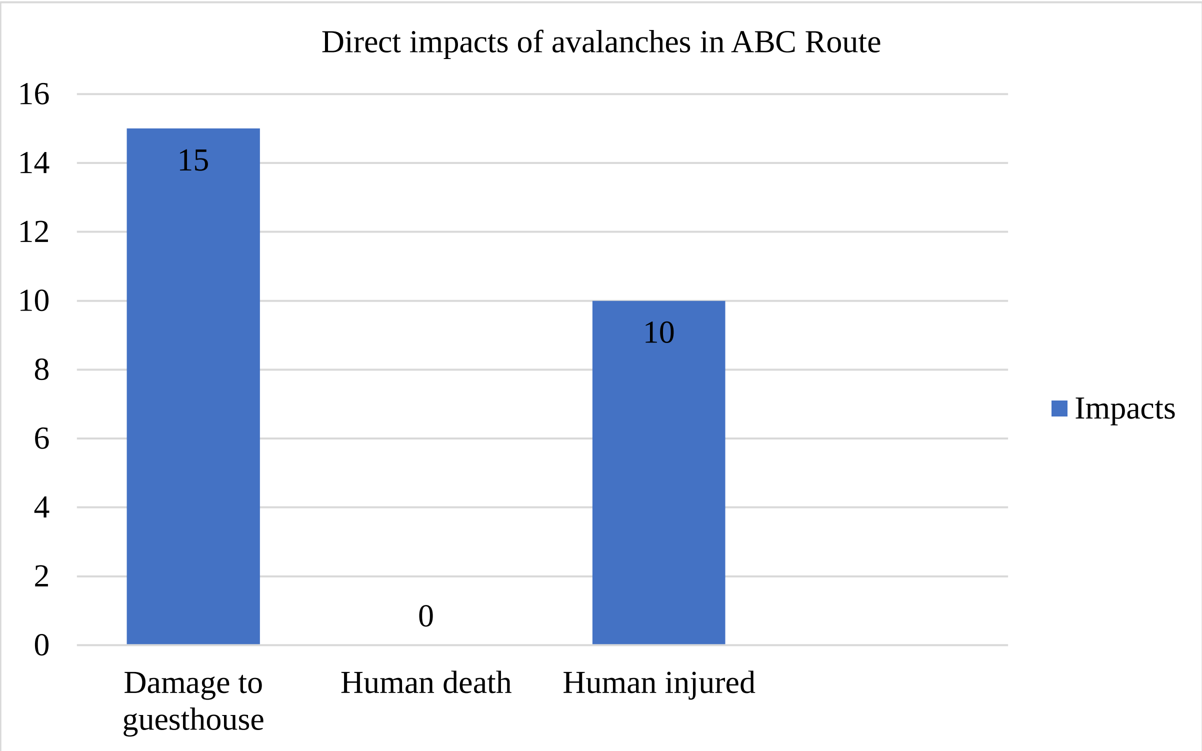

Figure 6.11 Impacts of avalanches in Kobang Area

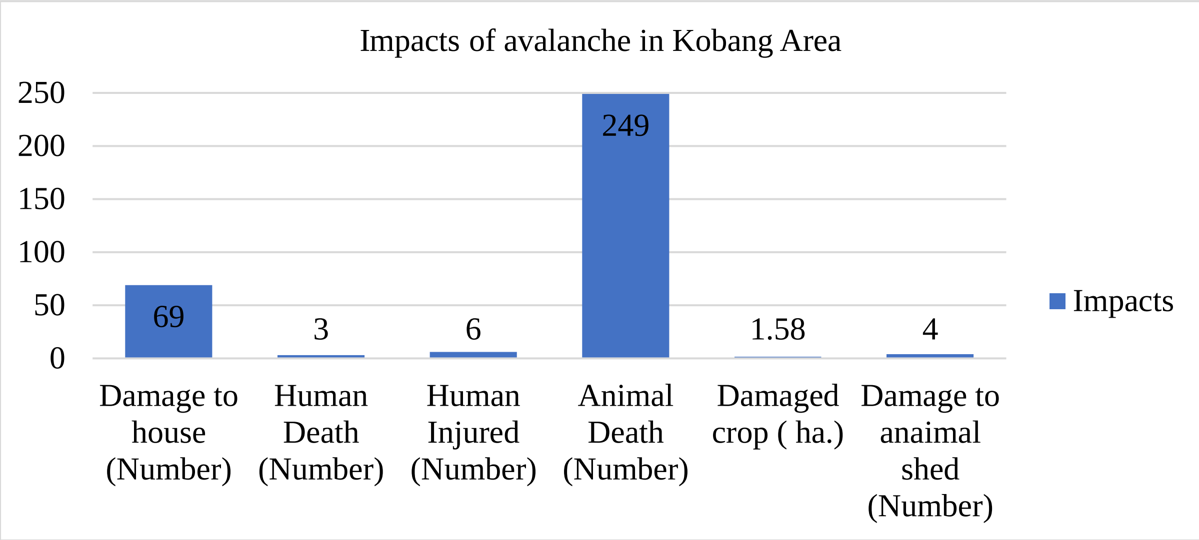

Figure 6.12 Impacts of avalanches in Kobang Area

6.8.1 ABC Route (Area 1)

There were 24 households in ABC Route, where 25% were migrants and 75% were non-migrants. Moreover, all of them are involved in the guesthouse business. Non-migrant households have slightly different experiences compared to migrant households. Migrant households, two in ABC, one in Himalaya, and one in Dovan, mentioned not experiencing severe impacts on the flow of tourism. In contrast, non-migrant households have three or more than three such experiences, including an avalanche in 2019 in ABC, an avalanche in Deurali in January 2021, and several others in 1998, 2009, 2013, and 2019. The primary livelihood activity there is the guesthouse business targeted to visitors. Only four women stayed in the ABC route. Two of them were in Dovan, location less challenging regarding weather and access to nearby infrastructures. As men are considered breadwinners in Nepal, most men do business there while their families live mainly in Chhomrong and Pokhara.

Table 6.2 Socioeconomic information of the household in ABC Route (Area 1)

Settlement	Total H. N	Migration status		Livelihood		
		Migrants	Non-Migrants	Livestock rearing	Agricultural activities	Guesthouse business
ABC	6	2	4	0	0	6
MBC	5	0	5	0	0	5
Deurali	5	1	4	0	0	5
Himalaya	3	1	2	0	0	3
Dovan	5	2	3	0	0	5
Total	24	25%	75%	0	0	100%

In ABC Route, 133 people live there, of which 97% are male, and the remaining 3% are female (Figure 6.7). The active working age group of 18-60 comprises 92%, and the remaining 8% are below 18 or over 60. shows the age-based distribution of the population in the ABC Route. Out of 133, only 42% were the owners, and the remaining population of 58% were migrant workers, revealing that migrant workers are the leading group exposed to avalanche risks. Moreover, the workers from the Gorkha District, comprising 80% of the migrant workers group, are more likely to encounter avalanches as they primarily work as porters, helpers, and chefs.

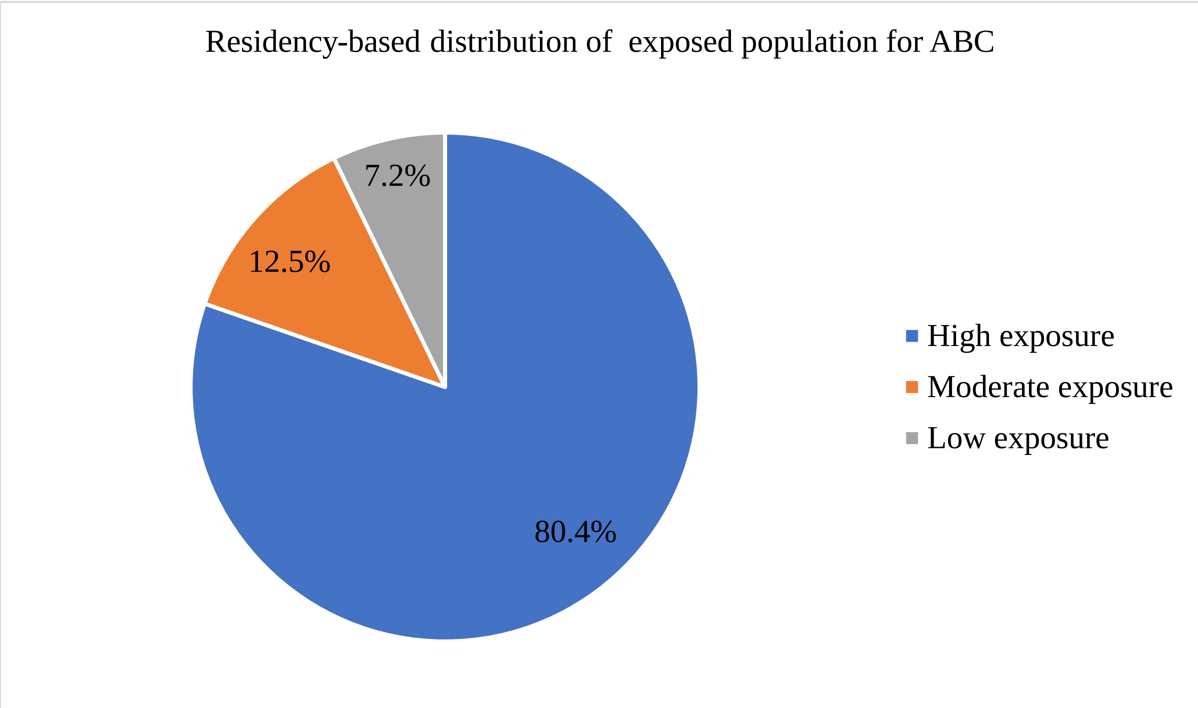

Figure 6.13 Residency-based distribution of exposed population for ABC Route

Figure 6.13 shows the percentage of the exposed population based on their frequency of staying in ABC Route. Around 80% of the population tends to stay the whole time during the trekking seasons. This group mainly includes migrant workers and a few owners. Similarly, the moderate exposure group, with 12.5%, mainly comprises owners who visit a few times and stay there for a few days. The low exposure, with 7.2%, includes the owners again, but they rarely come and stay there.

Figure 6.11 shows the impacts of avalanches on the ABC Route. In total, 15 guesthouses were damaged in the ABC area, and a total of 10 people were injured in the ABC Route, and no human deaths have been recorded from the guesthouses. Similarly, 14 people mentioned being severely affected by the avalanches in terms of tourism flow after major avalanches, such as the April Avalanche 2019 in ABC and the January Avalanche in 2021 in Deurali. Seven of the guesthouses mentioned being affected moderately, and one was affected at a low level.

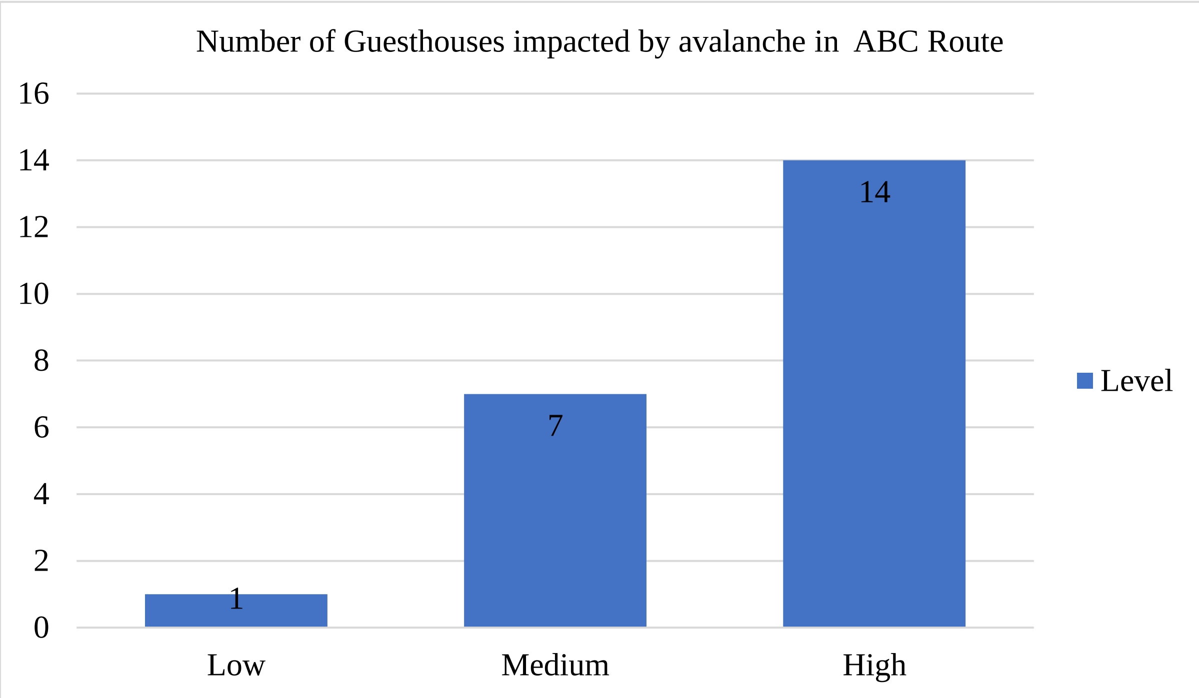

Figure 6.14 Number of Guesthouses impacted by avalanche in ABC Route

6.8.2 Kobang Area (Area 2)

Seventy households in the Kobang area have a total migrant population of 23%, whereas the remaining 77% are non-migrants. Unlike ABC Route, the Kobang Area has a diversified livelihood pattern. 33.2% of the surveyed population were involved in agriculture, whereas 25.6% were students and the non-working population. The information about this is presented in the Table 6.3.

Table 6.3 Socioeconomic information of households (A) and population (B) of Kobang Area

Socioeconomic information		Settlement					Total (%)
		Ghattekhola	Naurikot	Larjung	Kobang	Chhaktang	
A	Migrant	6	0	4	4	2	22.9
	Non-Migrant	3	18	15	18	0	77.1
	House owned	8	18	15	12	2	78.6
B	Agriculture	12	31	22	43	1	34.8
	Teacher	0	4	4	2	0	3.2
	Service	2	5	4	4	0	4.8
	Foreign employment	4	6	5	2	0	5.4
	Business	2	8	4	1	3	5.8
	Dependent population	17	23	32	39	5	37
	Others	4	1	12	9	2	9

Figure 6.9 presents the gender distribution of the exposed population for the Kobang Area. Unlike ABC Route, females make up slightly higher percentages in this area as the Kobang area is a residential place heavily dependent upon agricultural and occasional tourism activities. Like ABC Route, the Kobang area also has the active working age group of 18-60, comprising 64.9%, but with a significant percentage of 20.6% for 5-18 years, while the remaining 14.5% were under five and over 60. Figure 6.10 shows the age-based distribution of the population in the Kobang Area.

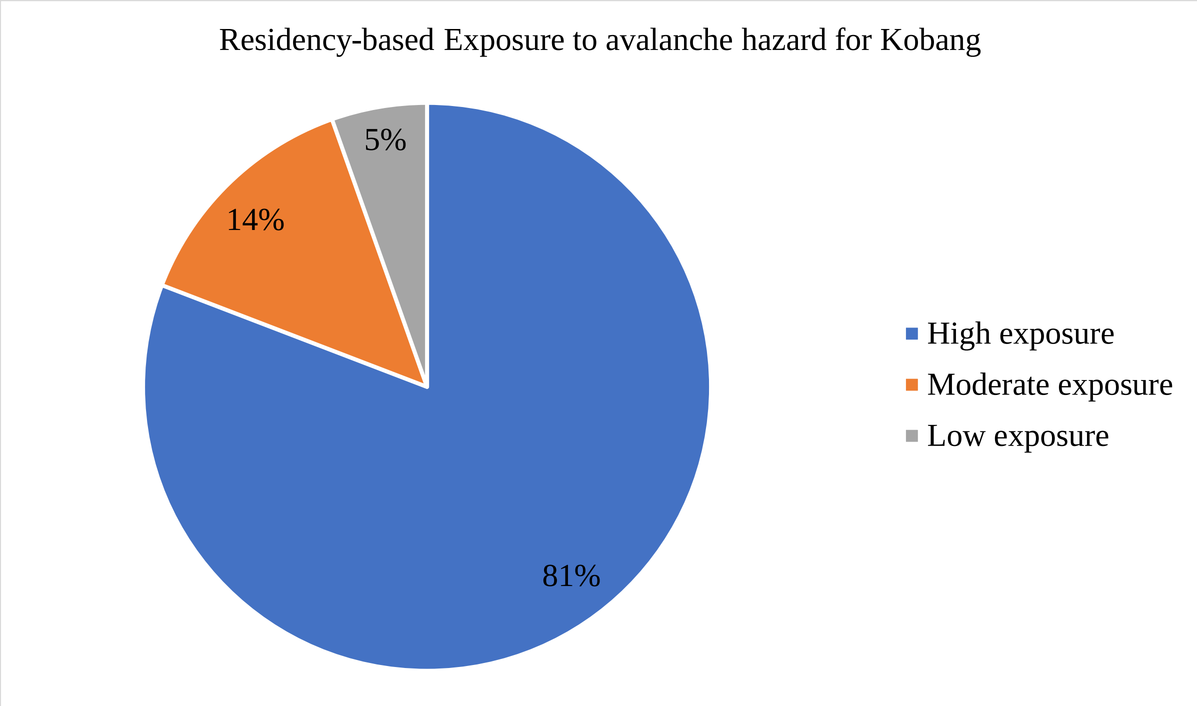

Figure 6.15 Residency-based distribution of exposed population for Kobang Area

Figure 6.15 shows the percentage of the exposed population based on their frequency of staying in the Kobang Area. 81% of the surveyed population were at high exposure, meaning they consistently stay there; the moderate exposure group, with 14%, are those located in nearby locations within the country for their jobs and often come to the Kobang Area. However, the low exposure group (5%) includes people who are outside of the country for foreign employment, and the frequency of their presence in the Kobang Area is rare

In Kobang, 69 houses were damaged, three people died from avalanches, and six were injured. The 249 animal deaths and four yak sheds being damaged show that the avalanches in the region adversely affect livestock rearing in Mustang. Similarly, 31 Ropani (~ 1.58 ha) worth of crops and land were damaged by avalanches in several cases Figure 6.12.

6.9 Statistical analysis of the prevention/mitigation efforts in the ABC Route and Kobang Area

A statistical analysis was performed to investigate potential correlations between responses in each category of prevention and mitigation efforts section of the social survey. Due to the small sample size, Fisher's exact test was utilized with a confidence level of 0.05. Null and alternative hypotheses were formulated accordingly, as illustrated in below. The p-value for each category was computed, and based on this value, the decision to accept or reject the hypothesis was made.

The results presented in Table 6.4 indicate that there were no significant differences between the areas regarding Early warning system, emergency food supply, family discussions, meeting place, evacuation practice and accessibility. This shows that that the attitudes of individuals across both areas were largely consistent in these aspects. However, divergent responses were observed for the remaining categories of public awareness, understanding of hazard maps, utilization of CRRT, implementation of prevention mitigation practices, and adherence to safety protocols. This variation is attributed to various factors, such as the unique characteristics of each area, Area one’s importance in tourism, and the level of involvement in activities beyond the local community.

Table 6.4 Fisher's exact test results for ABC Route and Kobang Area

Category	Result of hypothesis testing	p value
Public Awareness	Reject the null hypothesis	0.03013319
Hazard map	Reject the null hypothesis	0.03533662
Early warning system	Accept the null hypothesis	0.64324938
CRRT	Reject the null hypothesis	8.12E-18
Prevention Mitigation	Reject the null hypothesis	0.00000021
Prevention Mitigation Type	Accept the null hypothesis	0.25653595
Safe	Reject the null hypothesis	0.00012669
Emergency supply	Accept the null hypothesis	1.00000000
Family discussion	Accept the null hypothesis	1.00000000
Meeting place	Accept the null hypothesis	0.10909386
Nearest safe place	Reject the null hypothesis	0.00027510
Evacuation practice	Accept the null hypothesis	1.00000000
Accessibility	Accept the null hypothesis	0.48002587

Null Hypothesis	There is no significant difference in response distribution between Area 1 and Area 2.
Alternative Hypothesis	There is a significant difference in response distribution between Area 1 and Area 2.

6.10 Compensation status

In area 1, only four guesthouses in ABC received compensation for the damage caused by the avalanche on April 12, 2019, which destroyed them entirely. However, they preferred not to disclose the compensation amount.

In area 2, the government has taken some steps towards compensation for the households that lost their livestock in avalanches, particularly for events from November 2021 and March 2022. No household mentioned any past compensation experiences. Conservation Area Management Committee (CAMC) and Veterinary Hospital and Animal Service Expert Office 1000 (~$7.5) and 10000 (~$75) for each dead yak they lost. However, in the second case, the NECO insurance company also covered the compensation equivalent to NRs.25000 ($ 187) per yak after four months. As the insurance company requires proof of dead animals, the farmers could not gather photos or proof of dead yaks; hence, insurance only covered a few numbers. Sushila Gauchan, H.N 11, mentioned getting insurance covered for only six yaks while she lost 25 yaks to the avalanche in March 2022. However, the increased concern from government authorities towards livestock is commendable, but it is a temporary measure. Instead, the government should focus on a long-term avalanche risk management plan.

6.11 Insurance Status

In Area 2, 15 households have insured their livestock. Only one household insured eight cows; apart from that, all other households insured their yaks. After the devastating avalanche in November 2021, the rate of insuring yaks increased rapidly. Households preferred insuring yaks because they are usually not kept at home and are mostly on grazing land in high-altitude areas where the risk of avalanches is high.

Table 6.5 Information about insurance of animals in the Kobang Area

Settlement name	Total H	Animal insured households	Animal types	No. of Animal Insured
Ghattekhola	9	3	Yak, Cow	104
Naurikot	18	3	Yak	76
Larjung	19	1	Yak	70
Kobang	22	4	Yak	138
Chhaktang	2	2	Yak	93
Total	70	13	0	481

6.12 Strategies for disaster management by local government

6.12.1 Installation of meteorological weather stations

Nepal is widely recognized as one of the most disaster-prone countries globally, facing recurring risks from natural calamities such as floods, earthquakes, and landslides (Smith et al. 2017; Vaidya et al. 2019). In order to have a better disaster management plan, the installation of weather stations to gather meteorological information to apply in different types of disaster modeling is very important (Alens 2014)

Currently, only one weather station serves the ABC Route, AWS at MBC, but when trying to access data, the sensors needed to capture the datasets appropriately. On the brighter side, H.N 8 has installed its weather station for better preparedness. Currently, the owner of H.N 8 serves as a warner to warn everybody on the route to be careful or to go toward safety. Similarly, in the Kobang area, nearby stations are at Lete, Thakmarpha and Jomsom; these stations have been recording temperature and precipitation since long before but needs other snow information for detail analysis of avalanche dynamics. There is an AWS in Jomsom for other meteorological data, but data needs to be captured appropriately. The government should monitor continuously, work to produce quality data, and use that for avalanche analysis to improve preparedness and develop control measures.

6.12.2 Avalanche forecasting and early warning system

An early warning system is a tool and a lifeline for mitigating disaster risk and facilitating timely evacuation (Brabec et al. 2001). The absence of such a system could lead to catastrophic consequences; hence, prompt warnings, clear communication, and decisive actions are pivotal and potentially life-saving for effective disaster management (Segarceanu et al. 2021). However, ACA lacks an avalanche forecasting and early warning system. The only measures in place are warning signs and experience-based evacuations to safer locations.

In many countries, regional avalanche forecasts and the timely dissemination of bulletins to the public serve as primary strategies to mitigate avalanche risk (Techel and Schweizer 2017; Sielenou et al. 2021). These bulletins, typically issued in the afternoon or evening, offer forecasts for the following day(s). A regional avalanche is characterized by the simultaneous release of numerous avalanches in a specific area within a span of 24 hours or more, often triggered by snowfall (Brabec et al. 2001; Schirmer et al. 2009). Several attempts at avalanche predictions and early warnings have been made in the European Alps (Schweizer and van Herwijnen 2013; Stähli et al. 2015; Segarceanu et al. 2021), but in the context of the Himalaya, only a few studies have been conducted due to a lack of meteorological datasets and snowpack properties datasets. However, some efforts are being made by the Defence Geoinformatics Research Establishment, DGRE) in the Western Himalaya using multiple networks of AWS, remote sensing, and geographic information system (GIS) technology to extract snow cover and terrain information and regularly publishing snow bulletins (Singh et al. 2019a). In the western Himalaya and Karakoram, preliminary studies using RAMMS for specific avalanche events exist but are limited by insufficient data on snow depth, general snow properties, and local meteorological conditions (Mahboob et al. 2015; Gilany and Iqbal 2019; Singh et al. 2020). Similarly, in China, a research station in Tian Shan focuses on investigating avalanche hazards, particularly those affecting roads (Hao et al. 2018). Afghanistan, relying heavily on snow for livelihood, boasts the most comprehensive avalanche database maintained by AKAH. This database not only highlights the significant impact of avalanches on communities but also plays a crucial role in improving forecasting and mitigation efforts. So far, concrete mechanisms from the government have yet to be implemented to deal with avalanche hazards in the ACA. Apart from the strong meteorological network, the government should document avalanche locations and events with community people so they can adequately plan and get precise results. There is a problem of being reluctant to share about avalanches in the trekking trails in Nepal. They fear tourism may reduce if the cases of avalanches are reported regularly. However, there is a necessity for public awareness about it so that these inventory maps can serve their betterment and help government plan or design control measures like in other mountainous regions.

Chapter 7: Conclusion and Recommendations

A comprehensive investigation incorporating all accessible snow and ice avalanche records from the High Mountain Asia (HMA) region was conducted based on journal articles, technical reports, and newspapers. Additionally, previous scientific research, indigenous knowledge, and existing or active adaptation and mitigation strategies were investigated.

The developed avalanche database spans half a century between 1972 and 2022 and records 681 individual events (88% snow and 0.5% ice avalanches, excluding mountaineering accidents on high peaks), of which 21% had some recorded impact, and 17% fatalities were recorded. Avalanches killed more than 3100 people, more than 62 each year on average, most of them in Afghanistan (1057; 34%), India (952; 30%), and Nepal (508; 16%). This suggests that avalanches are a deadly hazard in high mountain environments in the region, causing considerably more fatalities than glacial lake outburst floods. On average, each avalanche in our database killed 27 people, making them exceptionally high-impact events. Approximately 1900 livestock killed in 24 events are also noteworthy, as this impact on livelihoods has been mentioned as an especially problematic aspect of the hazard in the region. More than 500 people have been killed in avalanches while climbing mountain peaks above 4500 m a.s.l., one-third of whom were porters or guides employed during these endeavors.

Scientific studies on avalanches with field investigations are limited to research stations on the Tibetan Plateau and the Indian western Himalaya. As a result, modeling studies that have been carried out in several locations still need to be more extensive, as information on snowpack and local climate is lacking.

Studies investigating the role of avalanches in glacier mass balances are still limited but suggest significant differences in their relative contribution between the monsoon-dominated Himalaya, where steep and very high headwalls surrounding glacier tongues are likely more common, conducive to avalanche occurrence (>75%) and the continental and less topographically extreme Tian Shan (<15%). Future studies should investigate their relevance at a more regional scale, considering the increasing dynamic disconnect of accumulation and ablation areas in many glaciers in the region.

Conversely, several adaptation and mitigation measures have been taken. In India and China, this has received large-scale funding for specific regions where avalanches have been identified as potential threats to road infrastructure. It includes dedicated monitoring programs coordinating with scientists and investments in state-of-the-art structural measures. However, nongovernmental efforts have been equally successful. The monitoring of avalanches in

Afghanistan is unparalleled in the region and is carried out by local stakeholders. It is the only country that records individual avalanche events irrespective of their impact, an effort that is incredibly valuable for future studies investigating meteorological drivers. Other examples of locally carried initiatives, such as harvesting avalanche deposits for meltwater to be used in high mountain irrigation in Pakistan, are also a testament to the existence of local solutions to address the hazard that should be investigated for potential scaling to other localities in the future.

An avalanche susceptibility map with five zones (very low, low, moderate, high, and very high) was developed using MCDA AHP within a GIS environment using terrain (source: ASTER DEM, NTB, ESRI LULC) and meteorological (DHM) factors obtained from different sources. The very low, low, moderate, high, and very high zones comprised 15.7%, 24.0%, 23.3%, 21.3%, and 15.6%, respectively. The high and very low lie mostly in the middle region of the ACA along the Annapurna range. The derived avalanche susceptibility map was validated through ROC curve analysis, which yielded a prediction rate of 89%, indicating good alignment with the documented avalanche locations.

In ABC Route, 62.5% out of 24 households claimed that their households were damaged by avalanches at some point. In contrast, in Mustang, 82.9% of households claimed that their houses were damaged due to avalanches—no human casualties in ABC Route but three deaths in Mustang. ABC Route also sustained ten injuries, and respondents in Kobang Area claimed six injuries. ABC Route is severely affected in terms of tourism flow, whereas Kobang Area is affected in terms agricultural activities.

It is crucial to note that prevention and mitigation efforts in both areas are insufficient and alarmingly non-existent. However, ABC Route is slightly more aware of the situation and is making personal contributions to sustain its livelihood. It is concerning to find that the relevant stakeholders should pay more attention to minimizing the risks posed by avalanches, leaving the population and infrastructure vulnerable.

ACA is one of the nation's major tourism hubs, and the tourism industry is the primary source of income. Avalanches affect the lives and livelihoods of the local population in both areas, subsequently impacting the country's revenue. The relevant authority should consider it seriously and plan and design policies and control measures to minimize the damage caused by avalanches.

Recommendations include using dynamic avalanche models to quantify risk and delineate run-out zones, which helps planners and engineers design effective mitigation measures and control structures. Similarly, strategic planning of zone-specific mitigation measures is highly endorsed. It is strongly recommended that human activities in high and very high susceptibility zones be strictly limited, with careful consideration for implementing necessary engineering avalanche control measures. In moderate susceptibility zones, a cautious approach to human activity and the potential adoption of engineering standards to mitigate risks are recommended.

Susceptibility maps serve as a crucial foundation for disaster management. These maps are considered effective and reliable tools for minimizing avalanche damage. Identifying avalanche-prone areas and accurately mapping susceptibility zones are essential tasks for decision-makers and planners to implement effective measures to mitigate these avalanche risks.

In terms of rescue and evacuation training and first aid training, capacity building of local people should be carried out regularly to enable them to act quickly and efficiently in time of need. Migrant workers, women, children, and other vulnerable groups should also be engaged in developmental practices without disturbing the natural state of the mountainous region, and approaches should be participatory and inclusive.

The database of avalanche events, including geolocation, timing, type of avalanche, and recorded impacts, allows for future investigations of the climatology of avalanche events in HMA. As a first step, they can be used to validate automated mapping efforts using remote sensing on a regional scale and subsequently correlated with distributed climate and snow datasets to understand important regional drivers for avalanche occurrence. This would provide a basis for more robust forecasting of avalanche danger in different parts of the HMA, where avalanche risks have been identified as a concern. Efforts by national agencies tasked with hazard monitoring should further invest in pairing scientific investigations of avalanche hazards by developing adaptation and mitigation solutions. This approach has seen success in other mountain regions. Based on the impacts that we record here that avalanches had in the past in the HMA, we suggest that the hazard should be given a higher priority in DRR strategies of different governmental and nongovernmental stakeholders in the domain of high mountain hazards. Methodologies and data are available to address this issue using remote sensing data and field-based installations. National and local solutions for such avalanche warning and forecasting should always consider existing local adaptation solutions and knowledge concerning the hazard. Future interdisciplinary studies should further investigate local solutions in response to avalanche hazards, record experiences with the hazard, and determine whether and how they have changed in the more recent past. This would allow one to understand whether avalanche risks are changing (either due to climate or more socio-economic exposure) and help build future adaptation solutions.

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Annexure

Annexure A

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Location	Year	Month	Day	Latitude	Longitude	Country	Region_HiMAP	Type	Impact	Fatalities	Injured	Livestock	Leisure	Remarks
Talgar Pass	1951	11	NA	43.114748	77.111547	Kazakhstan	4	NA	Y	5	3		Y	
Tuyuksu Gletscher	1958	11	NA	43.040461	77.039701	Kazakhstan	4	NA	Y	1				
Pioneer Pass	1961	3	NA	42.545453	74.548544	Kazakhstan	4	NA	Y	1	1		Y	
Komsomol Peak	1966	3	NA	42.571172	74.546949	Kazakhstan	4	NA	Y	2	2			
Deo-Tibba	1972	10	28	32.186436	77.383044	India	10	NA	Y	2	NA	NA		heavy snowfall triggered
Himanchal	1973	NA	NA	32.248596	77.190601	India	10	NA	Y	2	NA	NA		
Lippa Himanchal	1975	NA	NA	31.652325	78.384838	India	10	NA	Y	2	NA	NA		
Lahual and Spiti	1978	3	NA	32.759515	76.19334	India	10	NA	Y	30	NA	NA		
Lahaul Valley	1979	3		31.841332	77.485476	India	10	NA	Y	237	NA	NA		Intense snowstorms triggered the avalanches, which buried the valley under almost 6 m of snow
1980 avalanches	1980	NA	NA	27.982441	86.88153	Nepal	11	NA	Y	10	NA	NA		
Kilba, Kinnaur	1984	2	21	31.528548	78.142533	India	10	NA	Y	8	NA	NA		
Tuyuksu Gletscher	1986	3	NA	43.040461	77.039701	Kazakhstan	4	NA	Y		1			
Tuyuksu Gletscher	1986	11	7	43.040461	77.039701	Kazakhstan	4	NA	Y	6	2		Y	
Mustang	1987	NA	NA	28.688387	83.543016	Nepal	11	NA	Y	0	0	62		Yaks
Shymbulak	1987	3	NA	43.128277	77.080485	Kazakhstan	4	NA	Y	1	0	0	Y	
Shigar	1988	NA	NA	35.592339	75.568032	Pakistan	9	NA	Y	42	NA	NA		
Lenin peak	1990	7	13	39.344094	72.877599	Tajikistan	6	NA	Y	40	NA	NA		
Shymbulak	1990	5	1	43.128277	77.080485	Kazakhstan	4	NA	Y	4	0	0		
Shymbulak	1991	3	NA	43.128277	77.080485	Kazakhstan	4	NA	Y	0	1	0	Y	
Udaipur, Lahual	1992	3	29	32.729617	76.674216	India	10	NA	Y	9	NA	NA		
Shuraki Kapali catchment	1994	NA	NA	38.975	70.839	Tajikistan	6	glacier detachment	N	0	0	0		
Gokyo	1995	11	12	27.912404	86.683499	Nepal	11	NA	Y	48	NA	100		avalanche/snowstorms
Talgar Pass	1995	4	NA	43.114748	77.111547	Kazakhstan	4	NA	Y	0	8		Y	
Keylong, Lahual	1996	3	19	32.578084	77.033034	India	10	NA	Y	6	NA	NA		
Anzob	1997	10	23	39.041862	68.836962	Tajikistan	5	NA	Y	46	NA	NA		

Location	Year	Month	Day	Latitude	Longitude	Country	Region_HiMAP	Type	Impact	Fatalities	Injured	Livestock	Leisure	Remarks
Uri-Sector	1997	3	28	34.095994	74.035038	India	10	slab avalanche	Y	4	NA	NA		
Everest region	1997			28.000026	86.853861	Nepal	11	NA	Y	19	NA	NA		avalanche/snowstorm
Langtang	1997	8	NA	28.206287	85.62293	Nepal	11	NA	Y	0	NA	5		
Banihal, Jammu and Kashmir	1998	2	25	33.430363	75.214877	India	10	NA	Y	11	NA	NA		Avalanche caused by intense snowfall destroyed a remote house and claimed the lives of its inhabitants
Mustang	1998	NA	NA	28.688387	83.543016	Nepal	11	NA	Y	0	NA	25		Yaks
Mustang	1998	NA	NA	28.688387	83.543016	Nepal	11	ice and snow avalanche	Y	3	NA	85		85 cows dead
Tuyuksu Gletscher	1998	3	NA	43.040461	77.039701	Kazakhstan	4	NA	Y	0	1			
Chunchet, Gorkha	1999	1	2	28.509066	84.961227	Nepal	11	NA	Y	5	NA	NA		
Kinnaur, Himanchal	2002	3	5	31.811375	78.656008	India	11	NA	Y	3	NA	NA		
Shuraki Kapali catchment	2003	9	NA	38.969984	70.845789	Tajikistan	6	glacier detachment	N	0	0	0		
Shuraki Kapali catchment	2003	8		38.969984	70.845789	Tajikistan	6	glacier detachment	N	0	0	0		
Mustang	2003	NA	NA	28.601155	83.596533	Nepal	11	ice and snow avalanche	Y	0	NA	70		single owner lost 70 yaks
Pinoer Pass	2003	3	NA	42.545453	74.548544	Kazakhstan	4	NA	Y	1	0		Y	
Komsomol Peak	2003	3	3	42.571172	74.546949	Kazakhstan	4	NA	Y	1	1			
Shuraki Kapali catchment	2004	NA	NA	38.972831	70.840745	Tajikistan	6	glacier detachment	N	0	0	0		
Amney Machen	2004	1	NA	34.82	99.44	China	21	glacier detachment	N	0	0	0		happened between 26 Jan - 3 Feb
Degdonak	2005	2	3	38.928114	69.83007	Tajikistan	5	snow avalanche	Y	9	3	NA		3 people injured, 15 houses buried under snow
Jammu and Kashmir	2005	2	18	33.793152	74.346548	India	10	snow avalanche	Y	540	NA	NA		Series of avalanches since 18th Feb due to excessive snowfall, 1200 houses damaged, 4500 people evacuated,

Location	Year	Month	Day	Latitude	Longitude	Country	Region_HiMAP	Type	Impact	Fatalities	Injured	Livestock	Leisure	Remarks
														262 people missing
Shymbulak	2005	2	12	43.128277	77.080485	Kazakhstan	4	NA	Y	1	0	0		
Shymbulak	2005	3	NA	43.128277	77.080485	Kazakhstan	4	NA	Y	0	1	0	Y	
Jirgital	2006	1	30	39.405905	71.091765	Tajikistan	5	snow avalanche	Y	18	12	NA		
Shymbulak	2006	4	9	43.128277	77.080485	Kazakhstan	4	NA	Y	6	NA	NA	Y	
Butakovskoye	2006	1	0	43.16099	77.04667	Kazakhstan	4	NA	Y	2	0	0	Y	
Anzob	2007	12	22	39.272888	68.541344	Tajikistan	5	snow avalanche	Y	16	NA	NA		Dushanbe-Khujand road section
Sindhum	2007	11	NA	28.215008	85.526744	Nepal	11	NA	Y	2	0	NA		damaged all fifteen houses in that settlement
Amney Machen	2007	9		34.82	99.44	China	21	glacier detachment	N	0	0	0		happened between 23 Sep - 2 Nov
Bharatpur, Lahual	2008	9	22	32.797365	77.430127	India	10	NA	Y	7	NA	NA		12 trekkers went missing in the Chandertal area
Ili	2008	3	17	43.92	81.32	China	6	NA	Y	16	NA	NA		
Istikol	2009	2	27	39.070615	68.697412	Tajikistan	5	snow avalanche	Y	6	0	NA		driver and 5 passengers on a car were hit
Salang	2009	1	16	35.305848	69.049623	Afghanistan	8	NA	Y	10	11	NA		Southern part of the Salang Tunnel
Anzob	2010	3	17	39.272888	68.541344	Tajikistan	5	NA	Y	8	NA	NA		
Salang	2010	2	8	35.310158	69.045199	Afghanistan	8	NA	Y	175	70	NA		17 avalanches, triggered by heavy winds and rain, buried more than 2 miles of highway, more than 70 people injured
7 remote CDCs, Arghanj Khaw, Badakhshan	2010	6	18	36.949934	70.116616	Afghanistan	8	wet snow avalanche	N	0	0	0		
Ghumai & Shakardara, Maimai & Nusai, Badakhshan	2010	6	18	38.432174	70.801936	Afghanistan	6	wet snow avalanche	N	0	0	0		
Shuraki Kapali catchment	2010	9	NA	38.972831	70.840745	Tajikistan	6	glacier detachment	N	0	0	0		

Location	Year	Month	Day	Latitude	Longitude	Country	Region_HiMAP	Type	Impact	Fatalities	Injured	Livestock	Leisure	Remarks
Zodo Badoof, Arghanj Khaw, Badakhshan	2010	6	18	37.70279	71.10715	Afghanistan	6	wet snow avalanche	N	0	0	0		
Gharan, Ishkashim, Badakhshan	2010	3	11	36.708032	71.552187	Afghanistan	6	slab avalanche	N	0	0	0		
Kohistan	2010	2	16	35.411909	72.94035	Pakistan	8	snow avalanche	Y	120	72	NA		Families of 72 treated, Heavy snowfall
Gorno-Badakhshan	2010	2	6	38.474399	73.102399	Tajikistan	6	NA	Y	1	0	NA		one person died when hit by avalanche and tried to jump off the truck
Afghanistan	2012	1	23	36.949934	70.116616	Afghanistan	8	snow avalanche	Y	43	65	NA		
Afghanistan Fayzabad	2012	1	18	37.1175	70.579722	Afghanistan	6	snow avalanche	Y	29	40	NA		
Badakhshan	2012	3	4	38.2	70.933333	Afghanistan	6	snow avalanche	Y	196	NA	NA		death toll from 4th to 8th
Manikhawr, Shukai, Badakhshan	2012	6	18	38.199556	70.93725	Afghanistan	6	wet snow avalanche	N	0	NA	0		
Dad Ali, Arghanj Khaw, Badakhshan	2012	6	28	37.362794	71.131725	Afghanistan	6	wet snow avalanche	N	0	NA	0		
Shiduj Dara, Shighnan, Badakhshan	2012	3	19	37.690908	71.492748	Afghanistan	6	slab avalanche	N	0	NA	0		
Ners, Wakhan, Badakhshan	2012	3	20	36.982624	73.32445	Afghanistan	8	slab avalanche	N	0	NA	0		
Gayari Military Base, Ghanche	2012	4	7	35.498008	76.753358	Pakistan	9	ice and rock avalanche	Y	140	NA	NA		Indo-Pakistan border; 128 soldiers and 11 civilians
Kaicheng Town, Yuanzhou District	2012	6	5	36.210025	104.21308	China	22	NA	Y	10	NA	NA		
Chitral	2012	3	19	35.845718	71.809852	Pakistan	8	snow avalanche	Y	5	NA	NA		
Tajik Badhakshan	2012	3	19	38.474399	73.102399	Tajikistan	6	snow avalanche	Y	1	NA	50		
Gilgit	2012	3	19	35.856445	74.462647	Pakistan	8	snow avalanche	Y	4	3	NA		
Annapurna region	2014	10	14	28.673226	83.518843	Nepal	11	NA	Y	43	NA	NA		Not all died due to avalanches

Location	Year	Month	Day	Latitude	Longitude	Country	Region_HiMAP	Type	Impact	Fatalities	Injured	Livestock	Leisure	Remarks
Darwaza, Khenjan, Baghlan	2015	2	25	35.56925	68.90611	Afghanistan	8	slab avalanche	N	0	NA	0		
Zarsarag, Khenjan, Baghlan	2015	2	25	35.48399	68.941292	Afghanistan	8	slab avalanche	Y	0	1	0		1 persons injured
Malkhan, Khenjan, Baghlan	2015	2	25	35.475252	68.953564	Afghanistan	8	slab avalanche	Y	0	2	0		2 persons injured
youch, Banu, Baghlan	2015	2	26	35.361706	69.057838	Afghanistan	8	slab avalanche	Y	2	NA	0		
Mikhag, Banu, Baghlan	2015	2	26	35.614605	69.085274	Afghanistan	8	slab avalanche	Y	1	NA	0		
Kishan Abad, Banu, Baghlan	2015	2	26	35.619953	69.220108	Afghanistan	8	slab avalanche	Y	1	1	0		1 persons injured
Weghnan, Warsaj, Takhar	2015	3	3	36.008232	70.019539	Afghanistan	8	slab avalanche	N	0	NA	0		
Aspogh, Warsaj, Takhar	2015	3	3	35.948956	70.041901	Afghanistan	8	slab avalanche	N	0	NA	0		
Afghanistan	2015	2	24	35.576094	70.157491	Afghanistan	8	NA	Y	300	100	NA		198 casualties alone in Panjhsir Province, started from 24th Feb until early March
Chashma Angusht, Warsaj, Takhar	2015	3	3	36.122359	70.23306	Afghanistan	8	slab avalanche	N	0	NA	0		
Rubat Khombok, Tagab, Badakhshan	2015	3	4	36.559273	70.301048	Afghanistan	8	slab avalanche	Y	3	NA	0		
Wolgreen, Yawan, Badakhshan	2015	2	21	37.528028	70.378631	Afghanistan	6	slab avalanche	N	0	NA	0		
Khaibar, Darayim, Badakhshan	2015	1	7	36.872453	70.468836	Afghanistan	8	slab avalanche	Y	1	NA	0		
Shrinazm, Shukai, Badakhshan	2015	1	13	38.18705	70.56997	Afghanistan	6	slab avalanche	Y	3	5	0		5 persons injured
Khash, Yamgan, Badakhshan	2015	2	15	36.540119	70.667847	Afghanistan	8	slab avalanche	N	0	NA	0		
Munaw, Shukai, Badakhshan	2015	2	24	38.399106	70.692405	Afghanistan	6	slab avalanche	N	0	NA	0		
Kaj-Lar, Raghistan, Badakhshan	2015	2	21	37.702133	70.735718	Afghanistan	6	slab avalanche	Y	12	2	0		2 persons injured
Kalafzar, Yamgan,	2015	2	14	36.470431	70.776368	Afghanistan	8	slab avalanche	Y	5	NA	0		

Location	Year	Month	Day	Latitude	Longitude	Country	Region_HiMAP	Type	Impact	Fatalities	Injured	Livestock	Leisure	Remarks
Badakhshan														
Kalan Dara, Arghanj Khaw, Badakhshan	2015	2	23	37.349983	70.9095	Afghanistan	6	slab avalanche	N	0	NA	0		
Charsang, Arghanj Khaw, Badakhshan	2015	2	23	37.366943	70.940552	Afghanistan	6	slab avalanche	N	0	NA	0		
Charmaghzistan, Yamgan, Badakhshan	2015	2	19	36.520508	70.966665	Afghanistan	8	slab avalanche	N	0	NA	0		
Ghuzmurgh, Baharak, Badakhshan	2015	2	13	37.033821	71.027527	Afghanistan	6	slab avalanche	Y	2	3	0		3 persons injured
Jashtak, Maimai, Badakhshan	2015	1	12	38.397358	71.126916	Afghanistan	6	slab avalanche	Y	2	1	0		1 persons injured
Parabir, Maimai, Badakhshan	2015	2	26	37.88206	71.14417	Afghanistan	6	slab avalanche	Y	9	3	0		3 persons injured
Tanshive, Maimai, Badakhshan	2015	4	3	37.953445	71.201614	Afghanistan	6	wet snow avalanche	N	0	NA	0		
Eskitol, Zebak, Badakhshan	2015	2	26	36.414857	71.272312	Afghanistan	8	slab avalanche	Y	0	1	0		1 person injured
Besta Ched, Shighnan, Badakhshan	2015	2	21	37.364628	71.304352	Afghanistan	6	slab avalanche	N	0	NA	0		
Arakht, Shighnan, Badakhshan	2015	2	24	37.376715	71.412008	Afghanistan	6	slab avalanche	N	0	NA	0		
Zich, Ishkashim, Badakhshan	2015	2	16	37.077052	71.428276	Afghanistan	6	slab avalanche	N	0	NA	0		
Zich, Ishkashim, Badakhshan	2015	4	1	37.077052	71.428276	Afghanistan	6	wet snow avalanche	N	0	NA	0		
Yazgam, Shighnan, Badakhshan	2015	2	21	37.538081	71.445716	Afghanistan	6	slab avalanche	N	0	NA	0		
Andaj, Ishkashim, Badakhshan	2015	2	21	37.031037	71.448244	Afghanistan	6	slab avalanche	N	0	NA	0		
Bedarbun, Ishkashim,	2015	2	16	37.242458	71.470329	Afghanistan	6	slab avalanche	N	0	NA	0		

Location	Year	Month	Day	Latitude	Longitude	Country	Region_ HiMAP	Type	Impact	Fatalities	Injured	Livestock	Leisure	Remarks
Badakhshan														
Dakkhana, Shighnan, Badakhshan	2015	2	14	37.331601	71.480661	Afghanistan	6	slab avalanche	N	0	NA	0		
Chawgantrashan, Shighnan, Badakhshan	2015	3	3	37.428739	71.487789	Afghanistan	6	slab avalanche	N	0	NA	0		
Tebinak, Shughnan, Badakhshan	2015	2	15	37.295712	71.490486	Afghanistan	6	slab avalanche	N	0	NA	0		
Tirive (Weyer), Shighnan, Badakhshan	2015	2	21	37.608561	71.500956	Afghanistan	6	slab avalanche	N	0	NA	0		
Tirive (Dehshar), Shighnan, Badakhshan	2015	2	21	37.608561	71.500956	Afghanistan	6	slab avalanche	N	0	NA	0		
Wereezn (Shighnan), Shighnan, Badakhshan	2015	2	21	37.650397	71.52035	Afghanistan	6	slab avalanche	N	0	NA	0		
Nawadak, Shighnan, Badakhshan	2015	2	22	37.754768	71.533969	Afghanistan	6	slab avalanche	N	0	NA	0		
GBAO	2015	1	14	38.474399	73.102399	Tajikistan	6	NA	Y	10	1	NA		avalanche incidents since Jan 14
Langtang	2015	4	25	28.237596	85.498829	Nepal	11	ice and rock avalanche	Y	350	NA	1000		Triggered by Gorkha earthquake and completely destroyed Langtang Village
Ghazwin, Kufab, Badakhshan	2016	4	22	38.04121	70.478759	Afghanistan	6	wet snow avalanche	Y	0	NA	2		
Mashtive, Shukai, Badakhshan	2016	1	8	38.12314	70.61495	Afghanistan	6	slab avalanche	N	0	NA	0		
Dehkha, Shukai, Badakhshan	2016	12	28	38.35055	70.662524	Afghanistan	6	slab avalanche	N	0	NA	0		
Shuraki Kapali catchment	2016	8	28	38.972	70.835	Tajikistan	6	glacier detachment	Y	0	0	0		swept away few cattles, destroyed 10 buildings, bridge, avalanche passes through the villages of

Location	Year	Month	Day	Latitude	Longitude	Country	Region_HiMAP	Type	Impact	Fatalities	Injured	Livestock	Leisure	Remarks
														Fathobod and Kapali
Shuraki Kapali catchment	2016	7	NA	38.969984	70.845789	Tajikistan	6	glacier detachment	N	0	0	0		
Zood Raban, Arghanj Khaw, Badakhshan	2016	1	13	37.70279	71.10715	Afghanistan	6	slab avalanche	Y	3	NA	0		
Begaw (Warv), Maimai, Badakhshan	2016	12	29	38.164165	71.274468	Afghanistan	6	slab avalanche	N	0	NA	0		
Pishprind, Shughnan, Badakhshan	2016	2	10	37.616856	71.449766	Afghanistan	6	slab avalanche	N	0	NA	0		
Dakkhana, Shighnan, Badakhshan	2016	2	10	37.331601	71.480661	Afghanistan	6	slab avalanche	N	0	NA	0		
Siachen Glacier	2016	2	3	35.452442	77.085467	India	9	NA	Y	10	NA	0		
Aru-1	2016	7	17	34.02	82.25	China	16	glacier detachment	Y	9	NA	100		>100 yaks killed
Aru-2	2016	9		34	82.265	China	16	glacier detachment	N	0	NA	0		
2016 Karnali avalanche	2016	NA	NA	29.43017	83.095098	Nepal	11	NA	Y	16	NA	NA		Yarsagumba pickers hit by an avalanche
Amney Machen	2016	10		34.82	99.44	China	21	glacier detachment	N	0	NA	0		happened between 4 - 7 Oct
Anzob	2017	1	29	39.272888	68.541344	Tajikistan	5	NA	Y	7	NA			
Toot Darra, Darayim, Badakhshan	2017	2	15	36.870641	70.489682	Afghanistan	8	slab avalanche	N	0	NA	0		
Rawand (Nusai), Nusai, Badakhshan	2017	2	18	38.16884	70.50885	Afghanistan	6	slab avalanche	N	0	NA	0		
Munaw, Shukai, Badakhshan	2017	1	30	38.399106	70.692405	Afghanistan	6	slab avalanche	N	0	NA	0		
Khawand, Shukai, Badakhshan	2017	2	11	38.368839	70.693923	Afghanistan	6	slab avalanche	N	0	NA	0		
Purtel, Shukai, Badakhshan	2017	1	28	38.329088	70.707453	Afghanistan	6	slab avalanche	N	0	NA	0		

Location	Year	Month	Day	Latitude	Longitude	Country	Region_ HiMAP	Type	Impact	Fatalities	Injured	Livestock	Leisure	Remarks
Purtel, Shukai, Badakhshan	2017	1	28	38.329088	70.707453	Afghanistan	6	slab avalanche	N	0	NA	0		
Purtel, Shukai, Badakhshan	2017	2	4	38.329088	70.707453	Afghanistan	6	slab avalanche	N	0	NA	0		
Purtel, Shukai, Badakhshan	2017	2	4	38.329088	70.707453	Afghanistan	6	slab avalanche	N	0	NA	0		
Meyandeh (Nusai), Nusai, Badakhshan	2017	2	15	38.329088	70.707453	Afghanistan	6	slab avalanche	N	0	NA	0		
Purtel, Shukai, Badakhshan	2017	3	21	38.329088	70.707453	Afghanistan	6	slab avalanche	N	0	NA	0		
Meyandeh (Nusai), Nusai, Badakhshan	2017	3	21	38.329088	70.707453	Afghanistan	6	slab avalanche	N	0	NA	0		
Khahdara, Shukai, Badakhshan	2017	2	18	38.323751	70.723864	Afghanistan	6	slab avalanche	N	0	NA	0		
Khahdara, Shukai, Badakhshan	2017	6	5	38.323751	70.723864	Afghanistan	6	wet snow avalanche	Y	0	NA	40		
Bishkharw (Monikharw), Nusai, Badakhshan	2017	2	4	38.28018	70.80021	Afghanistan	6	slab avalanche	N	0	NA	0		
Dara-e-Baghar, Nusai, Badakhshan	2017	2	5	38.44258	70.80021	Afghanistan	6	slab avalanche	Y	0	NA	8		
Nusai Center, Nusai, Badakhshan	2017	1	30	38.443277	70.805036	Afghanistan	6	slab avalanche	N	0	NA	0		
Sari Jaway, Nusai, Badakhshan	2017	2	15	38.443056	70.805556	Afghanistan	6	slab avalanche	N	0	NA	0		
Badamak, Nusai, Badakhshan	2017	2	15	38.443056	70.805556	Afghanistan	6	slab avalanche	N	0	NA	0		
Badshar, Nusai, Badakhshan	2017	2	19	38.443056	70.805556	Afghanistan	6	slab avalanche	N	0	NA	0		
Meyanadeh, Shukai, Badakhshan	2017	2	4	38.28142	70.81297	Afghanistan	6	slab avalanche	Y	0	3	0		3 persons injured

Location	Year	Month	Day	Latitude	Longitude	Country	Region_ HiMAP	Type	Impact	Fatalities	Injured	Livestock	Leisure	Remarks
Khughaz, Nusai, Badakhshan	2017	1	30	38.413002	70.839546	Afghanistan	6	slab avalanche	N	0	NA	0		
Aroon, Nusai, Badakhshan	2017	1	29	38.30569	70.83967	Afghanistan	6	slab avalanche	N	0	NA	0		
Aroon, Nusai, Badakhshan	2017	2	16	38.30569	70.83967	Afghanistan	6	slab avalanche	N	0	NA	0		
Sedya-e-Payan, Nusai, Badakhshan	2017	2	5	38.314666	70.841185	Afghanistan	6	slab avalanche	N	0	NA	0		
Rasht	2017	7	10	38.975	70.85	Tajikistan	6	glacier detachment	N	0	0	0		in between 10-11 July
Rawand (Nusai), Nusai, Badakhshan	2017	1	29	38.330876	70.85293	Afghanistan	6	slab avalanche	N	0	NA	0		
Rawand (Nusai), Nusai, Badakhshan	2017	2	5	38.330876	70.85293	Afghanistan	6	slab avalanche	Y	0	4	0		4 persons injured
Parkhekh, Nusai, Badakhshan	2017	2	16	38.333841	70.863748	Afghanistan	6	slab avalanche	N	0	NA	0		
Parkhekh, Nusai, Badakhshan	2017	2	16	38.333841	70.863748	Afghanistan	6	slab avalanche	N	0	NA	0		
Ullarep, Jurm, Badakhshan	2017	2	1	36.805258	70.865907	Afghanistan	8	slab avalanche	N	0	NA	0		
Nuristan	2017	2	4	35.317202	70.898674	Afghanistan	8	NA	Y	137	NA	NA		
Arward, Nusai, Badakhshan	2017	3	26	38.338389	70.910459	Afghanistan	6	slab avalanche	Y	0	NA	15		
Ubaghn, Nusai, Badakhshan	2017	1	24	38.428811	70.930509	Afghanistan	6	slab avalanche	N	0	NA	0		
Ubaghn, Nusai, Badakhshan	2017	3	21	38.428811	70.930509	Afghanistan	6	slab avalanche	N	0	NA	0		
Ubaghn, Nusai, Badakhshan	2017	4	1	38.428811	70.930509	Afghanistan	6	wet snow avalanche	N	0	NA	0		
Ubaghn, Nusai, Badakhshan	2017	2	5	38.428811	70.930509	Afghanistan	6	slab avalanche	Y	0	NA	3		
Kughaz, Maimai, Badakhshan	2017	3	25	38.390667	71.070821	Afghanistan	6	slab avalanche	N	0	NA	0		

Location	Year	Month	Day	Latitude	Longitude	Country	Region_HiMAP	Type	Impact	Fatalities	Injured	Livestock	Leisure	Remarks
Rawand Sharist, Maimai, Badakhshan	2017	1	30	37.82732	71.09526	Afghanistan	6	slab avalanche	N	0	NA	0		
Rawand Sharist, Maimai, Badakhshan	2017	2	16	37.82732	71.09526	Afghanistan	6	slab avalanche	N	0	NA	0		
Payanshar, Maimai, Badakhshan	2017	2	17	38.388904	71.125436	Afghanistan	6	slab avalanche	N	0	NA	0		
Panjai Mard, Maimai, Badakhshan	2017	2	15	37.879683	71.135401	Afghanistan	6	slab avalanche	N	0	NA	0		
Panjai Mard, Maimai, Badakhshan	2017	2	15	37.879683	71.135401	Afghanistan	6	slab avalanche	N	0	NA	0		
Panjai Mard, Maimai, Badakhshan	2017	2	15	37.879683	71.135401	Afghanistan	6	slab avalanche	N	0	NA	0		
Panjai Mard, Maimai, Badakhshan	2017	2	15	37.879683	71.135401	Afghanistan	6	slab avalanche	N	0	NA	0		
Panjai Mard, Maimai, Badakhshan	2017	2	18	37.879683	71.135401	Afghanistan	6	slab avalanche	N	0	NA	0		
Panjai Mard, Maimai, Badakhshan	2017	2	18	37.879683	71.135401	Afghanistan	6	slab avalanche	N	0	NA	0		
Panjai Mard, Maimai, Badakhshan	2017	2	18	37.879683	71.135401	Afghanistan	6	slab avalanche	N	0	NA	0		
Mah-e-naw, Maimai, Badakhshan	2017	1	29	38.378548	71.136441	Afghanistan	6	slab avalanche	N	0	NA	0		
Mah-e-naw, Maimai, Badakhshan	2017	1	30	38.378548	71.136441	Afghanistan	6	slab avalanche	N	0	NA	0		
Mah-e-naw, Maimai, Badakhshan	2017	2	1	38.378548	71.136441	Afghanistan	6	slab avalanche	N	0	NA	0		
Mah-e-naw, Maimai, Badakhshan	2017	2	17	38.378548	71.136441	Afghanistan	6	slab avalanche	N	0	NA	0		

Location	Year	Month	Day	Latitude	Longitude	Country	Region_HiMAP	Type	Impact	Fatalities	Injured	Livestock	Leisure	Remarks
Mah-e-naw, Maimai, Badakhshan	2017	2	17	38.378548	71.136441	Afghanistan	6	slab avalanche	N	0	NA	0		
Mah-e-naw, Maimai, Badakhshan	2017	2	16	38.378548	71.136441	Afghanistan	6	slab avalanche	Y	0	NA	10		
Mah-e-naw, Maimai, Badakhshan	2017	2	18	38.378548	71.136441	Afghanistan	6	slab avalanche	Y	0	NA	23		
Parabir(Khizraw), Maimai, Badakhshan	2017	1	29	37.88206	71.14417	Afghanistan	6	slab avalanche	N	0	NA	0		
Parabir, Maimai, Badakhshan	2017	1	30	37.88206	71.14417	Afghanistan	6	slab avalanche	N	0	NA	0		
Rawand (Nusai), Nusai, Badakhshan	2017	1	30	37.88206	71.14417	Afghanistan	6	slab avalanche	N	0	NA	0		
Parabir(Khizraw), Maimai, Badakhshan	2017	2	15	37.88206	71.14417	Afghanistan	6	slab avalanche	N	0	NA	0		
Parabir, Maimai, Badakhshan	2017	2	18	37.88206	71.14417	Afghanistan	6	slab avalanche	N	0	NA	0		
Parabir, Maimai, Badakhshan	2017	2	19	37.88206	71.14417	Afghanistan	6	slab avalanche	N	0	NA	0		
Dara-e-Sher, Maimai, Badakhshan	2017	2	6	38.001648	71.167819	Afghanistan	6	slab avalanche	N	0	NA	0		
Sanglizh, Zebak, Badakhshan	2017	1	30	36.30173	71.187488	Afghanistan	8	slab avalanche	N	0	NA	0		
Dara-e-Sher, Maimai, Badakhshan	2017	2	16	37.95532	71.2004	Afghanistan	6	slab avalanche	N	0	NA	0		
Dara-e-Sher, Maimai, Badakhshan	2017	2	16	37.95532	71.2004	Afghanistan	6	slab avalanche	N	0	NA	0		
Dara-e-Sher, Maimai, Badakhshan	2017	2	16	37.95532	71.2004	Afghanistan	6	slab avalanche	N	0	NA	0		
Aylaq-i-Khodun (Tupdara 2)(DaraiSher),	2017	1	29	37.954739	71.20047	Afghanistan	6	slab avalanche	N	0	NA	0		

Location	Year	Month	Day	Latitude	Longitude	Country	Region_HiMAP	Type	Impact	Fatalities	Injured	Livestock	Leisure	Remarks
Maimai, Badakhshan														
Aylaq-i-Khodun (Tupdara 2)(DaraiSher), Maimai, Badakhshan	2017	2	6	37.954739	71.20047	Afghanistan	6	slab avalanche	N	0	NA	0		
Sarchashma, Maimai, Badakhshan	2017	2	19	38.053949	71.222429	Afghanistan	6	slab avalanche	N	0	NA	0		
Sarchashma, Maimai, Badakhshan	2017	2	15	38.053949	71.222429	Afghanistan	6	slab avalanche	Y	0	6	0		6 persons injured
Barghud, Maimai, Badakhshan	2017	2	4	38.155406	71.23988	Afghanistan	6	slab avalanche	Y	10	12	0		12 persons injured
Zhambyl	2017	2	17	42.915143	71.251291	Kazakhstan	NA	NA	Y	7	NA	NA		
Begaw, Maimai, Badakhshan	2017	2	16	38.164165	71.274468	Afghanistan	6	slab avalanche	N	0	NA	0		
Qala, Maimai, Badakhshan	2017	2	19	38.140234	71.285789	Afghanistan	6	slab avalanche	N	0	NA	0		
Rawand (Maimai), Maimai, Badakhshan	2017	1	29	38.044203	71.287688	Afghanistan	6	slab avalanche	N	0	NA	0		
Rawand (Maimai), Maimai, Badakhshan	2017	2	16	38.044203	71.287688	Afghanistan	6	slab avalanche	N	0	NA	0		
Chasnood Payan, Shighnan, Badakhshan	2017	1	28	37.922298	71.287994	Afghanistan	6	slab avalanche	N	0	NA	0		
Dara-i-Gushdar-Raghsunyak, Maimai, Badakhshan	2017	1	28	38.264139	71.315569	Afghanistan	6	slab avalanche	N	0	NA	0		
Shaikha, Shighnan, Badakhshan	2017	2	9	37.845228	71.332468	Afghanistan	6	slab avalanche	N	0	NA	0		
Shaikha, Shighnan, Badakhshan	2017	2	15	37.845228	71.332468	Afghanistan	6	slab avalanche	N	0	NA	0		
Shaikha, Shighnan, Badakhshan	2017	2	15	37.845228	71.332468	Afghanistan	6	slab avalanche	N	0	NA	0		

Location	Year	Month	Day	Latitude	Longitude	Country	Region_HiMAP	Type	Impact	Fatalities	Injured	Livestock	Leisure	Remarks
Shaikha, Shighnan, Badakhshan	2017	2	15	37.845228	71.332468	Afghanistan	6	slab avalanche	N	0	NA	0		
Shaikha, Shighnan, Badakhshan	2017	2	17	37.845228	71.332468	Afghanistan	6	slab avalanche	N	0	NA	0		
Amurn, Maimai, Badakhshan	2017	1	28	38.195824	71.3588	Afghanistan	6	slab avalanche	N	0	NA	0		
Chawid, Shighnan, Badakhshan	2017	2	15	37.900395	71.378387	Afghanistan	6	slab avalanche	N	0	NA	0		
Arakht, Shighnan, Badakhshan	2017	1	30	37.376715	71.412008	Afghanistan	6	slab avalanche	N	0	NA	0		
Arakht, Shighnan, Badakhshan	2017	2	16	37.376715	71.412008	Afghanistan	6	slab avalanche	N	0	NA	0		
Arakht, Shighnan, Badakhshan	2017	2	18	37.376715	71.412008	Afghanistan	6	slab avalanche	N	0	NA	0		
Arakht, Shighnan, Badakhshan	2017	2	18	37.376715	71.412008	Afghanistan	6	slab avalanche	N	0	NA	0		
Arakht, Shighnan, Badakhshan	2017	2	18	37.376715	71.412008	Afghanistan	6	slab avalanche	N	0	NA	0		
Arakht, Shighnan, Badakhshan	2017	2	18	37.376715	71.412008	Afghanistan	6	slab avalanche	N	0	NA	0		
Showaldara, Ishkashim, Badakhshan	2017	1	28	36.664534	71.424921	Afghanistan	6	slab avalanche	N	0	NA	0		
Zich, Ishkashim, Badakhshan	2017	1	29	37.077052	71.428276	Afghanistan	6	slab avalanche	N	0	NA	0		
Zich, Ishkashim, Badakhshan	2017	3	20	37.077052	71.428276	Afghanistan	6	slab avalanche	N	0	NA	0		
Gharjween, Shighnan, Badakhshan	2017	2	18	37.473246	71.437659	Afghanistan	6	slab avalanche	N	0	NA	0		
Yazgam, Shighnan, Badakhshan	2017	1	28	37.538081	71.445716	Afghanistan	6	slab avalanche	N	0	NA	0		
Yazgam, Shighnan, Badakhshan	2017	2	16	37.538081	71.445716	Afghanistan	6	slab avalanche	N	0	NA	0		

Location	Year	Month	Day	Latitude	Longitude	Country	Region_HiMAP	Type	Impact	Fatalities	Injured	Livestock	Leisure	Remarks
Yazgam, Shighnan, Badakhshan	2017	2	16	37.538081	71.445716	Afghanistan	6	slab avalanche	N	0	NA	0		
Yazgam, Shighnan, Badakhshan	2017	2	16	37.538081	71.445716	Afghanistan	6	slab avalanche	N	0	NA	0		
Yazgam, Shighnan, Badakhshan	2017	2	16	37.538081	71.445716	Afghanistan	6	slab avalanche	N	0	NA	0		
Pajwar, Shighnan, Badakhshan	2017	2	16	37.91226	71.44637	Afghanistan	6	slab avalanche	N	0	NA	0		
Meyandeh (Nusai), Nusai, Badakhshan	2017	1	30	37.332659	71.45955	Afghanistan	6	slab avalanche	N	0	NA	0		
Meyandeh (Nusai), Nusai, Badakhshan	2017	3	22	37.332659	71.45955	Afghanistan	6	slab avalanche	N	0	NA	0		
Meyanbar 1, Shighnan, Badakhshan	2017	3	28	37.332659	71.45955	Afghanistan	6	slab avalanche	Y	2	NA	0		
Gulbagh, Ishkashim, Badakhshan	2017	1	29	37.223078	71.460353	Afghanistan	6	slab avalanche	N	0	NA	0		
Shahran (Shighnan), Shighnan, Badakhshan	2017	1	28	37.405704	71.473986	Afghanistan	6	slab avalanche	N	0	NA	0		
Meyanshahr, Shighnan, Badakhshan	2017	2	17	37.486419	71.476315	Afghanistan	6	slab avalanche	N	0	NA	0		
Meyanshahr, Shighnan, Badakhshan	2017	2	18	37.486419	71.476315	Afghanistan	6	slab avalanche	N	0	NA	0		
Meyanshahr, Shighnan, Badakhshan	2017	2	18	37.486419	71.476315	Afghanistan	6	slab avalanche	N	0	NA	0		
Meyanshahr, Shighnan, Badakhshan	2017	2	18	37.486419	71.476315	Afghanistan	6	slab avalanche	N	0	NA	0		
Dakkhana, Shighnan, Badakhshan	2017	1	24	37.331601	71.480661	Afghanistan	6	slab avalanche	N	0	NA	0		
Dakkhana, Shighnan,	2017	1	28	37.331601	71.480661	Afghanistan	6	slab avalanche	N	0	NA	0		

Location	Year	Month	Day	Latitude	Longitude	Country	Region_ HiMAP	Type	Impact	Fatalities	Injured	Livestock	Leisure	Remarks
Badakhshan														
Khushpaki Payan, Ishkashim , Badakhshan	2017	2	9	36.660712	71.483049	Afghanistan	6	slab avalanche	N	0	NA	0		
Tebenak(Darmarakht), Shighnan, Badakhshan	2017	3	22	37.33333	71.483333	Afghanistan	6	slab avalanche	N	0	NA	0		
Meyandeh (Nusai), Nusai, Badakhshan	2017	3	27	37.476245	71.483743	Afghanistan	6	slab avalanche	N	0	NA	0		
Lachid-Parviz-Bezokh, Shighnan, Badakhshan	2017	2	19	37.556895	71.48441	Afghanistan	6	slab avalanche	N	0	NA	0		
Walij, Ishkashim , Badakhshan	2017	2	4	36.917685	71.485569	Afghanistan	6	slab avalanche	N	0	NA	0		
Bawer Rejistak, Shighnan, Badakhshan	2017	2	19	37.561206	71.486401	Afghanistan	6	slab avalanche	N	0	NA	0		
Chawgantrashan, Shighnan, Badakhshan	2017	2	19	37.428739	71.487789	Afghanistan	6	slab avalanche	N	0	NA	0		
Shiduj Dara, Shighnan, Badakhshan	2017	2	15	37.690908	71.492748	Afghanistan	6	slab avalanche	Y	1	12	0		12 persons injured
Tirive (Dehshar) , Shighnan, Badakhshan	2017	2	16	37.608561	71.500956	Afghanistan	6	slab avalanche	N	0	NA	0		
Wereezn (Shighnan), Shighnan, Badakhshan	2017	1	28	37.650397	71.52035	Afghanistan	6	slab avalanche	N	0	NA	0		
Wereezn (Shighnan), Shighnan, Badakhshan	2017	1	30	37.650397	71.52035	Afghanistan	6	slab avalanche	N	0	NA	0		
Wereezn (Shighnan), Shighnan, Badakhshan	2017	2	8	37.650397	71.52035	Afghanistan	6	slab avalanche	N	0	NA	0		

Location	Year	Month	Day	Latitude	Longitude	Country	Region_HiMAP	Type	Impact	Fatalities	Injured	Livestock	Leisure	Remarks
Wereezn (Shighnan), Shighnan, Badakhshan	2017	2	8	37.650397	71.52035	Afghanistan	6	slab avalanche	N	0	NA	0		
Wereezn (Shighnan), Shighnan, Badakhshan	2017	2	8	37.650397	71.52035	Afghanistan	6	slab avalanche	N	0	NA	0		
Wereezn (Shighnan), Shighnan, Badakhshan	2017	2	15	37.650397	71.52035	Afghanistan	6	slab avalanche	N	0	NA	0		
Wereezn (Shighnan), Shighnan, Badakhshan	2017	2	16	37.650397	71.52035	Afghanistan	6	slab avalanche	N	0	NA	0		
Khawar, Shighnan, Badakhshan	2017	2	19	37.686437	71.53385	Afghanistan	6	slab avalanche	N	0	NA	0		
Rubat (Shighnan), Shighnan, Badakhshan	2017	1	15	37.838971	71.583859	Afghanistan	6	slab avalanche	N	0	NA	0		
Rubat (Shighnan), Shighnan, Badakhshan	2017	1	28	37.838971	71.583859	Afghanistan	6	slab avalanche	N	0	NA	0		
Rubat (Shighnan), Shighnan, Badakhshan	2017	2	18	37.838971	71.583859	Afghanistan	6	slab avalanche	N	0	NA	0		
Archa, Wakhan, Badakhshan	2017	3	22	36.991545	73.229118	Afghanistan	8	slab avalanche	N	0	NA	0		
Ners, Wakhan, Badakhshan	2017	2	5	36.982624	73.32445	Afghanistan	8	slab avalanche	N	0	NA	0		
Gurez Sector	2017	1	25	34.634041	74.773255	India	10	NA	Y	24	NA	NA		20 soldiers and 4 civilians, some remain missing
Pithoragarh	2017	3	11	30.098666	80.800212	India	11	NA	Y	3	NA	NA		1 missing
Darchula avalanche	2017	6	1	29.85797	80.938675	Nepal	11	NA	Y	1	6	NA		6 injured, Yarsagumba picker
Okta, Dolpa avalanche	2017	3	11	29.07739	82.44277	Nepal	11	NA	Y	0	NA	8		8 horses and mules
Dolpa avalanche	2017	3	11	28.840926	83.059938	Nepal	11	NA	Y	1	1	NA		1 injured

Location	Year	Month	Day	Latitude	Longitude	Country	Region_HiMAP	Type	Impact	Fatalities	Injured	Livestock	Leisure	Remarks
NA	2017	2	19	NA	NA	Kyrgyzstan	5	snow avalanche	Y	3	NA	NA		
NA	2017	2	19	NA	NA	Tajikistan	6	snow avalanche	Y	5	NA	NA		
Shrinazm, Shukai, Badakhshan	2018	2	15	38.18705	70.56997	Afghanistan	6	slab avalanche	N	0	NA	0		
Shrinazm, Shukai, Badakhshan	2018	2	15	38.18705	70.56997	Afghanistan	6	slab avalanche	N	0	NA	0		
Zangeryai-Bala, Shukai, Badakhshan	2018	2	15	38.31179	70.60809	Afghanistan	6	slab avalanche	N	0	NA	0		
Ghumai, Shukai, Badakhshan	2018	2	14	38.287149	70.608765	Afghanistan	6	slab avalanche	N	0	NA	0		
Narghawn, Shukai, Badakhshan	2018	2	16	38.414351	70.689639	Afghanistan	6	slab avalanche	N	0	NA	0		
Munaw, Shukai, Badakhshan	2018	2	15	38.399106	70.692405	Afghanistan	6	slab avalanche	N	0	NA	0		
Munaw, Shukai, Badakhshan	2018	12	31	38.399106	70.692405	Afghanistan	6	slab avalanche	N	0	NA	0		
Khawand, Shukai, Badakhshan	2018	2	14	38.368839	70.693923	Afghanistan	6	slab avalanche	N	0	NA	0		
Khawand, Shukai, Badakhshan	2018	2	16	38.368839	70.693923	Afghanistan	6	slab avalanche	N	0	NA	0		
Purtel, Shukai, Badakhshan	2018	2	15	38.329088	70.707453	Afghanistan	6	slab avalanche	N	0	NA	0		
Dwak, Shukai, Badakhshan	2018	2	16	38.415398	70.729414	Afghanistan	6	slab avalanche	N	0	NA	0		
Dwak, Shukai, Badakhshan	2018	3	12	38.415398	70.729414	Afghanistan	6	slab avalanche	N	0	NA	0		
Nusai Center, Nusai, Badakhshan	2018	2	16	38.443277	70.805036	Afghanistan	6	slab avalanche	N	0	NA	0		
Meyandeh (Nusai), Nusai, Badakhshan	2018	2	15	38.280395	70.812735	Afghanistan	6	slab avalanche	N	0	NA	0		
Kerawar (Jawaidara), Nusai, Badakhshan	2018	2	16	38.291296	70.821109	Afghanistan	6	slab avalanche	N	0	NA	0		

Location	Year	Month	Day	Latitude	Longitude	Country	Region_HiMAP	Type	Impact	Fatalities	Injured	Livestock	Leisure	Remarks
Kerawar (Jawaidara), Nusai, Badakhshan	2018	2	16	38.291296	70.821109	Afghanistan	6	slab avalanche	N	0	NA	0		
Ubaghn, Nusai, Badakhshan	2018	2	16	38.428811	70.930509	Afghanistan	6	slab avalanche	N	0	NA	0		
Ubaghn, Nusai, Badakhshan	2018	2	16	38.428811	70.930509	Afghanistan	6	slab avalanche	N	0	NA	0		
Sakhachwa Zonun, Nusai, Badakhshan	2018	2	16	38.42942	70.930809	Afghanistan	6	slab avalanche	N	0	NA	0		
Jogani, Nusai, Badakhshan	2018	2	16	38.42942	70.930809	Afghanistan	6	slab avalanche	N	0	NA	0		
Rizway, Maimai, Badakhshan	2018	2	16	38.443704	71.032582	Afghanistan	6	slab avalanche	N	0	NA	0		
Dehkha, Shukai, Badakhshan	2018	2	14	37.65236	71.03805	Afghanistan	6	slab avalanche	N	0	NA	0		
Dehkha, Shukai, Badakhshan	2018	2	16	37.65236	71.03805	Afghanistan	6	slab avalanche	N	0	NA	0		
Dehkha, Shukai, Badakhshan	2018	3	13	37.65236	71.03805	Afghanistan	6	slab avalanche	N	0	NA	0		
Charbagh, Maimai, Badakhshan	2018	2	16	38.403944	71.050962	Afghanistan	6	slab avalanche	N	0	NA	0		
Sarchashma, Maimai, Badakhshan	2018	2	27	38.395201	71.062692	Afghanistan	6	slab avalanche	N	0	NA	0		
Rawand Sharist, Maimai, Badakhshan	2018	2	15	37.82732	71.09526	Afghanistan	6	slab avalanche	N	0	NA	0		
Madakhirs, Maimai, Badakhshan	2018	2	15	37.891129	71.148026	Afghanistan	6	slab avalanche	N	0	NA	0		
Dara-e-Sher, Maimai, Badakhshan	2018	2	15	37.987648	71.235256	Afghanistan	6	slab avalanche	N	0	NA	0		
Barghud, Maimai, Badakhshan	2018	2	15	38.155406	71.23988	Afghanistan	6	slab avalanche	N	0	NA	0		
Chasnood Payan, Shighnan,	2018	2	15	37.922298	71.287994	Afghanistan	6	slab avalanche	N	0	NA	0		

Location	Year	Month	Day	Latitude	Longitude	Country	Region_HiMAP	Type	Impact	Fatalities	Injured	Livestock	Leisure	Remarks
Badakhshan														
Yarkh, Shighnan, Badakhshan	2018	2	15	37.901831	71.31513	Afghanistan	6	slab avalanche	N	0	NA	0		
Yarkh, Shighnan, Badakhshan	2018	2	15	37.901831	71.31513	Afghanistan	6	slab avalanche	N	0	NA	0		
Dara-i-Gushdar-Raghsunyak, Maimai, Badakhshan	2018	2	16	38.269192	71.324997	Afghanistan	6	slab avalanche	N	0	NA	0		
Chawid, Shighnan, Badakhshan	2018	2	15	37.900395	71.378387	Afghanistan	6	slab avalanche	N	0	NA	0		
Arakht, Shighnan, Badakhshan	2018	2	15	37.376715	71.412008	Afghanistan	6	slab avalanche	N	0	NA	0		
Arakht, Shighnan, Badakhshan	2018	2	15	37.376715	71.412008	Afghanistan	6	slab avalanche	N	0	NA	0		
Arakht, Shighnan, Badakhshan	2018	2	16	37.376715	71.412008	Afghanistan	6	slab avalanche	N	0	NA	0		
Arakht, Shighnan, Badakhshan	2018	2	16	37.376715	71.412008	Afghanistan	6	slab avalanche	N	0	NA	0		
Arakht, Shighnan, Badakhshan	2018	2	16	37.376715	71.412008	Afghanistan	6	slab avalanche	N	0	NA	0		
Arakht, Shighnan, Badakhshan	2018	2	16	37.376715	71.412008	Afghanistan	6	slab avalanche	N	0	NA	0		
Yazgam, Shighnan, Badakhshan	2018	2	15	37.538081	71.445716	Afghanistan	6	slab avalanche	N	0	NA	0		
Yazgam, Shighnan, Badakhshan	2018	2	16	37.538081	71.445716	Afghanistan	6	slab avalanche	N	0	NA	0		
Andaj, Ishkashim, Badakhshan	2018	12	29	37.031037	71.448244	Afghanistan	6	slab avalanche	Y	1	NA	0		
Fenjan, Shighnan, Badakhshan	2018	2	15	37.342552	71.45874	Afghanistan	6	slab avalanche	N	0	NA	0		
Dakkhana, Shighnan, Badakhshan	2018	2	15	37.331601	71.480661	Afghanistan	6	slab avalanche	N	0	NA	0		
Dakkhana, Shighnan,	2018	2	15	37.331601	71.480661	Afghanistan	6	slab avalanche	N	0	NA	0		

Location	Year	Month	Day	Latitude	Longitude	Country	Region_HiMAP	Type	Impact	Fatalities	Injured	Livestock	Leisure	Remarks
Badakhshan														
Tirive (Weyer), Shighnan, Badakhshan	2018	2	15	37.608561	71.500956	Afghanistan	6	slab avalanche	N	0	NA	0		
Tirive (Weyer), Shighnan, Badakhshan	2018	2	15	37.608561	71.500956	Afghanistan	6	slab avalanche	N	0	NA	0		
Deshar, Shighnan, Badakhshan	2018	2	15	37.614479	71.504311	Afghanistan	6	slab avalanche	N	0	NA	0		
Rubat (Shighnan), Shighnan, Badakhshan	2018	1	29	37.838971	71.583859	Afghanistan	6	slab avalanche	N	0	NA	0		
Rubat (Shighnan), Shighnan, Badakhshan	2018	2	15	37.838971	71.583859	Afghanistan	6	slab avalanche	N	0	NA	0		
Rubat (Shighnan), Shighnan, Badakhshan	2018	2	17	37.838971	71.583859	Afghanistan	6	slab avalanche	N	0	NA	0		
Kashmir avalanches	2018	1	5	34.409163	74.098664	India	10	NA	Y	11	2	NA		2 people rescued, near simultaneous avalanches at 3 places in a stretch of about 10 km
Gurja base camp	2018	10	12	28.665882	83.300291	Nepal	11	powder snow avalanche	Y	9	NA	0	Y	
Lirung avalanche	2018	11		28.237891	85.536642	Nepal	11	powder snow avalanche	N	0	NA	0		
Toot Darra, Darayim, Badakhshan	2019	1	9	36.870641	70.489682	Afghanistan	8	slab avalanche	N	0	NA	0		
Toot Darra, Darayim, Badakhshan	2019	1	9	36.870641	70.489682	Afghanistan	8	slab avalanche	N	0	NA	0		
Shrinazm, Shukai, Badakhshan	2019	1	19	38.18705	70.56997	Afghanistan	6	slab avalanche	N	0	NA	0		
Ghumai, Shukai, Badakhshan	2019	1	8	38.287149	70.608765	Afghanistan	6	slab avalanche	N	0	NA	0		

Location	Year	Month	Day	Latitude	Longitude	Country	Region_HiMAP	Type	Impact	Fatalities	Injured	Livestock	Leisure	Remarks
Ghumai, Shukai, Badakhshan	2019	3	28	38.287149	70.608765	Afghanistan	6	slab avalanche	N	0	NA	0		
Rasht	2019	8	2	38.989	70.693	Tajikistan	6	glacier detachment	N	0	0	NA		between 2-3 August, avalanche stopped only 2.6km outside the village Degilmoni Poyon
Khawand, Shukai, Badakhshan	2019	1	5	38.368839	70.693923	Afghanistan	6	slab avalanche	N	0	NA	0		
Khawand, Shukai, Badakhshan	2019	3	19	38.368839	70.693923	Afghanistan	6	slab avalanche	N	0	NA	0		
Khawand, Shukai, Badakhshan	2019	3	28	38.368839	70.693923	Afghanistan	6	slab avalanche	N	0	NA	0		
Dwak, Shukai, Badakhshan	2019	3	28	38.415398	70.729414	Afghanistan	6	slab avalanche	N	0	NA	0		
Darjway, Nusai, Badakhshan	2019	1	12	38.44258	70.80021	Afghanistan	6	slab avalanche	Y	1	NA	0		
wodab Shuriyan, Nusai, Badakhshan	2019	1	25	38.438915	70.809476	Afghanistan	6	slab avalanche	N	0	NA	0		
Khurkat-Shuriyan, Nusai, Badakhshan	2019	1	21	38.438915	70.809476	Afghanistan	6	slab avalanche	Y	1	NA	0		1 persons injured
Sari Deh, Nusai, Badakhshan	2019	1	17	38.442681	70.81668	Afghanistan	6	slab avalanche	N	0	NA	0		
Shuraki Kapali catchment	2019	6	21	38.971146	70.835875	Tajikistan	6	glacier detachment	N	0	0	0		between 21-23 June
Shuraki Kapali catchment	2019	6	26	38.971146	70.835875	Tajikistan	6	glacier detachment	N	0	0	0		between 26 Jun - July 1
Arward, Nusai, Badakhshan	2019	1	16	38.338389	70.910459	Afghanistan	6	slab avalanche	N	0	NA	0		
Ubaghn, Shukai, Badakhshan	2019	1	14	38.428811	70.930509	Afghanistan	6	slab avalanche	N	0	NA	0		
Ubaghn, Nusai, Badakhshan	2019	2	14	38.428811	70.930509	Afghanistan	6	slab avalanche	N	0	NA	0		
Jarf, Shukai, Badakhshan	2019	1	15	38.199556	70.93725	Afghanistan	6	slab avalanche	N	0	NA	0		

Location	Year	Month	Day	Latitude	Longitude	Country	Region_HiMAP	Type	Impact	Fatalities	Injured	Livestock	Leisure	Remarks
Shagoon, Maimai, Badakhshan	2019	1	17	38.39655	71.027232	Afghanistan	6	slab avalanche	N	0	NA	0		
Dehkha, Shukai, Badakhshan	2019	1	12	37.65236	71.03805	Afghanistan	6	slab avalanche	N	0	NA	0		
Dehkha, Shukai, Badakhshan	2019	3	28	37.65236	71.03805	Afghanistan	6	slab avalanche	N	0	NA	0		
Sarchashmai Markazi, Maimai, Badakhshan	2019	1	17	38.404322	71.047113	Afghanistan	6	slab avalanche	N	0	NA	0		
Sarchashma, Maimai, Badakhshan	2019	1	9	38.395201	71.062692	Afghanistan	6	slab avalanche	Y	0	3	0		3 persons injured
Sarchashma, Maimai, Badakhshan	2019	1	17	38.395201	71.062692	Afghanistan	6	slab avalanche	Y	0	1	0		1 person injured
Kughaz, Maimai, Badakhshan	2019	1	16	38.390667	71.070821	Afghanistan	6	slab avalanche	Y	0	5	0		5 persons injured
Khuf (Warfad), Maimai, Badakhshan	2019	1	19	37.982926	71.100024	Afghanistan	6	slab avalanche	N	0	NA	0		
Jashtak, Maimai, Badakhshan	2019	1	16	38.397358	71.126916	Afghanistan	6	slab avalanche	N	0	NA	0		
Panjai Mard, Maimai, Badakhshan	2019	1	14	37.879683	71.135401	Afghanistan	6	slab avalanche	N	0	NA	0		
Mah-e-naw, Maimai, Badakhshan	2019	4	4	38.378548	71.136441	Afghanistan	6	wet snow avalanche	Y	0	NA	10		
Parabir, Maimai, Badakhshan	2019	1	14	37.88206	71.14417	Afghanistan	6	slab avalanche	N	0	NA	0		
Dara-e-Sher, Maimai, Badakhshan	2019	3	28	37.987648	71.235256	Afghanistan	6	slab avalanche	N	0	NA	0		
Budardha, Ishkashim, Badakhshan	2019	1	16	38.155406	71.23988	Afghanistan	6	slab avalanche	N	0	NA	0		
Barghud, Maimai, Badakhshan	2019	1	16	38.155406	71.23988	Afghanistan	6	slab avalanche	N	0	NA	0		

Location	Year	Month	Day	Latitude	Longitude	Country	Region_HiMAP	Type	Impact	Fatalities	Injured	Livestock	Leisure	Remarks
Rawand Sharist, Maimai, Badakhshan	2019	1	8	38.044203	71.287688	Afghanistan	6	slab avalanche	N	0	NA	0		
Rawand (Nusai), Nusai, Badakhshan	2019	1	9	38.044203	71.287688	Afghanistan	6	slab avalanche	N	0	NA	0		
Rawand (Nusai), Nusai, Badakhshan	2019	1	12	38.044203	71.287688	Afghanistan	6	slab avalanche	N	0	NA	0		
Rawand (Maimai), Maimai, Badakhshan	2019	3	19	38.044203	71.287688	Afghanistan	6	slab avalanche	Y	1	NA	0		
Chasnood Payan, Shighnan, Badakhshan	2019	4	16	37.922298	71.287994	Afghanistan	6	wet snow avalanche	N	0	NA	0		
Dewlagh jamarch bala, Maimai, Badakhshan	2019	2	6	38.256182	71.314715	Afghanistan	6	slab avalanche	N	0	NA	0		
Arakht, Shighnan, Badakhshan	2019	1	16	37.376715	71.412008	Afghanistan	6	slab avalanche	N	0	NA	0		
Arakht, Shighnan, Badakhshan	2019	4	3	37.376715	71.412008	Afghanistan	6	wet snow avalanche	Y	0	NA	42		
Showaldara, Ishkashim, Badakhshan	2019	2	11	36.664534	71.424921	Afghanistan	6	slab avalanche	Y	1	NA	0		
Zich, Ishkashim, Badakhshan	2019	1	5	37.077052	71.428276	Afghanistan	6	slab avalanche	N	0	NA	0		
Zich, Ishkashim, Badakhshan	2019	1	15	37.077052	71.428276	Afghanistan	6	slab avalanche	N	0	NA	0		
Zich, Ishkashim, Badakhshan	2019	1	15	37.077052	71.428276	Afghanistan	6	slab avalanche	N	0	NA	0		
Zich, Ishkashim, Badakhshan	2019	1	15	37.077052	71.428276	Afghanistan	6	slab avalanche	N	0	NA	0		
Zich, Ishkashim, Badakhshan	2019	1	15	37.077052	71.428276	Afghanistan	6	slab avalanche	N	0	NA	0		

Location	Year	Month	Day	Latitude	Longitude	Country	Region_HiMAP	Type	Impact	Fatalities	Injured	Livestock	Leisure	Remarks
Woned, Ishkashim, Badakhshan	2019	1	16	37.208885	71.434511	Afghanistan	6	slab avalanche	N	0	NA	0		
Safidsang, Ishkashim, Badakhshan	2019	2	14	37.216217	71.438482	Afghanistan	6	slab avalanche	N	0	NA	0		
Yazgam, Shighnan, Badakhshan	2019	1	8	37.538081	71.445716	Afghanistan	6	slab avalanche	N	0	NA	0		
Shughnan, Shighnan, Badakhshan	2019	1	8	37.616856	71.449766	Afghanistan	6	slab avalanche	N	0	NA	0		
Darmarakht, Shighnan, Badakhshan	2019	1	16	37.616856	71.449766	Afghanistan	6	slab avalanche	N	0	NA	0		
Darmarakht, Shighnan, Badakhshan	2019	1	16	37.616856	71.449766	Afghanistan	6	slab avalanche	Y	0	1	0		
Gulbagh, Ishkashim, Badakhshan	2019	1	15	37.223078	71.460353	Afghanistan	6	slab avalanche	N	0	NA	0		
Gulbagh, Ishkashim, Badakhshan	2019	1	15	37.223078	71.460353	Afghanistan	6	slab avalanche	N	0	NA	0		
Dakkhana, Shighnan, Badakhshan	2019	3	19	37.331601	71.480661	Afghanistan	6	slab avalanche	N	0	NA	0		
Chawgantrashan, Shighnan, Badakhshan	2019	1	16	37.428739	71.487789	Afghanistan	6	slab avalanche	N	0	NA	0		
Deerdehmurghan, Shighnan, Badakhshan	2019	1	16	37.540854	71.489308	Afghanistan	6	slab avalanche	N	0	NA	0		
Shiduj Dara, Shighnan, Badakhshan	2019	1	17	37.690908	71.492748	Afghanistan	6	slab avalanche	N	0	NA	0		
Nawabad (Ishkashiem), Ishkashim, Badakhshan	2019	3	19	36.707119	71.566287	Afghanistan	6	slab avalanche	N	0	NA	0		
Futoor, Wakhan, Badakhshan	2019	1	13	36.682542	71.652222	Afghanistan	6	slab avalanche	Y	1	NA	0		

Location	Year	Month	Day	Latitude	Longitude	Country	Region_HiMAP	Type	Impact	Fatalities	Injured	Livestock	Leisure	Remarks
Gorno-Badakshan	2019	1		38.474399	73.102399	Tajikistan	6	NA	Y	7	1	NA		
Siachen	2019	11	18	35.245329	77.158828	India	9	NA	Y	6	2	NA		2 civilian porters
Manang	2019	2	NA	28.591301	84.14375	Nepal	11	NA	Y	2	NA	NA		
Langtang	2019	4		28.217826	85.517401	Nepal	11	wet snow avalanche	N	0	NA	0		
Amney Machen	2019	7	9	34.82	99.44	China	21	glacier detachment	N	0	0	0		between 9-20 July
Wushnashahr, Nusai, Badakhshan	2019	2	5	NA	NA	Afghanistan	6	slab avalanche	N	0	NA	0		
Jamarch Bala, Maimai, Badakhshan	2019	2	6	NA	NA	Afghanistan	6	slab avalanche	N	0	NA	0		
Nawabad, Nusai, Badakhshan	2019	3	28	NA	NA	Afghanistan	6	slab avalanche	N	0	NA	0		
Ghazdara, Maimai, Badakhshan	2019	4	16	NA	NA	Afghanistan	6	wet snow avalanche	N	0	NA	0		
Safidsang, Khahan, Badakhshan	2019	1	16	NA	NA	Afghanistan	6	slab avalanche	Y	1	NA	0		
Hosshah, Khahan, Badakhshan	2019	2	2	NA	NA	Afghanistan	6	slab avalanche	Y	2	4	0		4 persons injured
Khaldis, Raghistan, Badakhshan	2019	1	17	NA	NA	Afghanistan	6	slab avalanche	Y	8	3	0		3 person injured
Daykundi	2020	2	13	33.703958	66.036936	Afghanistan	8	NA	Y	22	10	NA		series of avalanches in Daykundi between 13-14
Takhawi, Waras, Bamyan	2020	2	11	33.860994	66.750963	Afghanistan	8	slab avalanche	Y	1	NA	0		
Dahne Shor Siadara, Yaka Walang, Bamyan	2020	2	12	34.639964	66.946914	Afghanistan	8	slab avalanche	Y	1	NA	0		
Dehkha, Shukai, Badakhshan	2020	2	11	38.35055	70.662524	Afghanistan	6	slab avalanche	N	0	NA	0		
Dehkha, Shukai, Badakhshan	2020	4	13	38.35055	70.662524	Afghanistan	6	wet snow avalanche	N	0	NA	0		
Purtel, Shukai,	2020	1	4	38.329088	70.707453	Afghanistan	6	slab avalanche	N	0	NA	0		

Location	Year	Month	Day	Latitude	Longitude	Country	Region_HiMAP	Type	Impact	Fatalities	Injured	Livestock	Leisure	Remarks
Badakhshan														
Purtel, Shukai, Badakhshan	2020	1	4	38.329088	70.707453	Afghanistan	6	slab avalanche	N	0	NA	0		
Purtel, Shukai, Badakhshan	2020	2	11	38.329088	70.707453	Afghanistan	6	slab avalanche	N	0	NA	0		
Khahdara, Shukai, Badakhshan	2020	1	4	38.323751	70.723864	Afghanistan	6	slab avalanche	N	0	NA	0		
Darjaway, Nusai, Badakhshan	2020	2	11	38.433648	70.809719	Afghanistan	6	slab avalanche	N	0	NA	0		
Meyandeh (Nusai), Nusai, Badakhshan	2020	1	14	38.280395	70.812735	Afghanistan	6	slab avalanche	N	0	NA	0		
Meyandeh (Nusai), Nusai, Badakhshan	2020	1	14	38.280395	70.812735	Afghanistan	6	slab avalanche	N	0	NA	0		
Darjaway, Nusai, Badakhshan	2020	2	12	38.280395	70.812735	Afghanistan	6	slab avalanche	N	0	NA	0		
Newar, Nusai, Badakhshan	2020	12	27	38.310418	70.830089	Afghanistan	6	slab avalanche	N	0	NA	0		
Aroon, Nusai, Badakhshan	2020	12	27	38.30569	70.83967	Afghanistan	6	slab avalanche	N	0	NA	0		
Dehkha, Shukai, Badakhshan	2020	1	7	37.65236	71.03805	Afghanistan	6	slab avalanche	N	0	NA	0		
Dawlat Shahi, Arghanjkhaw, Badakhshan	2020	1	11	37.65236	71.03805	Afghanistan	6	slab avalanche	Y	1	NA	0		
Sarchashma, Maimai, Badakhshan	2020	2	12	38.395201	71.062692	Afghanistan	6	slab avalanche	N	0	NA	0		
Mah-e-naw, Maimai, Badakhshan	2020	2	19	38.378548	71.136441	Afghanistan	6	slab avalanche	N	0	NA	0		
Parabir, Maimai, Badakhshan	2020	1	12	37.88206	71.14417	Afghanistan	6	slab avalanche	N	0	NA	0		
Parabir, Maimai, Badakhshan	2020	1	12	37.88206	71.14417	Afghanistan	6	slab avalanche	N	0	NA	0		
Parabir, Maimai,	2020	1	12	37.88206	71.14417	Afghanistan	6	slab avalanche	N	0	NA	0		

Location	Year	Month	Day	Latitude	Longitude	Country	Region_HiMAP	Type	Impact	Fatalities	Injured	Livestock	Leisure	Remarks
Badakhshan														
Parabir, Maimai, Badakhshan	2020	1	12	37.88206	71.14417	Afghanistan	6	slab avalanche	N	0	NA	0		
Parabir, Maimai, Badakhshan	2020	1	13	37.88206	71.14417	Afghanistan	6	slab avalanche	N	0	NA	0		
Begaw, Maimai, Badakhshan	2020	2	21	38.164165	71.274468	Afghanistan	6	slab avalanche	N	0	NA	0		
Begaw, Maimai, Badakhshan	2020	2	12	38.164165	71.274468	Afghanistan	6	slab avalanche	Y	0	1	0		1 persons injured
Arakht, Shighnan, Badakhshan	2020	12	28	37.376715	71.412008	Afghanistan	6	slab avalanche	N	0	NA	0		
Dakkhana, Shighnan, Badakhshan	2020	12	27	37.331601	71.480661	Afghanistan	6	slab avalanche	N	0	NA	0		
Pamir khurd, Wakhan, Badakhshan	2020	1	16	36.994361	72.650815	Afghanistan	8	slab avalanche	Y	1	NA	0		
Kashmir	2020	11	17	34.397451	73.860665	India	10	snow avalanche	Y	1	2	NA		
Line of Control	2020	1	14	34.397451	73.860665	India	10	snow avalanche	Y	10	NA	NA		Excessive snowfall
Line of Control	2020	1	14	34.827012	74.358551	Pakistan	10	snow avalanche	Y	55	12	NA		>12 injuries, Excessive snowfall
Annapurna	2020	1	17	28.591216	84.208337	Nepal	11	NA	Y	7	NA	NA		
Lugnak La avalanche	2020	5	14	27.895319	88.481671	India	12	snow avalanche	Y	2	NA	NA		
Silla Shudag, Nusai, Badakhshan	2020	1	7	NA	NA	Afghanistan	6	slab avalanche	N	0	NA	0		
Parabir, Maimai, Badakhshan	2020	1	13	NA	NA	Afghanistan	6	slab avalanche	N	0	NA	0		
Ozbay, Maimai, Badakhshan	2020	4	15	NA	NA	Afghanistan	6	wet snow avalanche	Y	0	NA	200		
Salang	2021	3		35.310158	69.045199	Afghanistan	8	NA	Y	14	NA	NA		
Ebroy, Warsaj, Takhar	2021	5	2	36.140407	70.216326	Afghanistan	8	wet snow avalanche	N	0	NA	0		
Bedi Ashuk, Warsaj, Takhar	2021	4	26	36.119028	70.242864	Afghanistan	8	wet snow avalanche	N	0	NA	0		

Location	Year	Month	Day	Latitude	Longitude	Country	Region_HiMAP	Type	Impact	Fatalities	Injured	Livestock	Leisure	Remarks
Dehzar, Warsaj, Takhar	2021	3	29	36.147756	70.327149	Afghanistan	8	slab avalanche	N	0	NA	0		
Munjiha, Darayim, Badakhshan	2021	12	27	36.828498	70.552287	Afghanistan	8	slab avalanche	N	0	NA	0		
Khami Kasku, Shukai, Badakhshan	2021	3	10	38.22199	70.6515	Afghanistan	6	slab avalanche	Y	2	NA	0		
Khum Kasku, Shukai, Badakhshan	2021	3	10	38.22199	70.6515	Afghanistan	6	slab avalanche	Y	2	NA	0		
Dehkha, Shukai, Badakhshan	2021	2	22	38.35055	70.662524	Afghanistan	6	slab avalanche	N	0	NA	0		
Munaw, Shukai, Badakhshan	2021	2	24	38.399106	70.692405	Afghanistan	6	slab avalanche	N	0	NA	0		
Khawand, Shukai, Badakhshan	2021	2	9	38.368839	70.693923	Afghanistan	6	slab avalanche	N	0	NA	0		
Purtel, Shukai, Badakhshan	2021	3	11	38.329088	70.707453	Afghanistan	6	slab avalanche	N	0	NA	0		
Purtel, Shukai, Badakhshan	2021	3	14	38.329088	70.707453	Afghanistan	6	slab avalanche	N	0	NA	0		
Purtel, Shukai, Badakhshan	2021	3	28	38.329088	70.707453	Afghanistan	6	slab avalanche	N	0	NA	0		
Khundak, Shukai, Badakhshan	2021	2	22	38.3256	70.7282	Afghanistan	6	slab avalanche	N	0	NA	0		
Dwak, Shukai, Badakhshan	2021	2	23	38.415398	70.729414	Afghanistan	6	slab avalanche	N	0	NA	0		
Meyandeh (Nusai), Nusai, Badakhshan	2021	3	11	38.280395	70.812735	Afghanistan	6	slab avalanche	N	0	NA	0		
Mah-e-naw, Maimai, Badakhshan	2021	3	17	38.280395	70.812735	Afghanistan	6	slab avalanche	N	0	NA	0		
Mah-e-naw, Maimai, Badakhshan	2021	3	28	38.280395	70.812735	Afghanistan	6	slab avalanche	N	0	NA	0		
Meyandeh (Nusai), Nusai, Badakhshan	2021	3	28	38.280395	70.812735	Afghanistan	6	slab avalanche	Y	0	NA	10		

Location	Year	Month	Day	Latitude	Longitude	Country	Region_HiMAP	Type	Impact	Fatalities	Injured	Livestock	Leisure	Remarks
Sari Deh, Nusai, Badakhshan	2021	2	22	38.442681	70.81668	Afghanistan	6	slab avalanche	N	0	NA	0		
Sari Deh, Nusai, Badakhshan	2021	2	24	38.442681	70.81668	Afghanistan	6	slab avalanche	N	0	NA	0		
Panam, Kuran wa Munjan, Badakhshan	2021	3	28	35.839431	70.846463	Afghanistan	8	slab avalanche	N	0	NA	0		
Ubaghn, Nusai, Badakhshan	2021	3	13	38.428811	70.930509	Afghanistan	6	slab avalanche	N	0	NA	0		
Ubaghn, Nusai, Badakhshan	2021	3	29	38.428811	70.930509	Afghanistan	6	slab avalanche	N	0	NA	0		
Dawlat shayee, Arghanj khaw, Badakhshan	2021	4	6	37.65236	71.03805	Afghanistan	6	wet snow avalanche	Y	1	NA	0		
Sarchashmai Markazi, Maimai, Badakhshan	2021	2	9	38.395201	71.062692	Afghanistan	6	slab avalanche	N	0	NA	0		
Rawand Sharist, Maimai, Badakhshan	2021	3	17	37.82732	71.09526	Afghanistan	6	slab avalanche	N	0	NA	0		
Khuf, Maimai, Badakhshan	2021	3	29	37.982926	71.100024	Afghanistan	6	slab avalanche	N	0	NA	0		
Panjai Mard, Maimai, Badakhshan	2021	3	28	37.879683	71.135401	Afghanistan	6	slab avalanche	N	0	NA	0		
Tupdara 1(DaraiSher), Maimai, Badakhshan	2021	3	14	37.992642	71.161215	Afghanistan	6	slab avalanche	N	0	NA	0		
Rawand (Maimai), Maimai, Badakhshan	2021	3	10	38.044203	71.287688	Afghanistan	6	slab avalanche	N	0	NA	0		
Chasnood Payan, Shighnan, Badakhshan	2021	3	10	37.922298	71.287994	Afghanistan	6	slab avalanche	N	0	NA	0		
Zwardara, Ishkashim, Badakhshan	2021	3	28	37.157631	71.407145	Afghanistan	6	slab avalanche	N	0	NA	0		
Arakht, Shighnan,	2021	2	9	37.376715	71.412008	Afghanistan	6	slab avalanche	N	0	NA	0		

Location	Year	Month	Day	Latitude	Longitude	Country	Region_HiMAP	Type	Impact	Fatalities	Injured	Livestock	Leisure	Remarks
Badakhshan														
Arakht, Shighnan, Badakhshan	2021	3	28	37.376715	71.412008	Afghanistan	6	slab avalanche	N	0	NA	0		
Zich, Ishkashim, Badakhshan	2021	3	18	37.077052	71.428276	Afghanistan	6	slab avalanche	N	0	NA	0		
Meyanbar 1, Shighnan, Badakhshan	2021	1	21	37.332659	71.45955	Afghanistan	6	slab avalanche	N	0	NA	0		
Meyanbar 1, Shighnan, Badakhshan	2021	2	9	37.332659	71.45955	Afghanistan	6	slab avalanche	N	0	NA	0		
Chasnood Bala, Shighnan, Badakhshan	2021	3	10	37.405704	71.473986	Afghanistan	6	slab avalanche	N	0	NA	0		
Shahran (Shighnan), Shighnan, Badakhshan	2021	3	29	37.405704	71.473986	Afghanistan	6	slab avalanche	N	0	NA	0		
Meyanshahr, Shighnan, Badakhshan	2021	3	29	37.486419	71.476315	Afghanistan	6	slab avalanche	N	0	NA	0		
Dakkhana, Shighnan, Badakhshan	2021	1	21	37.331601	71.480661	Afghanistan	6	slab avalanche	N	0	NA	0		
Dakkhana, Shighnan, Badakhshan	2021	3	5	37.331601	71.480661	Afghanistan	6	slab avalanche	N	0	NA	0		
Dakkhana, Shighnan, Badakhshan	2021	3	28	37.331601	71.480661	Afghanistan	6	slab avalanche	N	0	NA	0		
Dakkhana, Shighnan, Badakhshan	2021	3	29	37.331601	71.480661	Afghanistan	6	slab avalanche	N	0	NA	0		
Budardha, Ishkashim, Badakhshan	2021	3	28	37.239096	71.481093	Afghanistan	6	slab avalanche	N	0	NA	0		
Tibanak-Darmarakht, Shighnan, Badakhshan	2021	3	5	37.33333	71.483333	Afghanistan	6	slab avalanche	N	0	NA	0		

Location	Year	Month	Day	Latitude	Longitude	Country	Region_HiMAP	Type	Impact	Fatalities	Injured	Livestock	Leisure	Remarks
Chawgantrashan, Shighnan, Badakhshan	2021	3	28	37.428739	71.487789	Afghanistan	6	slab avalanche	N	0	NA	0		
Jangal (Pajwar), Shighnan, Badakhshan	2021	3	10	37.939917	71.499149	Afghanistan	6	slab avalanche	N	0	NA	0		
Shiva-Bamdara Pass, Arghanjkhaw, Badakhshan	2021	11	12	37.493747	71.504798	Afghanistan	6	wet snow avalanche	Y	2	NA	0		
Sari Shakh, Ishkashim, Badakhshan	2021	3	28	36.883772	71.512318	Afghanistan	6	slab avalanche	N	0	NA	0		
Wereezn (Shighnan), Shighnan, Badakhshan	2021	3	17	37.650397	71.52035	Afghanistan	6	slab avalanche	N	0	NA	0		
Wereezn (Shighnan), Shighnan, Badakhshan	2021	3	29	37.650397	71.52035	Afghanistan	6	slab avalanche	N	0	NA	0		
Sarjaway, Nusai, Badakhshan	2021	2	9	36.70689	71.569366	Afghanistan	6	slab avalanche	Y	2	7	0		7 persons injured
Rubat (Shighnan), Shighnan, Badakhshan	2021	3	17	37.838971	71.583859	Afghanistan	6	slab avalanche	N	0	NA	0		
Panja, Wakhan, Badakhshan	2021	3	30	36.997108	72.578561	Afghanistan	8	slab avalanche	N	0	NA	0		
Korut, Wakhan, Badakhshan	2021	3	21	36.948499	72.967535	Afghanistan	6	slab avalanche	N	0	NA	0		
Siachen	2021	4	25	35.33656	77.158828	India	9	NA	Y	2	NA	NA		
Chamoli	2021	4	23	30.822323	79.966271	India	11	NA	Y	8	NA	NA		
Kobang	2021	11	14	28.718882	83.582068	Nepal	11	ice and snow avalanche	Y	0	NA	14		
Kapuche, Kaski	2021	1	9	28.465885	84.110242	Nepal	11	snow avalanche	N	0	NA	0		
Langtang avalanche	2021	1	NA	28.237596	85.498829	Nepal	11	powder snow avalanche	N	0	NA	0		

Location	Year	Month	Day	Latitude	Longitude	Country	Region_ HiMAP	Type	Impact	Fatalities	Injured	Livestock	Leisure	Remarks
Darmarakht, Shighnan, Badakhshan	2021	1	21	NA	NA	Afghanistan	6	slab avalanche	N	0	NA	0		
Gharan bala Woned, Ishkashim, Badakhshan	2021	3	28	NA	NA	Afghanistan	6	slab avalanche	N	0	NA	0		
Zarandabd, Khahan, Badakhshan	2021	3	5	NA	NA	Afghanistan	6	slab avalanche	Y	14	18	0		18 persons injured
Gharan, Ishkashim, Badakhshan	2021	3	18	NA	NA	Afghanistan	6	slab avalanche	N	0	NA	0		
Woned, Ishkashim, Badakhshan	2021	3	29	NA	NA	Afghanistan	6	slab avalanche	N	0	NA	0		
Guldara (Dushi), Dushi, Baghlan	2022	3	15	35.389998	68.548638	Afghanistan	8	slab avalanche	N	0	NA	0		
Bibedara, Dushi, Baghlan	2022	3	14	35.38581	68.65556	Afghanistan	8	slab avalanche	N	0	NA	0		
Bibedara, Dushi, Baghlan	2022	3	15	35.385509	68.656469	Afghanistan	8	slab avalanche	N	0	NA	0		
Khambil, Raghistan, Badakhshan	2022	1	18	34.550579	69.163414	Afghanistan	8	slab avalanche	Y	3	5	0		5 persons injured
Chashma Angusht, Warsaj, Takhar	2022	3	15	36.122359	70.23306	Afghanistan	8	slab avalanche	N	0	NA	0		
Zaiton, Warsaj, Takhar	2022	3	12	36.111374	70.251868	Afghanistan	8	slab avalanche	N	0	NA	0		
Seel Posida, Warsaj, Takhar	2022	1	19	36.132138	70.27335	Afghanistan	8	slab avalanche	N	0	NA	0		
Dehzar, Warsaj, Takhar	2022	3	12	36.147756	70.327149	Afghanistan	8	slab avalanche	N	0	NA	0		
Peo, Warsaj, Takhar	2022	3	14	36.149051	70.348187	Afghanistan	8	slab avalanche	N	0	NA	0		
Badkay, Shukai, Badakhshan	2022	2	6	38.18003	70.57319	Afghanistan	6	slab avalanche	N	0	NA	0		
Ghumai, Shukai, Badakhshan	2022	3	8	38.287149	70.608765	Afghanistan	6	slab avalanche	N	0	NA	0		
Ghumai, Shukai, Badakhshan	2022	3	13	38.287149	70.608765	Afghanistan	6	slab avalanche	N	0	NA	0		

Location	Year	Month	Day	Latitude	Longitude	Country	Region_ HiMAP	Type	Impact	Fatalities	Injured	Livestock	Leisure	Remarks
Dehkha, Shukai, Badakhshan	2022	1	2	38.35055	70.662524	Afghanistan	6	slab avalanche	N	0	NA	0		
Dehkha, Shukai, Badakhshan	2022	1	4	38.35055	70.662524	Afghanistan	6	slab avalanche	N	0	NA	0		
Dehkha, Shukai, Badakhshan	2022	1	18	38.35055	70.662524	Afghanistan	6	slab avalanche	N	0	NA	0		
Dehkha, Shukai, Badakhshan	2022	3	6	38.35055	70.662524	Afghanistan	6	slab avalanche	N	0	NA	0		
Dehkha, Shukai, Badakhshan	2022	3	8	38.35055	70.662524	Afghanistan	6	slab avalanche	N	0	NA	0		
Dehkha, Shukai, Badakhshan	2022	3	12	38.35055	70.662524	Afghanistan	6	slab avalanche	N	0	NA	0		
Dehkha, Shukai, Badakhshan	2022	3	13	38.35055	70.662524	Afghanistan	6	slab avalanche	N	0	NA	0		
Khawand, Shukai, Badakhshan	2022	1	2	38.368839	70.693923	Afghanistan	6	slab avalanche	N	0	NA	0		
Khawand, Shukai, Badakhshan	2022	1	4	38.368839	70.693923	Afghanistan	6	slab avalanche	N	0	NA	0		
Khawand, Shukai, Badakhshan	2022	2	14	38.368839	70.693923	Afghanistan	6	slab avalanche	N	0	NA	0		
Khawand, Shukai, Badakhshan	2022	2	23	38.368839	70.693923	Afghanistan	6	slab avalanche	N	0	NA	0		
Khawand, Shukai, Badakhshan	2022	3	6	38.368839	70.693923	Afghanistan	6	slab avalanche	N	0	NA	0		
Khawand, Shukai, Badakhshan	2022	3	8	38.368839	70.693923	Afghanistan	6	slab avalanche	N	0	NA	0		
Khawand, Shukai, Badakhshan	2022	3	12	38.368839	70.693923	Afghanistan	6	slab avalanche	N	0	NA	0		
Khawand, Shukai, Badakhshan	2022	2	6	38.368839	70.693923	Afghanistan	6	slab avalanche	Y	1	NA	0		
Purtel, Shukai, Badakhshan	2022	1	2	38.329088	70.707453	Afghanistan	6	slab avalanche	N	0	NA	0		
Purtel, Shukai, Badakhshan	2022	1	18	38.329088	70.707453	Afghanistan	6	slab avalanche	N	0	NA	0		
Purtel, Shukai,	2022	2	6	38.329088	70.707453	Afghanistan	6	slab avalanche	N	0	NA	0		

Location	Year	Month	Day	Latitude	Longitude	Country	Region_HiMAP	Type	Impact	Fatalities	Injured	Livestock	Leisure	Remarks
Badakhshan														
Purtel, Shukai, Badakhshan	2022	3	20	38.329088	70.707453	Afghanistan	6	slab avalanche	N	0	NA	0		
Purtel, Shukai, Badakhshan	2022	3	21	38.329088	70.707453	Afghanistan	6	slab avalanche	N	0	NA	0		
Purtel, Shukai, Badakhshan	2022	3	22	38.329088	70.707453	Afghanistan	6	slab avalanche	N	0	NA	0		
Purtel, Shukai, Badakhshan	2022	3	23	38.329088	70.707453	Afghanistan	6	slab avalanche	N	0	NA	0		
Khahdara, Shukai, Badakhshan	2022	3	12	38.323751	70.723864	Afghanistan	6	slab avalanche	N	0	NA	0		
Dwak, Shukai, Badakhshan	2022	1	4	38.415398	70.729414	Afghanistan	6	slab avalanche	N	0	NA	0		
Dwak, Shukai, Badakhshan	2022	2	7	38.415398	70.729414	Afghanistan	6	slab avalanche	N	0	NA	0		
Dwak, Shukai, Badakhshan	2022	2	12	38.415398	70.729414	Afghanistan	6	slab avalanche	N	0	NA	0		
Dwak, Shukai, Badakhshan	2022	2	23	38.415398	70.729414	Afghanistan	6	slab avalanche	N	0	NA	0		
Dwak, Shukai, Badakhshan	2022	3	6	38.415398	70.729414	Afghanistan	6	slab avalanche	N	0	NA	0		
Dwak, Shukai, Badakhshan	2022	3	9	38.415398	70.729414	Afghanistan	6	slab avalanche	N	0	NA	0		
Dwak, Shukai, Badakhshan	2022	3	12	38.415398	70.729414	Afghanistan	6	slab avalanche	N	0	NA	0		
Dwak, Shukai, Badakhshan	2022	3	13	38.415398	70.729414	Afghanistan	6	slab avalanche	N	0	NA	0		
Nusai Center, Nusai, Badakhshan	2022	3	9	38.443277	70.805036	Afghanistan	6	slab avalanche	N	0	NA	0		
Meyandeh (Nusai), Nusai, Badakhshan	2022	1	4	38.280395	70.812735	Afghanistan	6	slab avalanche	N	0	NA	0		
Sari Deh, Nusai, Badakhshan	2022	3	8	38.442681	70.81668	Afghanistan	6	slab avalanche	N	0	NA	0		
Sari Deh, Nusai,	2022	3	11	38.442681	70.81668	Afghanistan	6	slab avalanche	N	0	NA	0		

Location	Year	Month	Day	Latitude	Longitude	Country	Region_ HiMAP	Type	Impact	Fatalities	Injured	Livestock	Leisure	Remarks
Badakhshan														
Aroon, Nusai, Badakhshan	2022	1	5	38.30569	70.83967	Afghanistan	6	slab avalanche	N	0	NA	0		
Wujmi Payan, Nusai, Badakhshan	2022	3	14	38.366926	70.853192	Afghanistan	6	slab avalanche	N	0	NA	0		
Wujmi Payan, Nusai, Badakhshan	2022	3	19	38.366926	70.853192	Afghanistan	6	slab avalanche	N	0	NA	0		
Parkhekh, Nusai, Badakhshan	2022	3	12	38.333841	70.863748	Afghanistan	6	slab avalanche	N	0	NA	0		
Paryad, Nusai, Badakhshan	2022	3	13	38.443453	70.896645	Afghanistan	6	slab avalanche	N	0	NA	0		
Ubaghn, Nusai, Badakhshan	2022	1	4	38.428811	70.930509	Afghanistan	6	slab avalanche	N	0	NA	0		
Ubaghn, Nusai, Badakhshan	2022	2	23	38.428811	70.930509	Afghanistan	6	slab avalanche	N	0	NA	0		
Ubaghn, Nusai, Badakhshan	2022	3	9	38.428811	70.930509	Afghanistan	6	slab avalanche	N	0	NA	0		
Ubaghn, Nusai, Badakhshan	2022	3	11	38.428811	70.930509	Afghanistan	6	slab avalanche	N	0	NA	0		
Ubaghn, Nusai, Badakhshan	2022	3	13	38.428811	70.930509	Afghanistan	6	slab avalanche	N	0	NA	0		
Ubaghn, Nusai, Badakhshan	2022	3	18	38.428811	70.930509	Afghanistan	6	slab avalanche	N	0	NA	0		
Wereezn (Shighnan), Shighnan, Badakhshan	2022	3	12	38.414026	71.081631	Afghanistan	6	slab avalanche	N	0	NA	0		
Mah-e-naw, Maimai, Badakhshan	2022	2	6	38.378548	71.136441	Afghanistan	6	slab avalanche	N	0	NA	0		
Mah-e-naw, Maimai, Badakhshan	2022	3	10	38.378548	71.136441	Afghanistan	6	slab avalanche	N	0	NA	0		
Mah-e-naw, Maimai, Badakhshan	2022	3	12	38.378548	71.136441	Afghanistan	6	slab avalanche	N	0	NA	0		

Location	Year	Month	Day	Latitude	Longitude	Country	Region_HiMAP	Type	Impact	Fatalities	Injured	Livestock	Leisure	Remarks
Parabir, Maimai, Badakhshan	2022	1	19	37.88206	71.14417	Afghanistan	6	slab avalanche	N	0	NA	0		
Sarchashma, Maimai, Badakhshan	2022	3	13	38.053949	71.222429	Afghanistan	6	slab avalanche	N	0	NA	0		
Pitab (Warv), Maimai, Badakhshan	2022	3	13	38.0731	71.22766	Afghanistan	6	slab avalanche	N	0	NA	0		
Dara-e-Sher, Maimai, Badakhshan	2022	1	20	37.987648	71.235256	Afghanistan	6	slab avalanche	N	0	NA	0		
Dara-e-Sher, Maimai, Badakhshan	2022	3	13	37.987648	71.235256	Afghanistan	6	slab avalanche	N	0	NA	0		
Barghud, Maimai, Badakhshan	2022	1	16	38.155406	71.23988	Afghanistan	6	slab avalanche	N	0	NA	0		
Barghud, Maimai, Badakhshan	2022	3	9	38.155406	71.23988	Afghanistan	6	slab avalanche	N	0	NA	0		
Barghud, Maimai, Badakhshan	2022	3	17	38.155406	71.23988	Afghanistan	6	slab avalanche	N	0	NA	0		
Begaw (Warv), Maimai, Badakhshan	2022	3	13	38.164165	71.274468	Afghanistan	6	slab avalanche	N	0	NA	0		
Yasech, Shuhada, Badakhshan	2022	3	19	37.05354	71.281206	Afghanistan	6	slab avalanche	N	0	NA	0		
Rawand (Maimai), Maimai, Badakhshan	2022	2	7	38.044203	71.287688	Afghanistan	6	slab avalanche	N	0	NA	0		
Rawand (Maimai), Maimai, Badakhshan	2022	3	8	38.044203	71.287688	Afghanistan	6	slab avalanche	N	0	NA	0		
Rawand (Maimai), Maimai, Badakhshan	2022	3	9	38.044203	71.287688	Afghanistan	6	slab avalanche	N	0	NA	0		
Rawand (Maimai), Maimai, Badakhshan	2022	3	13	38.044203	71.287688	Afghanistan	6	slab avalanche	N	0	NA	0		
Chasnood Payan, Shighnan, Badakhshan	2022	1	4	37.922298	71.287994	Afghanistan	6	slab avalanche	N	0	NA	0		

Location	Year	Month	Day	Latitude	Longitude	Country	Region_HiMAP	Type	Impact	Fatalities	Injured	Livestock	Leisure	Remarks
Chasnood Payan, Shighnan, Badakhshan	2022	3	10	37.922298	71.287994	Afghanistan	6	slab avalanche	N	0	NA	0		
Chasnood Payan, Shighnan, Badakhshan	2022	3	11	37.922298	71.287994	Afghanistan	6	slab avalanche	N	0	NA	0		
Chasnood Payan, Shighnan, Badakhshan	2022	3	13	37.922298	71.287994	Afghanistan	6	slab avalanche	N	0	NA	0		
Chasnood Payan, Shighnan, Badakhshan	2022	3	17	37.922298	71.287994	Afghanistan	6	slab avalanche	N	0	NA	0		
Sadwadg, Maimai, Badakhshan	2022	2	7	38.015086	71.288737	Afghanistan	6	slab avalanche	N	0	NA	0		
Sadwadg, Maimai, Badakhshan	2022	2	23	38.015086	71.288737	Afghanistan	6	slab avalanche	N	0	NA	0		
Sadwadg, Maimai, Badakhshan	2022	3	13	38.015086	71.288737	Afghanistan	6	slab avalanche	N	0	NA	0		
Horan Shahr Bala, Arghanjkhaw, badakhshan	2022	3	13	37.09024	71.2891	Afghanistan	6	slab avalanche	Y	1	1	0		1 person injured
Yarkh, Shighnan, Badakhshan	2022	2	7	37.901831	71.31513	Afghanistan	6	slab avalanche	N	0	NA	0		
Amurn, Maimai, Badakhshan	2022	3	9	38.195824	71.3588	Afghanistan	6	slab avalanche	N	0	NA	0		
Gharib, Zebak, Badakhshan	2022	3	15	36.62634	71.367366	Afghanistan	6	slab avalanche	N	0	NA	0		
Arakht, Shighnan, Badakhshan	2022	1	5	37.376715	71.412008	Afghanistan	6	slab avalanche	N	0	NA	0		
Arakht, Shighnan, Badakhshan	2022	2	6	37.376715	71.412008	Afghanistan	6	slab avalanche	N	0	NA	0		
Arakht, Shighnan, Badakhshan	2022	2	22	37.376715	71.412008	Afghanistan	6	slab avalanche	N	0	NA	0		
Arakht, Shighnan, Badakhshan	2022	2	22	37.376715	71.412008	Afghanistan	6	slab avalanche	N	0	NA	0		
Arakht, Shighnan, Badakhshan	2022	3	3	37.376715	71.412008	Afghanistan	6	slab avalanche	N	0	NA	0		

Location	Year	Month	Day	Latitude	Longitude	Country	Region_ HiMAP	Type	Impact	Fatalities	Injured	Livestock	Leisure	Remarks
Arakht, Shighnan, Badakhshan	2022	3	12	37.376715	71.412008	Afghanistan	6	slab avalanche	N	0	NA	0		
Arakht, Shighnan, Badakhshan	2022	3	15	37.376715	71.412008	Afghanistan	6	slab avalanche	N	0	NA	0		
Arakht, Shighnan, Badakhshan	2022	3	16	37.376715	71.412008	Afghanistan	6	slab avalanche	N	0	NA	0		
Darmadar, Ishkashim, Badakhshan	2022	3	12	37.218351	71.428095	Afghanistan	6	slab avalanche	N	0	NA	0		
Zich, Ishkashim, Badakhshan	2022	1	30	37.077052	71.428276	Afghanistan	6	slab avalanche	N	0	NA	0		
Zich, Ishkashim, Badakhshan	2022	3	9	37.077052	71.428276	Afghanistan	6	slab avalanche	N	0	NA	0		
Zich, Ishkashim, Badakhshan	2022	3	12	37.077052	71.428276	Afghanistan	6	slab avalanche	N	0	NA	0		
Zich, Ishkashim, Badakhshan	2022	3	6	37.077052	71.428276	Afghanistan	6	slab avalanche	Y	1	3	13		3 persons injured
Shahran (Shighnan), Shighnan, Badakhshan	2022	1	4	37.405704	71.473986	Afghanistan	6	slab avalanche	N	0	NA	0		
Chasnood Bala, Shighnan, Badakhshan	2022	1	4	37.405704	71.473986	Afghanistan	6	slab avalanche	N	0	NA	0		
Chasnood Bala, Shighnan, Badakhshan	2022	1	18	37.405704	71.473986	Afghanistan	6	slab avalanche	N	0	NA	0		
Shahran (Shighnan), Shighnan, Badakhshan	2022	1	30	37.405704	71.473986	Afghanistan	6	slab avalanche	N	0	NA	0		
Gulbagh, Ishkashim, Badakhshan	2022	1	30	37.405704	71.473986	Afghanistan	6	slab avalanche	N	0	NA	0		
Chasnood Payan, Shighnan, Badakhshan	2022	2	7	37.405704	71.473986	Afghanistan	6	slab avalanche	N	0	NA	0		

Location	Year	Month	Day	Latitude	Longitude	Country	Region_HiMAP	Type	Impact	Fatalities	Injured	Livestock	Leisure	Remarks
Chasnood Bala, Shighnan, Badakhshan	2022	2	7	37.405704	71.473986	Afghanistan	6	slab avalanche	N	0	NA	0		
Shahran (Shighnan), Shighnan, Badakhshan	2022	2	7	37.405704	71.473986	Afghanistan	6	slab avalanche	N	0	NA	0		
Shahran (Shighnan), Shighnan, Badakhshan	2022	2	13	37.405704	71.473986	Afghanistan	6	slab avalanche	N	0	NA	0		
Shahran (Shighnan), Shighnan, Badakhshan	2022	2	23	37.405704	71.473986	Afghanistan	6	slab avalanche	N	0	NA	0		
Chasnood Payan, Shighnan, Badakhshan	2022	2	27	37.405704	71.473986	Afghanistan	6	slab avalanche	N	0	NA	0		
Shahran (Shighnan), Shighnan, Badakhshan	2022	3	6	37.405704	71.473986	Afghanistan	6	slab avalanche	N	0	NA	0		
Shahran (Shighnan), Shighnan, Badakhshan	2022	3	8	37.405704	71.473986	Afghanistan	6	slab avalanche	N	0	NA	0		
Shahran (Shighnan), Shighnan, Badakhshan	2022	3	9	37.405704	71.473986	Afghanistan	6	slab avalanche	N	0	NA	0		
Chasnood Payan, Shighnan, Badakhshan	2022	3	9	37.405704	71.473986	Afghanistan	6	slab avalanche	N	0	NA	0		
Shahran (Shighnan), Shighnan, Badakhshan	2022	3	10	37.405704	71.473986	Afghanistan	6	slab avalanche	N	0	NA	0		
Shahran (Shighnan), Shighnan, Badakhshan	2022	3	11	37.405704	71.473986	Afghanistan	6	slab avalanche	N	0	NA	0		
Shahran (Shighnan), Shighnan, Badakhshan	2022	3	12	37.405704	71.473986	Afghanistan	6	slab avalanche	N	0	NA	0		

Location	Year	Month	Day	Latitude	Longitude	Country	Region_HiMAP	Type	Impact	Fatalities	Injured	Livestock	Leisure	Remarks
Shahran (Shighnan), Shighnan, Badakhshan	2022	3	19	37.405704	71.473986	Afghanistan	6	slab avalanche	N	0	NA	0		
Dakkhana, Shighnan, Badakhshan	2022	1	4	37.331601	71.480661	Afghanistan	6	slab avalanche	N	0	NA	0		
Dakkhana, Shighnan, Badakhshan	2022	1	5	37.331601	71.480661	Afghanistan	6	slab avalanche	N	0	NA	0		
Dakkhana, Shighnan, Badakhshan	2022	1	30	37.331601	71.480661	Afghanistan	6	slab avalanche	N	0	NA	0		
Dakkhana, Shighnan, Badakhshan	2022	2	7	37.331601	71.480661	Afghanistan	6	slab avalanche	N	0	NA	0		
Dakkhana, Shighnan, Badakhshan	2022	2	24	37.331601	71.480661	Afghanistan	6	slab avalanche	N	0	NA	0		
Dakkhana, Shighnan, Badakhshan	2022	3	6	37.331601	71.480661	Afghanistan	6	slab avalanche	N	0	NA	0		
Dakkhana, Shighnan, Badakhshan	2022	3	7	37.331601	71.480661	Afghanistan	6	slab avalanche	N	0	NA	0		
Dakkhana, Shighnan, Badakhshan	2022	3	8	37.331601	71.480661	Afghanistan	6	slab avalanche	N	0	NA	0		
Dakkhana, Shighnan, Badakhshan	2022	3	9	37.331601	71.480661	Afghanistan	6	slab avalanche	N	0	NA	0		
Dakkhana, Shighnan, Badakhshan	2022	3	11	37.331601	71.480661	Afghanistan	6	slab avalanche	N	0	NA	0		
Dakkhana, Shighnan, Badakhshan	2022	3	12	37.331601	71.480661	Afghanistan	6	slab avalanche	N	0	NA	0		
Dakkhana, Shighnan, Badakhshan	2022	3	16	37.331601	71.480661	Afghanistan	6	slab avalanche	N	0	NA	0		
Budardha, Ishkashim,	2022	1	30	37.239096	71.481093	Afghanistan	6	slab avalanche	N	0	NA	0		

Location	Year	Month	Day	Latitude	Longitude	Country	Region_ HiMAP	Type	Impact	Fatalities	Injured	Livestock	Leisure	Remarks
Badakhshan														
Khawer-Redaj, Shighnan, Badakhshan	2022	3	13	37.551233	71.482798	Afghanistan	6	slab avalanche	N	0	NA	0		
Chawgantrashan, Shighnan, Badakhshan	2022	3	8	37.428739	71.487789	Afghanistan	6	slab avalanche	N	0	NA	0		
Deerdeh murghan, Shighnan, Badakhshan	2022	3	6	37.540854	71.489308	Afghanistan	6	slab avalanche	N	0	NA	0		
Badam Tendir, Shighnan, Badakhshan	2022	3	13	37.577006	71.491324	Afghanistan	6	slab avalanche	N	0	NA	0		
Shiduj Dara, Shighnan, Badakhshan	2022	2	23	37.690908	71.492748	Afghanistan	6	slab avalanche	N	0	NA	0		
Shiduj Dara, Shighnan, Badakhshan	2022	2	25	37.690908	71.492748	Afghanistan	6	slab avalanche	N	0	NA	0		
Shiduj Dara, Shighnan, Badakhshan	2022	3	13	37.690908	71.492748	Afghanistan	6	slab avalanche	N	0	NA	0		
Shiduj Dara, Shighnan, Badakhshan	2022	3	16	37.690908	71.492748	Afghanistan	6	slab avalanche	N	0	NA	0		
Shiduj Dara, Shighnan, Badakhshan	2022	3	17	37.690908	71.492748	Afghanistan	6	slab avalanche	N	0	NA	0		
Shiduj Dara, Shighnan, Badakhshan	2022	3	19	37.690908	71.492748	Afghanistan	6	slab avalanche	N	0	NA	0		
Sawan, Shighnan, Badakhshan	2022	3	13	37.511841	71.493783	Afghanistan	6	slab avalanche	N	0	NA	0		
Vazh Reem, Shighnan, Badakhshan	2022	3	15	37.589777	71.497208	Afghanistan	6	slab avalanche	N	0	NA	0		
Jangal (Pajwar), Shighnan, Badakhshan	2022	3	5	37.939917	71.499149	Afghanistan	6	slab avalanche	N	0	NA	0		
Jangal (Pajwar), Shighnan, Badakhshan	2022	3	6	37.939917	71.499149	Afghanistan	6	slab avalanche	N	0	NA	0		

Location	Year	Month	Day	Latitude	Longitude	Country	Region_HiMAP	Type	Impact	Fatalities	Injured	Livestock	Leisure	Remarks
Jangal (Pajwar), Shighnan, Badakhshan	2022	3	6	37.939917	71.499149	Afghanistan	6	slab avalanche	N	0	NA	0		
Jangal (Pajwar), Shighnan, Badakhshan	2022	3	17	37.939917	71.499149	Afghanistan	6	slab avalanche	N	0	NA	0		
Wirathn, Shighnan, Badakhshan	2022	3	13	37.618217	71.505595	Afghanistan	6	slab avalanche	N	0	NA	0		
Wereezn (Shighnan), Shighnan, Badakhshan	2022	3	6	37.650397	71.52035	Afghanistan	6	slab avalanche	N	0	NA	0		
Wereezn (Shighnan), Shighnan, Badakhshan	2022	3	14	37.650397	71.52035	Afghanistan	6	slab avalanche	N	0	NA	0		
Nawadak, Shighnan, Badakhshan	2022	1	5	37.754768	71.533969	Afghanistan	6	slab avalanche	N	0	NA	0		
Nawadak, Shighnan, Badakhshan	2022	2	6	37.754768	71.533969	Afghanistan	6	slab avalanche	N	0	NA	0		
Nawadak, Shighnan, Badakhshan	2022	2	7	37.754768	71.533969	Afghanistan	6	slab avalanche	N	0	NA	0		
Nawadak, Shighnan, Badakhshan	2022	3	2	37.754768	71.533969	Afghanistan	6	slab avalanche	N	0	NA	0		
Nawadak, Shighnan, Badakhshan	2022	3	10	37.754768	71.533969	Afghanistan	6	slab avalanche	N	0	NA	0		
Nawadak, Shighnan, Badakhshan	2022	3	13	37.754768	71.533969	Afghanistan	6	slab avalanche	N	0	NA	0		
Nawadak, Shighnan, Badakhshan	2022	3	14	37.754768	71.533969	Afghanistan	6	slab avalanche	N	0	NA	0		
Nawadak, Shighnan, Badakhshan	2022	3	15	37.754768	71.533969	Afghanistan	6	slab avalanche	N	0	NA	0		
Nawadak, Shighnan, Badakhshan	2022	3	16	37.754768	71.533969	Afghanistan	6	slab avalanche	N	0	NA	0		
Nawadak, Shighnan, Badakhshan	2022	3	17	37.754768	71.533969	Afghanistan	6	slab avalanche	N	0	NA	0		
Chasnood Bala, Shighnan, Badakhshan	2022	3	17	37.777881	71.545796	Afghanistan	6	slab avalanche	N	0	NA	0		

Location	Year	Month	Day	Latitude	Longitude	Country	Region_HiMAP	Type	Impact	Fatalities	Injured	Livestock	Leisure	Remarks
Kunar Province, Afghanistan	2022	2	7	35.117071	71.559069	Afghanistan	8	snow avalanche	Y	19	NA	NA		
Khak Ali, Darayim, Badakhshan	2022	3	14	36.706726	71.569351	Afghanistan	6	slab avalanche	N	0	NA	0		
Khashak, Nusai, Badakhshan	2022	1	4	36.70668	71.569359	Afghanistan	6	slab avalanche	N	0	NA	0		
Rubat (Shighnan), Shighnan, Badakhshan	2022	3	13	36.70668	71.569359	Afghanistan	6	slab avalanche	N	0	NA	0		
Larky, Yamgan, Badakhshan	2022	3	14	36.70668	71.569359	Afghanistan	6	slab avalanche	N	0	NA	0		
Rubat (Shighnan), Shighnan, Badakhshan	2022	3	14	36.70668	71.569359	Afghanistan	6	slab avalanche	N	0	NA	0		
Rubat (Shighnan), Shighnan, Badakhshan	2022	3	14	36.70668	71.569359	Afghanistan	6	slab avalanche	N	0	NA	0		
Wirathn, Shighnan, Badakhshan	2022	3	14	36.70668	71.569359	Afghanistan	6	slab avalanche	N	0	NA	0		
Gharjween, Shighnan, Badakhshan	2022	3	14	36.70668	71.569359	Afghanistan	6	slab avalanche	N	0	NA	0		
Arakht, Shighnan, Badakhshan	2022	3	14	36.70668	71.569359	Afghanistan	6	slab avalanche	N	0	NA	0		
Rubat (Shighnan), Shighnan, Badakhshan	2022	2	24	37.838971	71.583859	Afghanistan	6	slab avalanche	N	0	NA	0		
Rubat (Shighnan), Shighnan, Badakhshan	2022	3	16	37.838971	71.583859	Afghanistan	6	slab avalanche	N	0	NA	0		
Rubat (Shighnan), Shighnan, Badakhshan	2022	3	17	37.838971	71.583859	Afghanistan	6	slab avalanche	N	0	NA	0		
Kherkat, Nusai, badakhshan	2022	3	7	36.985416	73.38244	Afghanistan	8	slab avalanche	N	0	NA	0		

Location	Year	Month	Day	Latitude	Longitude	Country	Region_HiMAP	Type	Impact	Fatalities	Injured	Livestock	Leisure	Remarks
Kherkat, Nusai, Badakhshan	2022	3	12	36.985416	73.38244	Afghanistan	8	slab avalanche	N	0	NA	0		
Jalal-Abad	2022	2	14	41.12026	73.772608	Kyrgyzstan	4	NA	Y	3	NA	NA		
2022 Kyrgyzstan avalanche	2022	2	15	41.12026	73.772608	Kyrgyzstan	4	NA	Y	3	NA	NA		
Nilt	2022	4	22	36.231076	74.418877	Pakistan	9	NA	N	0	0	0		
Molodejny	2022	4		43.054354	77.047463	Kazakhstan	4	NA	Y	2	NA	NA		
Shymbulak	2022	3	10	43.128277	77.080485	Kazakhstan	4	NA	Y	1	NA	NA	Y	
Byasimare, Bajhang	2022	6	2	29.641032	81.074734	Nepal	11	NA	Y	1	NA	NA		Local people suspected wildfire in pine forest as a cause of avalanche
Kobang	2022	3		28.718882	83.582068	Nepal	11	NA	Y	0	NA	7		
Katon-Karagay	2022	6	23	49.152485	85.562966	Kazakhstan	NA	NA	Y	2	1	NA		
Kameng sector	2022	2	6	27.478782	92.11086	India	12	snow avalanches	Y	7	NA	NA		
Jamarch Bala, Maimai, Badakhshan	2022	2	23	NA	NA	Afghanistan	8	slab avalanche	N	0	NA	0		
Lech (Sanglige), Shukai, Badakhshan	2022	1	3	NA	NA	Afghanistan	6	slab avalanche	N	0	NA	0		
Taajdara, Raghistan, Badakhshan	2022	1	3	NA	NA	Afghanistan	8	slab avalanche	Y	5	NA	0		
Chamber	2022	6	24	NA	NA	Pakistan		NA	Y	1	0			
Nathula, Sikkim	2023	4	4	27.376775	88.763713	India		NA	Y	7	11			
Chika	2023	2	5	NA	NA	India		NA	Y	3		0		
Naltar	2023	1	18	36.171337	74.16054	Pakistan	8	NA	Y	2	0	0		
Medog	2023	1	17	29.726213	95.666218	China		NA	Y	28	5	0		
Khorog	2023	2	14	37.494658	71.550686	Tajikistan		NA	Y	18				
NA	2023	2	14	NA	NA	Tajikistan		NA	Y	1				
NA	2023	2	14	NA	NA	Tajikistan		NA	Y	1				
Badakhshan	2023	2	25	NA	NA	Afghanistan	6	NA	Y	4				
Badakhshan	2023	2	18	NA	NA	Afghanistan	6	NA	Y	12	12			The avalanches also injured 12 people and de-stroyed 50

Location	Year	Month	Day	Latitude	Longitude	Country	Region_HiMAP	Type	Impact	Fatalities	Injured	Livestock	Leisure	Remarks
														homes, he added.
Darchula	2023	5	2	29.778079	81.246683	Nepal		NA	Y	5	3			
Mugu	2023	5	7	29.804486	82.533269	Nepal		NA	Y	3	12			
Astore	2023	5	27	34.979141	74.529228	Pakistan	8	NA	Y	11	13			
Bajhang	2023	5	21	NA	NA	Nepal	11	NA	Y	3	3	0		
Chamoli	2023	6	7	NA	NA	India		NA	Y	1	0			
Gozhak	2023	2	16	NA	NA	Tajikistan		NA	Y	1	0			
Manaslu	2023	9	26	28.601824	84.621013	Nepal		NA	Y	0	15	0		
Gulmarg	2023	1	30	34.05491	74.392715	India		NA	Y	2	0	0	Y	
Dangam	2023	2	6	34.996706	71.413035	Afghanistan	6	NA	Y	10	9			
NA	2002-2008	NA	NA	NA	NA	Kyrgyzstan	5	NA	Y	56	NA	NA		
Saif ul Mulook	2016	8	21	34.908453	73.670089	Pakistan	8	NA	Y	3	0	0	Y	
Babusar	2018	5	30	35.142921	74.039331	Pakistan	8	NA	Y	4	NA	0		
Besai	2015	10	25	35.052945	73.93391	Pakistan	8	NA	Y	2				
Saif ul Mulook	2024	3	21	34.908453	73.670089	Pakistan	8	NA	Y	0	0	0		

Annexure B

Table B. Fatalities in the Peaks

Peak	Elevation	Country	Total_fatalities	Total_events	Staff_fatalities
Shimshal	?	Pakistan	1	1	0
Gangapurna	7455	Nepal	8	1	0
Sisne Himal	5911	Nepal	1	1	0
Pik Lenin	7134	Tajikistan/Kyrgyzstan	43	1	0
Khan Tengri	7010	Kyrgyzstan/Kazakhstan	11	3	0
Belukha	4506	Kazakhstan	2	1	0
Mingbo Eiger	6017	Nepal	3	1	0
Tashi Kang	6386		1	1	0
Langshisa Ri	6412	Nepal	9	3	0
Hiunchuli (Patal Hiunchuli)	6434	Nepal	4	2	1
Kande Hiunchuli North I	6521	Nepal	1	1	0
Chobuje	6686	Nepal	2	1	0
Ganesh V	6770	Nepal	4	1	0
Ama Dablam	6814	Nepal	7	2	3
Leonpo Gang	6979	Nepal	3	1	2
Kang Guru	6981	Nepal	15	1	11
Thulagi	7059	Nepal	1	1	0
Ganesh IV	7104	Nepal	4	2	0
Ganesh II	7118	Nepal	3	1	0
Himlung Himal	7126	Nepal	4	2	4
Tilicho	7134	Nepal	4	2	0
Pumori	7138		19	5	5
Chamar North (Peak 23)	7165	Nepal	1	1	0
Gurja Himal	7193	Nepal	9	1	4
Annapurna South (Annapurna Dakshin)	7219	Nepal	5	2	2
Langtang Lirung	7227	Nepal	13	3	4
Putha Hiunchuli	7246	Nepal	3	1	1

(Dhaulagiri VII)					
Himalchuli North	7331	Nepal	3	1	0
Churen Himal West	7371	Nepal	2	1	0
Gangapurna	7455	Nepal	10	2	5
Shartse II	7457	Nepal	1	1	0
Annapurna IV	7525	Nepal	3	2	1
Annapurna III	7555	Nepal	3	1	0
Annapurna III	7555	Nepal	1	1	0
Dhaulagiri V	7618	Nepal	1	1	0
Dhaulagiri IV	7661	Nepal	4	2	4
Jannu (Khumbhakarna)	7711	Nepal	2	1	0
Dhaulagiri II	7751	Nepal	2	1	2
Nuptse	7864	Nepal	1	1	0
Peak 29 (Ngadi Chuli, Dr Harka Gurung Chuli)	7871	Nepal	3	1	0
Shisha Pangma	8013	China	17	9	4
Gasherbrum II	8035	Pakistan/China	4	3	0
Broad Peak	8047	Pakistan	5	4	1
Gasherbrum I	8068	Pakistan/China	10	4	4
Annapurna I	8091	Nepal	41	19	13
Nanga Parbat	8125	Pakistan	36	11	11
Manaslu	8163	Nepal	39	11	13
Dhaulagiri	8167	Nepal	44	16	16
Cho Oyu	8201	Nepal/China	10	5	5
Makalu	8463	Nepal/China	3	3	1
Lhotse	8516	Nepal	14	8	2
Kangchenjunga	8586	Nepal/India	6	0	2
K2	8611	Pakistan/China	24	10	4
Qomolongma	8848	Nepal/China	98	33	69

Annexure C

Sheet No:

Questionnaire for Avalanche hazard analysis

Hokkaido University, Graduate School of Environmental Science
Anushilan Acharya

The results of this questionnaire will be used in my research to analyze the avalanche hazards in Annapurna Conservation Area (ACA), Nepal. They will be compiled as part of my doctoral thesis

Section A

Socio economic information

Q1. How many years have you lived in this place?

....

Q2. Do you own a house? (*Tick one*)

☐ Yes
☐ No

If "Yes", proceed to **Q3**.

If "No", please provide detail on following and then proceed to **Q3**.

a. How are you living here? (*Tick one*)

☐ Rented
☐ As a caretaker
☐ Others…………………….

Q3. Did avalanche events damage your house? (*Tick one*)

☐ Yes
☐ No

If "No", please proceed to **Q4**

If "Yes", please provide the detail on

When							
Level of damage (Low=1, Med=2, High=3)							

Q4. Do you own livestock? (*Tick one*)

☐ Yes
☐ No

If "No", proceed to **Section B.**

If "Yes", please provide the detail on following and then proceed to **Section B**

a. Detail about livestock

Type	Number
Yak	
Cow	
Lulu	
Jhhopa	
Horse	
Mule	
Himalayan Goat	
Goat	
Sheep	
Others	
Total	

b. Have you insured your livestock (*Tick one*)

☐ Yes
☐ No

If "No", please proceed to **Section B**

If "Yes", please provide the detail on

c. Which livestock have you insured?

S.N.	Livestock	Remarks
1		
2		
3		

Section B

Impacts of avalanches

Q5. Please provide the detail on human fatalities/Injuries if your family has experienced any

S.N.	Date of event	Number of human fatalities	Number of human injuries	Remarks
1				
2				
3				
4				
5				
Total				

Q6. Please provide detail on Livestock fatalities if you have experienced any

S.N.	Date of event	Types of livestock	Number of livestock killed	Remarks
1				
2				
3				
4				
5				
Total				

Q7. Please provide detail on crop damage if you have experienced any

S.N.	Date of event	Name of the crops	Area destroyed (Ropani)	
1				
2				
3				
4				
5				
Total				

Q8. Please provide detail on shed damage if you have experienced any

S.N.	Date of event	No of shed destroyed	Remarks
1			
2			
3			
4			
5			
Total			

Q9. Guesthouse damage

S.N.	No of guest house damaged	Date of event	Remarks
Total			

Section C

Supports to avalanche affected people:

Q10. Have you got any loan from government to overcome the impacts of avalanches? (*Tick one*)

☐ Yes
☐ No

Q11. Was there any support or relief program after major avalanches? (*Tick one*)

☐ Yes
☐ No

If "No", proceed to **Section D**

If "Yes", proceed to **Q12** and continue.

Q12. How many times have you received relief? (*Tick one*)

☐ Once
☐ Twice
☐ Thrice
☐ More than four times

Q13.Who supported? (*Tick one or more*)

Relatives	Friends	Government bodies	Local bodies	NGO/INGO	Others

Q14. Please provide detail on

S.N.	Agency	Date of event	Date of relief	Type of support

Section D

Avalanche mitigation and adaptation efforts:

Q15. Have you made any avalanche hazard mitigation in your house/shed?

If "No", proceed to **Q16**

If "Yes", please provide detail on

a. What it is? ………….

Q16. Do you know any avalanche awareness program of your rural municipality? (*Tick one*)

☐ Yes
☐ No
☐ Do not know

Q17. Have you heard about avalanche hazard map of your rural municipality? (*Tick one*)

☐ Yes
☐ No
☐ Do not know

Q18. Have you heard about avalanche early warning system of your rural municipality? (*Tick one*)

☐ Yes

☐ No
☐ Do not know

Q19. Do you know about Community Emergency Response Team in your rural municipality? (*Tick one*)

☐ Yes
☐ No
☐ Do not know

Q20. Do you think your family is well prepared for avalanche disaster? (*Tick one*)

☐ Yes
☐ No

Q21. Do you have 72-hour minimum disaster supplies on hand? (*Tick one*)

☐ Yes
☐ No

Q22. Have you discussed avalanche disaster preparedness with your family? (*Tick one*)

☐ Yes
☐ No

Q23. Has your family discussed where to meet outside if there is an avalanche disaster in your home? (*Tick one*)

☐ Yes
☐ No

Q24. Do you know the safe area in and near your shed/house? (*Tick one*)

☐ Yes
☐ No

If "No", proceed to **section E**

If "Yes",

a. Where……………….
b. How many minutes does it take to the area on foot?..........

Q25. Do you regularly practice to evacuate to safe area? (*Tick one*)

☐ Yes
☐ No

Q26. Is it easy for all family members to go to the safe area? (*Tick one*)

☐ Yes
☐ No

Section E

General Information:

Q27. Family Description

S. N	Name	Age	Sex	Marital status	Occupation	Remarks

Q28. Address: RM/Municipality………………. Ward No…..…

Village…………………………

Q29. Ethnicity (*Tick one*)

Thakali	Gurung	Dalit	Brahmin	Chhetri	Others

Q30. Education (*Tick one*)

Illiterate	Literate	Remarks

Annex D

Photo 1: Freshly released avalanche in Deurali, ABC, Area 1 (Anushilan Acharya, May 2023)

Photo 2: Avalanche slopes with avalanches near ABC, Area 1 (Anushilan Acharya, May 2023)

Photo 3: Runout zone of avalanche in Kobang, Area 2 (Anushilan Acharya, 2023)

Photo 4: Forest destroyed due to avalanche in November 2021 in Kobang, Area 2 (Anushilan Acharya, 2023)

Photo 5: Questionnaire survey in ABC, Area 1 (Photo: Harsha Thakuri, May2023)

Photo 6 Questionnaire survey in Chhaktang, Area 2 (Photo: Jivan Thakali, May2023)


Photo 7: Questionnaire survey in Larjung, Area 2 (Photo: Jivan Thakali, May2023)