GEO511 – Master's thesis

Analysis of weather- and climate-related disasters in mountain regions using different disaster databases

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Cover pictures:

1. Drought (Getty Images, 2014)
2. Tian Shan Mountains of Kyrgyzstan (Nico Rohrbach 2014)
3. Kedarnath Flood India (Getty Images, 2013)

Abstract

Mountains are fragile ecosystems with global importance as water towers for adjacent, densely populated lowlands. Mountains are source of forests and timber, minerals, biodiversity hotspots, cultural diversity and are home to 600 million people. Mountains are crucial regions for sustainable development and human wellbeing regarding food security and poverty mitigation. However, mountains are natural disaster-prone regions and exposed to multiple hazards such as avalanches, landslides, floods, debris flows and glacial lake outbursts. Thus, the projected global temperature increase will strongly influence the frequency and intensity of natural disasters in mountain regions, especially with regard to hydro-meteorological events.

For a systematic registration of these hazards, various global, regional and local disaster databases record and store information about occurrences and impacts of natural disasters in time and space. They help to identify disaster-prone areas and destructive hazards by a number of variables including human and economic losses. Information from databases enables analysis of occurrences and impacts of disasters over time and space and supports preparedness and the mitigation of events.

The first objective of this study comprises an analysis of the quality and completeness of the four selected databases (EM-DAT, NatCatSERVICE, DesInventar and Dartmouth) and investigates the reliability of the various databases for weather- and climate-related natural disasters. The study identifies the numbers of fatalities as the most reliable loss parameters, whereby the number of people affected and the economic loss are less trustworthy and highly dependent on the purposes of each databases. This study emphasizes the main limitations regarding sustainable mountain development such as the inhomogeneity in database definitions, spatial resolutions, database purposes and reveals the lack of data registration for human and economic losses.

The second objective focuses on the analysis of the occurrence and frequency of natural disasters in the time period 1980-2014 in the context of climatic and global changes in the five mountain regions: Hindu Kush-Himalaya, Andes, Alps, the mountainous parts of Africa and Central Asia. The regional analysis and the disaster risk statistics emphasize that floods and mass movement (avalanche, landslide, debris flow) disasters are most frequent and imply the highest relative vulnerability for mountain people. Although the number of registered disasters has generally increased, the number of fatalities is stable, whereas the number of affected people shows an increased trend over the observed time period.

Climate changes with higher temperatures and change in precipitation patterns in the past have increased the disaster frequencies in mountain regions. These important impacts have changed the livelihoods of mountain people and increased their economic, social and environmental vulnerabilities. With growing population, land use changes and higher exposure, the frequencies and intensities of natural hazards in mountain areas are expected to increase in future.

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Abbreviations

CRED	Centre for Research on the Epidemiology of Disasters
DesInventar	Disaster Inventory System
DFO	Dartmouth Flood Observatory
EM-DAT	Emergency Events Database
FAO	Food and Agriculture Organization of the United Nations
GDP	Gross Domestic Product
GRIP	Global Risk Identification Program
HKH	Hindu Kush-Himalaya
IFRC	International Federation of Red Cross and Red Crescent Societies
LA RED	Network for Social Studies on Disaster Prevention in Latin America
Munich RE	Munich Reinsurance Company
NatCatSERVICE	Natural Catastrophe Loss Database
NGO	Non-Governmental Organization
OCHA	United Nations Office for the Coordination of Humanitarian Affairs
SMD	Sustainable Mountain Development
SMD4GC	Promoting Sustainable Mountain Development for Global Change
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
USAID	United States Agency for International Development
WFP	World Food Programme

1. Introduction

1.1 Significance of Mountains regarding Natural Disasters and Sustainable Development

Mountain areas cover 24% of the global land surface (Kapos et al. 2000) and are home to 600 million people, which correspond to 12% of the global human population (Huddleston et al. 2003). The majority of mountain people live in developing countries and are among the world's poorest and most disadvantaged people due to harsh climatic and environmental conditions, political, social and economic marginalization and lack of access to health and education services (Veith 2011). Mountain ecosystems are sources of water for more than half of the world's population and are important for providing freshwater for the adjacent areas downstream for drinking, domestic use, irrigation, hydropower, industry and transportation (Viviroli et al. 2007).. Mountains are crucial for sustainable development and human wellbeing (Singh et al. 2011). Sustainable mountain development therefore is essential for achieving food security and poverty alleviation. Sustainable mountain development requires that mountain ecosystems will be managed in ways that allow them to provide goods and services for local livelihoods and lowland people, now and in the future (Veith 2011).

However, mountains are high-risk environments and are highly vulnerable to environmental degradation. Climate change, pollution, globalization, armed conflicts, population growth, deforestation, exploitative agricultural practices, mining and tourism are growing problems confronting mountains as water towers of the world (Veith 2011). Mountain regions are typically exposed to multiple hazards and have become increasingly disaster-prone in recent decades (Kohler & Maselli 2009). These hazards are associated with tectonic and mountain environmental processes such as avalanches, rockfalls, debris flows, glacial lake outbursts and floods (Price et al. 2004).

The United Nations International Strategy for Disaster Reduction (UN/ISDR 2009) defines natural hazards as:

> *Any natural process or phenomenon that may cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption or environmental damage.*

Whereas the term disaster is defined as:

> *A serious disruption of the functioning of a community or a society involving widespread human, material, economic or environmental losses or impacts which exceed the ability of the affected community or society to cope using its own resources.*

A natural hazard therefore does not necessarily cause a disaster. Thus, natural disasters are the consequences of events triggered by natural hazards that overcome local response capacity from vulnerable and exposed population and seriously affect the social, political and economic development of a region (Kohler & Maselli 2009). Natural disasters are a global issue because they occur worldwide. Losses due to extreme natural hazards have increased substantially in recent decades and will likely continue to increase in frequency and severity in the ongoing century (Kron 2000). Globally, the highest death toll due to natural disasters is concentrated in developing countries (Alcántara-Ayala 2002).

Mountain regions are characterized by sensitive ecosystems, high number of extreme weather events, and natural disasters. Future impacts of climatic change on physical systems will affect water, snow, and ice and will lead to changes in the frequency and intensity of natural hazards (IPCC 2014). Changes in glaciers, snow and permafrost and corresponding impacts on natural hazards in high mountain systems are among the most directly visible signals of global warming and may seriously affect human activities (Haeberli & Beniston 1998; Kääb et al. 2005). The IPCC Fifth Assessment Report 2013 indicates an increasing global average surface temperature for the end of the 21st century (2081-2010) relative to 1986-2005 of between 0.3°C to 4.8°C according to scenario (IPCC 2014). There is high evidence that the rate of warming is intensified with elevation, such that high-mountain environments experience more rapid changes in temperature than environments at lower elevations (Pepin et al. 2015). Several studies (e.g. Kohler & Maselli 2009; Price et al. 2004) suggest that high elevation environments with glaciers, snow, permafrost and water are among the areas most sensitive to climatic changes occurring on a global scale. The high vulnerability of mountain regions occurs due to high relief, steep slopes, shallow soils, adverse climatic conditions and geological variability. The IPCC assumed that changes in heat waves, extreme precipitation events, glacier retreat, and/or permafrost degradation will affect high mountain phenomena such as slope instabilities, mass movements and glacial lake outburst floods. Changes in heavy precipitation will affect landslides in some regions (IPCC 2012).

A number of studies (e.g. Huggel et al. 2004; Kääb et al. 2005) of high mountain areas indicate a continuous threat from glacial hazards to human lives and infrastructure in high mountain regions. These hazards include avalanches, outburst of glacier lake, causing floods and debris flows, destabilization of frozen or unfrozen debris slopes and rock walls and chain reactions of these processes as cascading effects. In general, the highest potential for disaster and damage from glacial risk are glacier floods (Huber et al. 2005).

Various studies (e.g. IPCC 2012; Kohler et al. 2009) determine that the increases of natural disaster are directly related to human activity. Population change, urbanization, environmental degradation and changes caused by human activities, are key drivers for this increasing disaster trend observed in the past (Huppert & Sparks 2006). Hence, damage due to hazards in mountain regions will increase irrespective of global warming, especially in regions where populations are growing and infrastructure has been developed at exposed locations. However, there is an increased recognition of the linkages between climate change and natural disasters. Globally, climate change is very likely to increase the number of non-seismic hazards. Therefore, higher temperatures will enhance the hydrological cycle and it is predicted that they will change rainfall patterns and intensity, heat waves and glacier melt (Kohler & Maselli 2009). The frequency and severity of hot and cold extremes and heavy precipitation events is increasing. Hence, the ongoing climate change seems to impact on the frequency and intensity of hydro meteorological disasters (Shaw 2015).

Comprehensive databases on disaster due to natural hazards indicate worldwide trends with an increasing number of reported events, people affected and economic loss, but a generally decreasing number of reported fatalities in the last decades (IFRCRS 2005; Munich RE 2012; Fuchs et al. 2013). The global Emergency Events Database (EM-DAT), maintained by the Center for Research on the Epidemiology of Disasters (CRED), recorded a total number of 6,873 natural disasters between 1994 and 2013, worldwide. These include hazards such as landslides, avalanches, droughts, famines, earthquakes, extreme temperatures, floods, fires, windstorms and other natural hazards. During this 20-year period, 1.35 million or almost 68,000 people per year were killed and 218 million people were affected on average per year. The frequency of geophysical disasters was almost constant, whereas the climate-related events increased significantly (CRED 2015). EM-DAT data indicate that the majority of disasters were caused by floods, accounting for 43% of all recorded events and affecting almost 2.5 billion people. Storms were the second most frequent type of disaster, which killing more than 244,000 people. Drought affected more than one billion people, or 25% of the global total in the time period 1994 to 2013 (CRED 2015). Overall and insured losses from natural disasters have increased significantly in recent years. According to the reinsurance company Munich RE, economic losses from natural catastrophes increased from 520 billion dollars (1981-1990), 1,197 billion dollars (1991-2000) to 1,213 billion dollars (2001-2010). The economic impact of natural disasters largely depends on the level of economic development in the affected country. Scientific analyses indicate that countries with lower per capita incomes generally suffer more than countries with higher per capita incomes in terms of economic losses as a percentage of the GDP (Munich RE 2013).

For an understanding of natural hazards, it is indispensable to track, record and analyze them. Geohazard databases play a critical role in each of these steps (Klose et al. 2015). Disaster databases therefore are an important source for the storage and further processing of natural disaster data. They are a primary tool for the analysis of disaster characteristics and trends, and support disaster risk reduction and climate change adaption (Huggel et al. 2015). Numerous loss and damage databases have been developed over the last several decades with data at global, regional, national and sub-national levels (UNDP 2013). To provide reliable disaster data, there is a need for adequate database structures, standardized methodology and interoperable data (Below et al. 2010). Therefore, systematic disaster data collection is crucial in order to understand the impacts and costs of natural disasters and to help reduce disaster risk and increase resilience in affected populations (UNISDR 2015b).

The global importance of mountain issues has increased in the last decade. The term Sustainable Mountain Development (SMD) appeared first in Chapter 13 of Agenda 21 at the 1992 Rio conference. This notes the importance of mountains as sources for water, energy, agricultural and forest products, biological and cultural diversity, religion, recreation and tourism. Ten years later, the United Nations General Assembly proclaimed the year 2002 as the International Year of Mountains (IYM) with the aim to ensure the wellbeing of mountain and lowland communities by promoting the conservation and sustainable development of mountain regions (Price et al. 2004).

In the year 1990, the International Decade for Natural Disaster Reduction (IDNDR) aimed to reduce loss of life, poverty damage and social and economic disruption caused by natural disasters, especially in developing countries. Loss databases with historical and current natural catastrophes have become a valuable instrument for risk assessment in the insurance business and for socio-economic analyses to provide background for decision-making and for calling attention to natural disasters worldwide. These databases are therefore used by scientific institutes, researchers, national and international governmental and non-governmental organizations, the media and the financial and insurance sectors (Kron et al. 2012). However, a number of studies (e.g. LA RED 2002; Below et al. 2010) indicate the lack of comparable data from different disaster databases because of inhomogeneity in scale, entry criteria, structure, coverage and information files. This absence of clear standards and definitions leads to inconsistent reliability and poor interoperability of diverse disaster data (Below et al. 2009). Hence, uniform standards, operability and terminology are essential for a reliable comparison of natural disasters in different disaster databases. Therefore, in 2007, the three global databases Munich Re, CRED and Swiss Re defined a common terminology in consultation with the United Nations Development Programme (UNDP), the Asian Disaster Reduction Centre and the United Nations International Strategy for Disaster Reduction (UNISDR). As a result of this standardization, natural hazard events are divided into four hazard families: geophysical, meteorological, hydrological and climatological events (Ismail-Zadeh et al. 2014). Therefore, for UNDP, the ideal loss and damage database has to be sustainable, continuous, credible, publicly accessible, quality assured and applicable to decision-making (UNDP 2013).

1.2 Context and Motivation of the Study

The incidence of natural disasters has increased in frequency across the globe over the past decades. However, mountains are among the most disaster-prone regions and are more frequently affected than other environments by destructive natural processes. Mountains are highly vulnerable to global (climate) change and related risks and suffer from high poverty rates, multiple hazards and risks, land degradation and land grabs. Mountain ecosystems and their inhabitants are among the regions most vulnerable to and already affected by climate change and are hazard-prone environments with mountain-specific hazards such as avalanches and landslides (Wehrli 2012).

Sustainable mountain development therefore is essential to reduce poverty and improve the livelihoods of mountain people, to preserve and protect natural resources, promote political stability and build resilience and capacity for climate change adaptation and mitigation (Veith 2011).

A number of disaster databases on a global, national and regional exist but there is a research gap regarding their reliability for natural disasters occurring in mountain regions and for serving the needs of SMD. Unfortunately, little has been known about weather- and climate-related natural disasters in mountain regions with data originated from worldwide disaster databases. This present study is aimed at filling in this knowledge gap and helps to better understand the importance of disaster occurrence in mountain regions under ongoing global changes, and reveals the need for sustainable mountain development. Disaster data analyses therefore are important for a better understanding of the risk of natural hazards and vulnerability and measures the impact of mountain people regarding SMD and illustrates the complexity of mountain specific disaster data procedures.

This study investigates the quality and reliability of the four databases, which is crucial for the usefulness of diverse database systems and their applications. Furthermore, the study illustrates the main limitations of the selected databases and presents suggestions for a more reliable comparability and interoperability of these data entries for serving the needs of SMD.

This study is part of the SMD4GC (Promoting Sustainable Mountain Development for Global Change) project, which started in 2013 and will end in 2017. The program includes four major mountain regions of the global South and East with a view towards sustainable mountain development. The mountain regions are Africa, South America, Hindu Kush-Himalaya and Central Asia. Additionally, the European Alps as a mountain range in the northern hemisphere are also part of the present study. The main target of the SMD4GC program is to provide an essential contribution to sustainable development in mountainous areas under uncertain changes in climatic, environmental and socio-economic conditions by focusing on poverty and risk reduction. The main topics of this program are climate change adaption, water and land management, as well as food security, energy and migration (Wehrli 2012).

The aim of the present study is to compare and evaluate four selected disaster databases with respect to data quality and completeness in mountain regions. Therefore, three global disaster databases (EM-DAT, Dartmouth and NatCatSERVICE) and one regional database (DesInventar) are analyzed and evaluated, regarding the reliability of different data entries. The disaster database quality assessment is based on a model from Below et al. (2010b), which allows an evaluation of different databases. For the analysis of completeness of contents of each database, basic data elements such as the geographical location, economic loss, date and zero values are investigated.

The first part of the study focuses on the structure, quality and completeness of the four disaster databases used in the analysis with following research questions:

- How reliable are the selected disaster databases and their basic elements for an analysis of weather- and climate-related natural disasters in mountain regions?

- What are the main limitations of the selected disaster databases and how could they be improved regarding sustainable mountain development?

Furthermore, the study describes an analysis of weather- and climate- related disasters in mountain regions with an identification of the global disaster distribution and disaster trends, in the time period from 1980 until today. The study area includes five mountain regions: the Andes in South America, mountainous areas in North and East Africa, the Alps, Central Asia and the Hindu Kush-Himalaya region. The focus of the spatiotemporal changes in disaster occurrence lies on the most disaster-prone regions Hindu Kush-Himalaya, East Africa and Central Andes. The disaster loss analysis gives an overview of the disaster mortality rate together with the ratio of affected people in the past and illustrates the accordance between different data sources. The extreme event case study of the Kedarnath flood in northern India in 2013 indicates the various database entries and geographical locations. The study makes reference to the importance of disasters in mountain regions and describes the main limitations of different databases and their influence on the results as well as providing some suggestions for improvements regarding disaster database quality and sustainable mountain development.

The second part of the study analyzes disaster data with a focus on disaster types, disaster occurrence and change over time in the five mountain regions with following research questions:

- What is the frequency and geographical distribution of weather- and climate-related disasters in mountain regions?

- How did disaster occurrence change over time (1980-2014) in the context of climatic and global change?

2 Study Regions

The focus of the study lies on five mountain regions. The selection is based on the research priority of the SMD4GC program and includes the Hindu Kush-Himalaya region, the Andes and the mountains of Africa and Central Asia. For a more comprehensive and complete evaluation, the European Alps as a mountain range in the northern hemisphere, are also included in the analysis. The central subjects for study are the five coherent mountain regions and not the individual countries located in these mountainous areas. For a disaster analysis not only physical mountain aspects are important, but also socio-economic issues. The following chapter gives an overview of the five mountain regions. For a more detailed overview of each of the mountain countries with corresponding mountain states see Appendix A.1.

2.1 Hindu Kush-Himalaya

The Hindu Kush-Himalayan (HKH) region covers an area of more than 4 million km^2, which is about 2.9% of the global land area and approximately 18% of the global mountain area (Figure 1). The Himalaya region consists of the large thrust sheets formed from the basement of the advancing Indian continent (Gerrard 1990). The massive mountain ranges contain many of the world's tallest peaks such as Mount Everest (8,848 m a.s.l.), K2 (8,611 m a.s.l.) and Annapurna (8,091 m a.s.l.) (Singh et al. 2011). The HKH region encompasses the mountains of eight South and East Asian countries including all of Nepal and Bhutan and the mountainous parts of Afghanistan, Bangladesh, China, India, Myanmar and Pakistan (Karki et al. 2011).

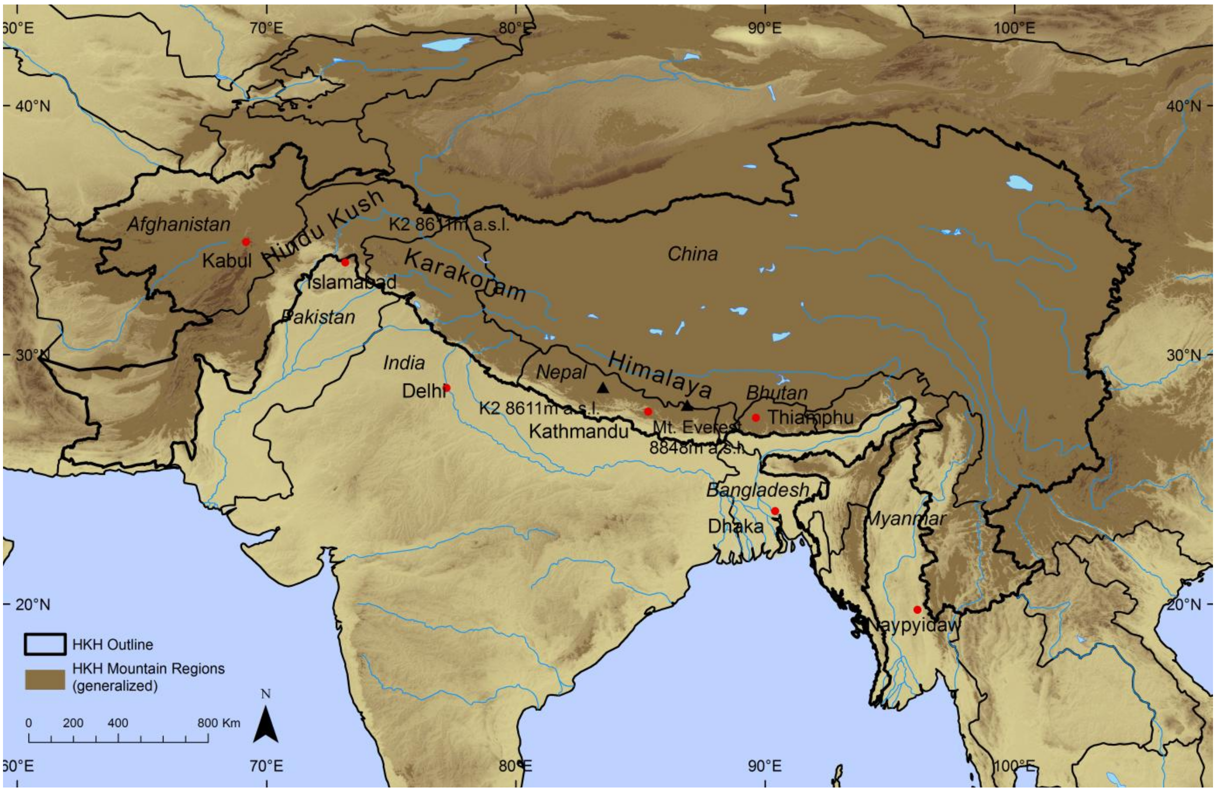

Figure 1: Mountain regions of the Hindu Kush-Himalaya

The HKH region is often referred to as the “water tower of Asia” as it stores a large volume of water in the form of ice and snow, and the mountainous part is the source of many major river systems in the region such as the Amu Darya, Indus, Ganges, Brahmaputra, Mekong and Yangtze (Schild 2008). The HKH region covers the largest glaciated areas in the world, excluding the Polar Regions, with more than 50,000 glaciers. They cover an area greater than 61,000 km^2 which represents about 30% of the total glaciated mountain area of the world (Singh et al. 2011). The HKH region contains three climatic zones: western, central and eastern Himalaya. The western Himalaya has two major rainy seasons, whereas the two other zones only have one (Kulkarni et al. 2013). The HKH mountain area is home to 210 million people with an annual growth of 2% in 2011 and with a continuing state of high birth and death rates with an increasing urban population growth rate. Almost all the mountain regions of the HKH are subsistence agricultural economics with 31% of the HKH living below the official poverty line (Karki et al. 2011).

2.2 Central Asia

The region of Central Asia covers an area of 4 million km^2 and has a population of 59 million (Gupta 2009) with an annual population growth of 0.7% in 2014. Central Asia includes the five countries Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan and Uzbekistan (Figure 2). Mountains cover 800,000 km^2 or about 20% of the total area of Central Asia. The Pamir Mountains in Tajikistan and the Tien Shan in Kyrgyzstan are the two major mountain ranges in this region. The highest peak of Tien Shan is Jengish Chokusu (7,439 m a.s.l.), Somoni peak (7,495 m a.s.l.) the highest in the Pamir Mountains, located in Kyrgyzstan and Tajikistan

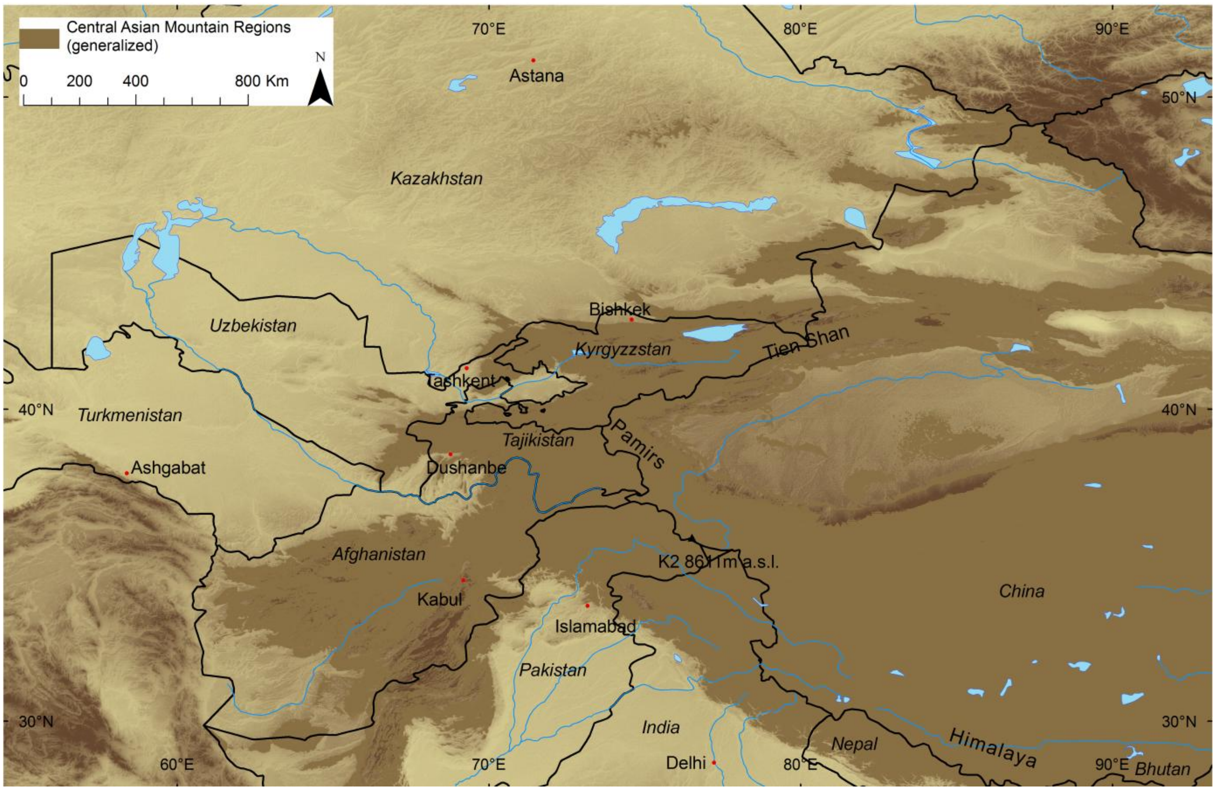

Figure 2: Mountain regions of Central Asia

respectively. Mountain ecosystems also cover parts of eastern Kazakhstan (10%), southeast Uzbekistan (20%) and Turkmenistan (5%). However, Kyrgyzstan with 90% mountain-covered area, Tajikistan with 93%, contain the greatest mountain areas and are importance as water source regions for the two main river systems Syr Darya in the Tien Shan mountains and Amu Darya in the Pamir. Tajikistan and Kyrgyzstan hold 40% and 30% respectively of the water resources serving the five Central Asia countries. Glaciers cover in total an area of about 12,000 - 14,000 km^2 of which an area of 4% in Kyrgyzstan and 6% in Tajikistan are covered (Batjargal et al. 2008). Most parts of Central Asia have a semiarid or arid climate. The Tien Shan and Pamir climatic conditions vary and are characterized by harsh and dry conditions in the interior and in the eastern part with below zero annual surface temperatures and 150-300 mm average annual precipitation. The western parts are more humid and temperate with average annual precipitation of 1,000 mm - 1,500 mm, mainly in winter and spring (Batjargal et al. 2008). Mountain pastoralism is a significant part of the GDP (gross domestic product) in Kyrgyzstan and Tajikistan with a population below poverty line of 35% (Kerven et al. 2012).

2.3 Africa

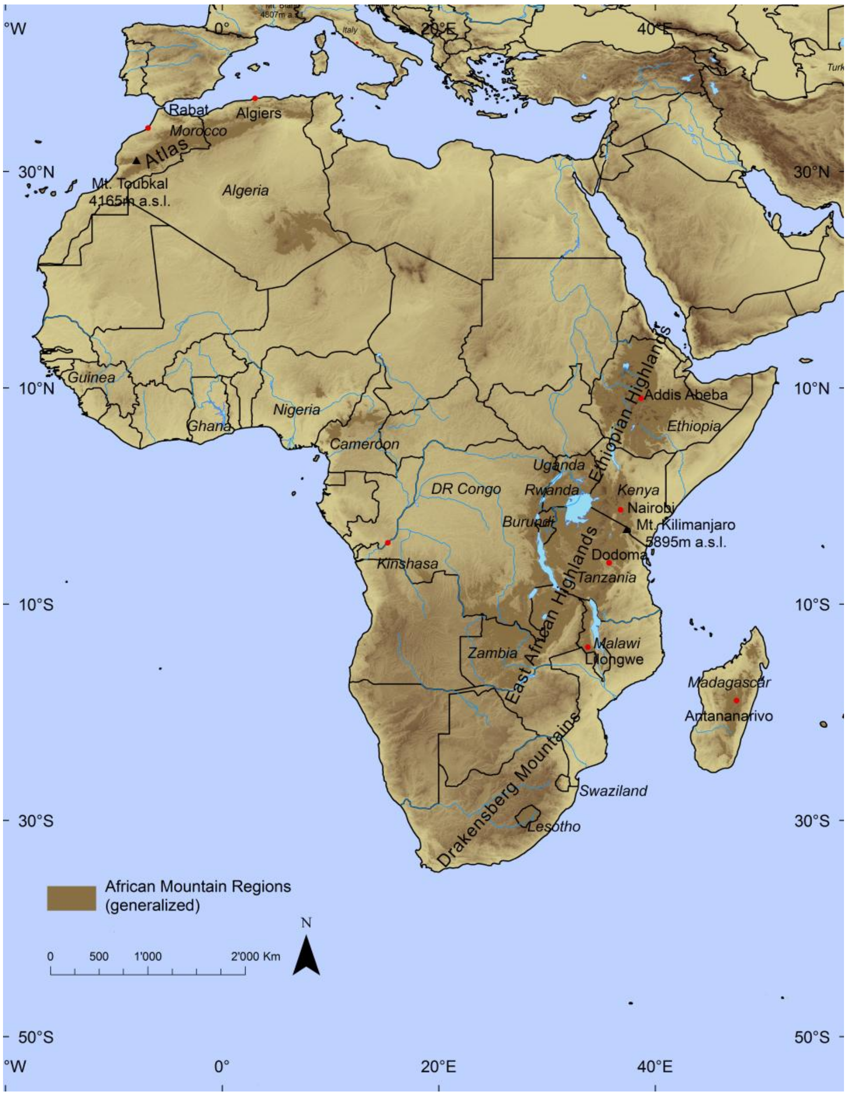

Figure 3: Mountain regions of Africa

Mountains in Africa generally occur widely scattered between the plateaus and plains that dominate the landscape (Figure 3). Approximately half of Africa's countries encompass mountains higher than 2000 m. The mountainous parts higher than 4,500 m are concentrated in the northwestern, central and eastern regions of the continent. These mountainous regions cover about 3 million km^2. The Atlas Mountain Range is located in the northwestern end of the continent, formed by the collision of the African and Eurasian tectonic plates. The Atlas Mountains extend 1,610 km across Morocco, Algeria and Tunisia. The highest peak in the Atlas Mountains is Mount Toubkal at 4,165 m a.s.l. The Ethiopian Highlands in northeastern Africa include 90% of its arable lands and are occupied by 90% of the human population of the country (Hurni et al. 2010). The Muchinga (Mitumba) Mountain range in East Africa and other mountain ranges surround the eastern and western Rifts including Mount Kilimanjaro (5,895 m a.s.l.) and Mount Meru (4,565 m a.s.l.) in Tanzania, Mount Kenya (5,199 m a.s.l.) in Kenya, Mount Elgon (4,321 m a.s.l.) on the border of Kenya and Uganda and the Ruwenzori massif (5,109 m a.s.l.), located on the border of Uganda and Congo. In southern Africa the Drakensberg mountains represent the highest elevations in South Africa with the highest peak being Thabana Ntlenyana (3,482 m a.s.l.) (UNEP 2008). Glacier distribution in Africa is limited to three specific geographic locations - the two volcanoes Mount Kenya and Kilimanjaro and the Ruwenzori mountain range located in East Africa near the equator (UNEP 2012). The mountainous sources of large river systems such as the Nile, Niger, Senegal, Congo, Tana, Zambezi and Orange supply the arid lowland areas with water. The eastern Africa climate is dominated by three monsoon winds - a dry northeasterly monsoon in the northern hemisphere winter, a shallow southeasterly summer monsoon and a wet monsoon from the Equatorial Atlantic. The seasonal rainfall correlates with these seasonal wind patterns and changes in the intertropical convergence zone (ITCZ). Precipitation of the Kenyan Highlands, including Mount Kenya and Mount Elgon, has a variation of 700-1,300 mm, whereas the maximum rainfall occurs at 2,500 - 3,000 m a.s.l. on southeast Kenya with 2,500 mm per year. Above 4,500 m, most precipitation originates as snow and hail. The annual temperature range decreases from the subtropics to the equator, with Mount Kenya experiencing an annual range of about 2°C and a daily range of 10 - 20°C (Funnel & Parish 2002). The average population density in mountain areas is more than triple compared to the lowland areas with up to 40% population under poverty line (UNEP 2015).

2.4 Andes

The Andes are the longest mountain range in the world with a length of about 8,000 km. The Andes stretch from the north of Colombia south through the seven Andean countries Venezuela, Colombia, Ecuador, Peru, Bolivia, Argentina and Chile to Tierra del Fuego in Argentina (Figure 4). The High Cordillera of the Andes were formed during the Mesozoic and Cenozoic Ages (Gerrard 1990). The Andes consist of a single mountain chain in Chile which widens in Peru and Bolivia to split into the two east and west Cordilleras (Cordillera Oriental and Cordillera Occidental) separated by the high plateau of the Altiplano (Gerrard 1990). Aconcagua (6,968 m a.s.l.) is the highest peak of the Andes, located in Argentina (Borsdorf & Stadel 2015). The Andes cover an area of more than 2.5 million km^2 and are home to 85 million people with a maximum of 50% of total population under poverty line in Peru. The tropical Andes host about 99% of all tropical glaciers in the world, most of them in Peru (71%), followed by Bolivia (20%), Ecuador (4%) and Colombia-Venezuela (4%). The tropical Andes glaciers cover an estimated area of about 1,920km^2 in the early 2000s (Rabatel et al. 2013). The tropical Andes can be divided into two climatic zones. The inner tropical zone (Colombia and Ecuador) receives relatively continuous precipitation throughout the year, while the outer tropical zone (Peru and Bolivia) experiences subtropical conditions with a dry season from May to September and tropical conditions with a wet season from October to March (Rabatel et al. 2013).

Figure 4: Mountain regions of the Andes

2.5 Alps

The (European) Alps are a folded mountain range stretching along an arc of about 1,200 km, from Nice to Vienna (Figure 5). This Alpine belt was formed by the movement of many plates over the last 200 million years (Gerrard 1990). The Western Alps are higher and more curved, being located in France, Italy and western Switzerland, whereas the Eastern Alps are longer and extend from eastern Switzerland through parts of Italy, Germany, Austria to Slovenia. The Alps cover an area of about 191,000 km^2. Fourteen million people live in the Alps, concentrated in towns and cities around the periphery and in low-lying valleys (Chatré et al. 2010). Generally, migration is more important than natural population change, whereas population in central and northern Alps is growing with a decrease of the eastern and southern Alps (Price et al. 2012). Most jobs are in the tertiary sector (Price et al. 2012). Mont Blanc is the highest massif in the Alps with an elevation of 4,807 m a.s.l. The mountains and glaciers in the Alps are the reservoir of Europe's water with headwaters of the rivers Danube, Rhine, Po and Rhone being located in the region (Schwaiger 2007). Zemp & Paul (2004) describe glacier fluctuations in the European Alps from 1850 to 2000. The Alpine glacier-covered areas decreased from 4,470 km^2 in 1850 to 2,270 km^2 in 2000. This corresponds to an overall glacier area loss since 1850 of almost 50% by 2000 (Zemp et al. 2008).

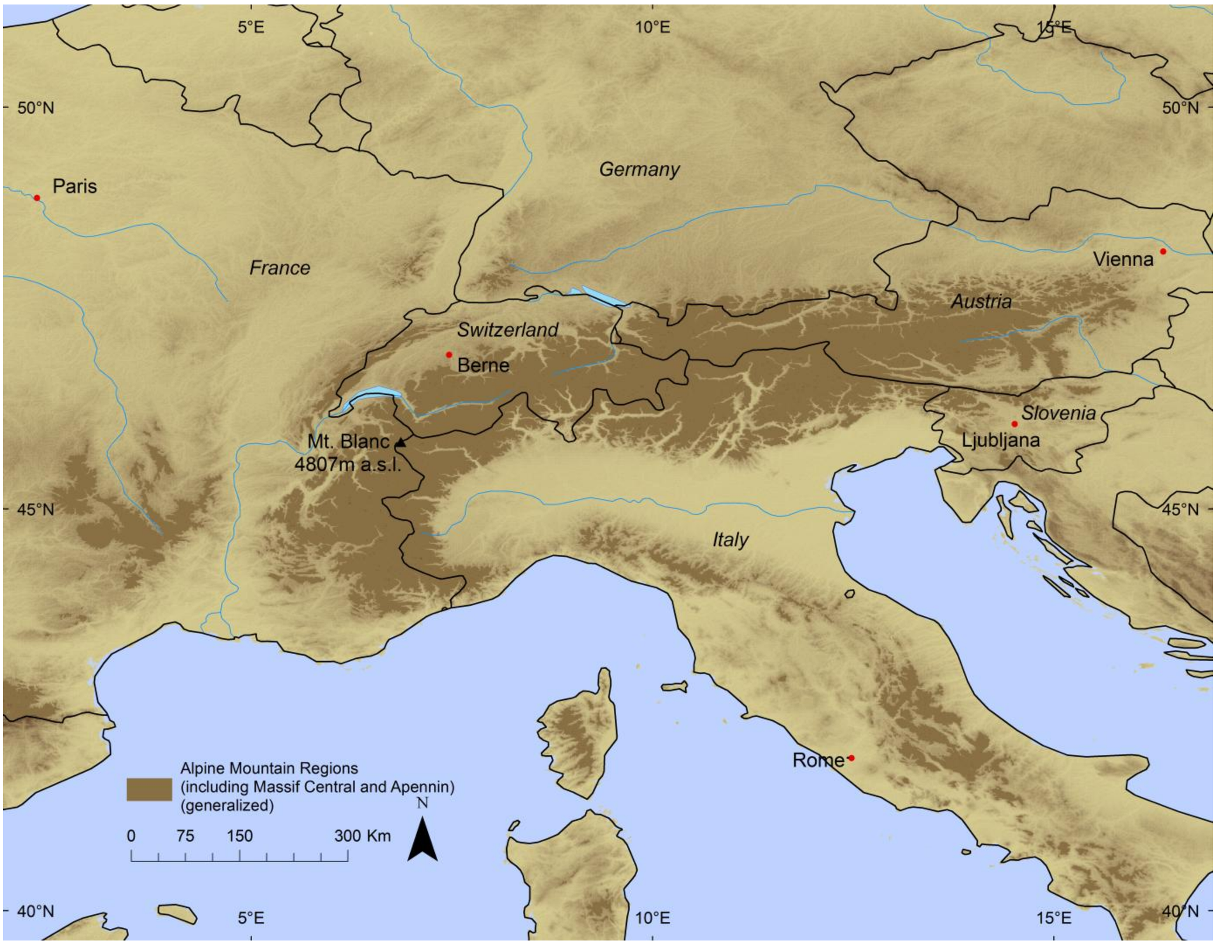

Figure 5: Mountain regions of the Alps

3 Disaster Databases and Spatial Data used in the Study

This section gives an overview of the four databases used in the study (EM-DAT, DesInventar, Dartmouth and NatCatSERVICE) with indications of their different purposes, structures and organizations and with information to the various spatial data used in this study.

Disaster loss and damage databases contain impacts of hazard events over time. These databases typically record a number of parameters such as deaths, economic losses, physical damage and losses in affected sectors such as housing and infrastructure. A number of disaster loss databases at global, regional, national and sub-national levels have been developed in the last several decades (UNDP 2013). Disaster databases are a primary tool for the analysis of disaster characteristics and trends, and support disaster risk reduction and climate change adaption (Huggel et al. 2015). The UNDP's Global Risk Identification Programme (GRIP) has identified a total number of 62 disaster databases worldwide with data collection on mortality and physical damage in the social, economic and infrastructure sectors (UNDP 2013). These 62 damage databases consist of five global inventories (EM-DAT, NatCatSERVICE, Sigma, Disaster Database Project and the on-line Global disaster identifier database (GLIDEnumber database)), two regional, 50 national, four sub-national and one event-based (Hurricane Mitch) database. Of these 57 regional, country and sub-national level loss and damage databases, 26 originate in North and South America, 19 in the Asia-Pacific region, five in Africa, six in the Arabian States and one in the Europe-Commonwealth of Independent States (EU-CIS) (UNDP 2013). Disasters are recorded by different organizations including international organizations, national government agencies, insurance companies and academic institutions. Because of differing resources and reasons for data collection, the resulting information varies in content and quality (Smith 2013). An ideal loss and damage database, therefore, is sustainable, continuous, credible, publicly accessible, quality assured and applicable to decision-making (UNDP 2013).

The current study refers to four disaster databases, three with a global coverage (EM-DAT, NatCatSERVICE and Dartmouth) and one database with regional coverage (DesInventar). EM-DAT and DesInventar both contain information of natural and technological hazards, whereas NatCatSERVICE only includes natural events, while only flood events are included in the Dartmouth database. Access to the databases varies. EM-DAT offers limited on-line data access through a range of search options. The raw data used for this study was available upon raw data request for the selected countries and is available in Excel format. DesInventar enables a country-wise data download in Excel format through their website. NatCatSERVICE offers limited access outside the insurance industry for scientific projects upon raw-data request in Excel format and offers a range of analyses online. Dartmouth is a free, publicly accessible flood inventory with global coverage where flood data can be downloaded as an Excel file. While all databases contain the same overall information such as economic loss, social losses (people killed and affected), the focus of EM-DAT, DesInventar and Dartmouth is primarily on the humanitarian aspects, whereas the reinsurance database NatCatSERVICE focuses more on the material losses (Kron et al. 2012). Table 1 gives a first overview of the four databases used in the study and analyzes disaster databases and their different entries. See Appendix A.3 for a more detailed and comparative overview of the basic elements of the databases.

Table 1: Overview of the four selected disaster databases (Source: Guha-Sapir et al. 2015; LA RED 2015; Dartmouth Flood Observatory 2007; Wirtz & Below 2009).

	EM-DAT	**DesInventar**	**Dartmouth**	**NatCatSERVICE**
Geographic coverage	Global	Regional [South America, Africa, Asia]	Global	Global
Hazard types	Natural and technological	Natural and technological	Floods	Natural
Disaster entry criteria	At least 10 people killed, and/or 100 people affected, and/or state of emergency/call for international assistance	No minimum threshold - any event that may have had any effect on life, property or infrastructure	Large floods with damage to structures/ agriculture, and/or fatalities	Any property damage and/or any person severely affected (injured, dead), before 1970 only major events
Principal data source	Humanitarian agencies, governments, international media	Local/national media, agency and government reports	News, governmental, instrumental and remote sensing sources	Branch offices, insurance associations, insurance press, scientific sources, weather services,
Period covered	1900-present, (good accuracy from 1980)	1970-present	1985-present	0079-present, (good accuracy from 1980)
Management	University (CRED)	University/NGO (LA RED)	University of Colorado	Munich RE
Number of entries	> 21,000	> 44,000	Depends on the country	> 35,000
Accessibility	Open (raw data request)	Open	Open	Limited

3.1 EM-DAT

EM-DAT (Emergency Disasters Database) has been maintained by the Centre for Research on the Epidemiology of Disasters (CRED) at the Université Catholique de Louvain in Brussels, since 1988. It is the most complete, internationally accessible, public database on disaster loss at the national scale. EM-DAT is a global database and covers natural and technological disasters from 1900 onwards. The main objectives of the emergency disaster database are to serve the purposes of humanitarian action at national and international levels, to rationalize decision-making for disaster preparedness, and to provide an objective basis for vulnerability assessment and priority setting (Guha-Sapir et al. 2015). The database is based on various sources, including UN agencies, government sources, non-governmental organizations, insurance companies, research institutes and press agencies. The EM-DAT data recording system uses a unique identifier for each disaster and includes a disaster if one of the following enter criteria is fulfilled: (1) at least ten or more people killed (2) 100 or more people reported affected (3) call for international assistance/state of emergency (CRED 2009). EM-DAT distinguishes two generic categories for disasters (natural and technological). The natural disasters are divided into five sub-groups (geophysical, meteorological, hydrological, climatological and biological) with twelve disaster types and more than 30 sub-types (Davis et al. 2015). Disasters in EM-DAT are defined as “a situation or event which overwhelms local capacity, necessitating a request to the national or international level for external assistance, or is recognized as such by a multilateral agency or by at least two sources, such as national, regional or international assistance groups and the media” (Below 2006).

EM-DAT data from the following fields were extracted:
Disaster number, country, disaster group, disaster sub-group, disaster main type and sub-type, date (start and end), killed, injured, homeless, affected, total affected, victims, estimated damage (thousands, in USD), and additional fields. See Appendix A.5 for more detailed definitions of important terms.

3.2 DesInventar

DesInventar (Disaster Inventory System) is a conceptual and methodological tool which deals with natural disasters of all magnitudes on a local, national and regional scale and was developed by LA RED in 1994. DesInventar is managed by a regional group of academic and non-governmental actors and covers 16 countries in Latin America, the Caribbean and some in Africa and Asia. DesInventar distinguishes between event and disaster. An event therefore is defined as “any social-natural phenomena that can be considered as a threat of life, properties and infrastructure” (UNISDR 2015a). Whereas a disaster is defined as “the set of adverse effects caused by social-natural and natural phenomena on human life, properties and infrastructure (an event) within a specific geographic unit during a given period of time”(UNISDR 2015a). DesInventar includes disasters with very little effect as well as those with an important effect on human life and infrastructure. The DesInventar analysis module allows access to the database through queries of variables such as type of event, causes, sites, dates, economic loss, etc. This tool also provides tables, graphics and thematic maps based on those queries (LA RED 2015). The DesInventar database reports disasters with any social loss. Hence, for the present study, the entry criterion for the data query in DesInventar is modified according to the entry criterion of EM-DAT for a better comparability of these two data sources. The criteria are 10 people missing or killed or 100 people affected or victims. The third criterion of the state of emergency or call for international assistance could not be taken into account for DesInventar. See Appendix A.5 for more detailed definitions of important terms.

DesInventar data from the following fields were extracted:
Date, serial number, event, region, district, village, code, data cards, deaths, missing, affected, victims, evacuated, relocated, injured, houses and hospitals destroyed, damages for roads, damages for crops, lost cattle, education centers, losses USD, losses local and duration in days. See Appendix C for more detailed definitions of important terms.

3.3 Dartmouth Flood Observatory

The Dartmouth Flood Observatory is a global active archive of large flood events. DFO is a research project supported by the National Aeronautics and Space Administration (NASA) and Dartmouth University in Hanover, New Hampshire, USA and later at the University of Colorado. The main DFO objectives are to generate global remote sensing-based fresh water measurement and a registration of such information into a permanent archive. Further, DFO collaborates with humanitarian and water organizations for a better utility of information. The observatory uses satellite images to detect, map, measure, and analyze extreme flood events on rivers worldwide. Dartmouth also provides annual catalogs, large-scale maps, and images of river floods in the years from 1985 to the present (Prentzas 2006). The information derived from Dartmouth is based on news, governmental, instrumental and remote sensing sources. The archive includes “large” flooding events with significant damage to structures or agriculture, length of reported intervals (decades) since the last similar event, and/or fatalities (Dartmouth Flood Observatory 2015). See Appendix A.5 for more detailed definitions of important terms.

Dartmouth data from the following fields were extracted:
DFO archive number, GLIDE number, country, location and name of river flooded, begin/end dates, duration, number of deaths, number of displaced, damage (in USD), cause of the flood, severity (based on a severity class), size of affected area, magnitude, and notes or comments about the event. Additionally, archive notes on the Web site provide definitions for database elements.

3.4 NatCatSERVICE

The NatCatSERVICE is a private disaster database maintained by the Munich Reinsurance Company. This global database collects information on natural disasters (excluding technological disasters). The entries cover a period from 79 AD to the present with good accuracy after 1980. The disasters are registered on a country and event level. The database is based on more than 200 sources worldwide, including national insurance companies, international agencies (e.g. UN, EU, Red Cross), NGOs, scientific sources and weather and warning services. Due to the availability of resources, NatCatSERVICE is able to provide detailed economic loss data. The database is partially accessible to the public, especially for clients of Munich RE. The access and search function of the database provides only information on a very limited number of natural disaster entries (Tschoegl et al. 2006). NatCatSERVICE includes disasters with any property damage and/or any person severely affected (injured, dead); before 1970 only major events. The data entries are structured according to catastrophe classes reflecting the impact of a catastrophe in financial and human terms on a scale from 0 to 6. The catastrophe class 0 comprises natural disasters without financial or human losses, whereas class 6 comprises great and devastating natural catastrophes (Munich RE 2011). The free, publicly available information includes information on the most expensive and deadliest disasters, information on great natural disasters since 1950, detailed annual statistics from 2004 onwards, informative maps and focus analysis. An online registration is required. For the following study, NatCatSERVICE provides global disaster data for mass movement disasters.

NatCatSERVICE data from the following fields were extracted:
MR number, MR ID, continent, country and ISO code, detailed region, year, begin/end dates, event family, event type, event name, direct overall loss (in USD), insured loss (in USD), deaths, houses damaged, houses destroyed, infrastructure affected such as agriculture, roads, railways, bridges, water supply, electricity communication, marine offshore, together with longitude, latitude. See Appendix A.5 for more detailed definitions of important terms.

3.5 Spatial Data

All maps are based on a SRTM DEM with 1 km spatial resolution. Mapping was done in ArcGIS. All features were stored in a geodatabase and projected either to the WGS 1984 or Mollweide (sphere) coordinate system. Free raster and vector data including country and state boundaries, rivers and lakes, capitals and mountain peaks were downloaded from *Natural Earth* with a spatial resolution of 50 m.

4 Methods

This section presents the analysis principle of the disaster database structure and content. Furthermore, the different disaster data processing steps will be explained with indications of the definition of mountain regions, mountain disaster data extraction and the classification of disaster types. The disaster analysis gives an overview of the application and realization of data procedures regarding spatiotemporal trends of disaster occurrence, comparative disaster analysis and the importance of mountain regions with respect to natural disasters and sustainable mountain development.

4.1 Disaster Database Structure and Content

4.1.1 Disaster Database Quality Assessment

Information and data quality are among the most important characteristics of a disaster database. A study of 31 databases from Tschoegl et al. (2006) concluded that a lack of standardization in definitions and disaster classifications, inadequate accounts of methodology and variations in the availability of the sources diminished the usefulness of the information from databases (Smith 2013). Therefore, a quality framework for disaster databases was recommended by Below et al. (2010). This framework was developed by CRED with the objective of capturing and evaluating the quality of disaster loss databases. In this work, quality of databases refers not only to the correctness of the data, but also includes aspects such as database accessibility, serviceability, credibility of the database hosting institute, database methodology, and accuracy and reliability of the data. Below et al. (2010) describe the six key features as follows:

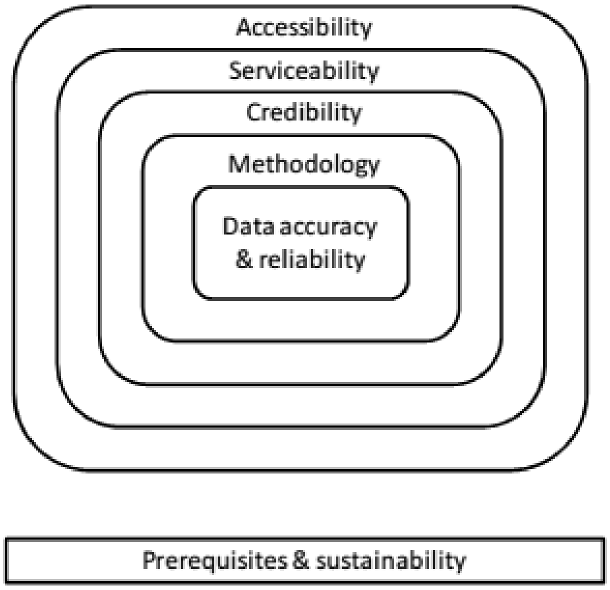

Figure 6: Elements of the quality framework for disaster loss databases. (Source: Below et al. 2010).

Prerequisites and sustainability

This category focuses on the institutional framework of the database institute. The archiving organization should have enough institutional support and other resources to maintain the dataset over a representative period of time. The sustainability of the database should allow the possibility of maintaining the database independently from its institutional framework.

Data accuracy and reliability

The focus lies on the completeness of information and geographical coverage. The information should be as complete as possible, with good geographical coverage. Data entry procedures, selection and number of data sources and data validation procedures should be in place to test for bias and other faults.

Methodology

The raw information should be processed according to clear concepts and definitions regarding issues like entry criteria, disaster definitions and classifications.

Credibility

There should be evidence of the expertise and impartiality of the archiving body that includes assurances on transparency and quality-control procedures. Information available through a website or other medium representing the institute should include database goals and objectives, methodology and data distribution.

Serviceability

The information should be useful and convenient, it should be easy to interpret, have perceived relevance and be geographically and temporally distributed. The availability of user documentation is investigated with information about methodology that is necessary for understanding and making a correct interpretation and use of data, outputs and analytical functions.

Accessibility

The data should be readily accessible to a wide variety of users and contact details should be available in case of demand for further information.

All disaster databases which are part of this study are analyzed regarding the six key features listed above. These elements build the baseline of the qualitative assessment methodology for disaster databases. Therefore, the qualitative analysis is based on the predefined categories and the qualitative questionnaire from Below et al. (2010) (Appendix A.2).

4.1.2 Analysis of Disaster Database Completeness of Contents

Disaster databases typically contain a number of data elements which form the basis of each database. These basic data elements are those fields which are crucial and indispensable for its logic and structure of a database and for its comprehensibility by the users. For Below et al. (2010), the basic entries in disaster databases are an event identification code, disaster type, geographical location, start and end dates of disaster occurrence and human, economic, and structural impacts. The completeness of recorded information in the four databases is analyzed by calculating the percentage of records which contain information on human and economic impact, as well as missing values. The following four aspects will be studied for all event entries in the four databases for all regions: the geographical location, economic loss, date (start and end) and the number of zero values and empty fields. These four elements are particularly important for an identification of disasters in mountain regions with indications of human and/or economic losses. The geographical location can be provided either with coordinates or with a clear indication (e.g. the naming of affected states, provinces, cities etc.). The study includes only disaster entries with a clear geographical location, otherwise, the entries were not taken into account. Information about the economic losses is very important because these numbers, in combination with the number of deaths, are the most frequently used parameters for tracking trends in disaster losses (UNDP 2013). The economic loss can either be provided as the total or the insured damage. The start and end dates of specific disasters give information about the temporal extension of an event. Zero values signify no information about any loss (economic, social and infrastructural). Some databases distinguish between zero and blank values, between no losses information versus no data. In DesInventar and EM-DAT databases this distinction is not made. Thus, in these two databases only non-zero values are meaningful. Therefore, for the DesInventar and the EM-DAT databases the percentage of non-zero values has been calculated as an indicator of data completeness. Empty fields in the EM-DAT database represent missing values or non-reported information. Zero fields do not represent a value and imply that no information is available (Guha-Sapir et al. 2015). For the Dartmouth and the NatCatSERVICE databases the percentage of non-blank values (data available) has been calculated and analyzed. The analysis of data from the EM-DAT database includes mountain and non-mountain entries, whereas DesInventar only includes mountain states of the Andean countries (Colombia, Ecuador, Peru, Bolivia, Argentina, Chile and Venezuela). Dartmouth and NatCatSERVICE only refer to events in mountain regions.

4.2 Disaster Data Processing

4.2.1 Definition of Mountain Regions

Numerous mountain definitions exist in the literature. Because of the extremely diverse landforms of mountains, it is difficult to achieve consistency in description and analysis of these formations. In the past, several criteria have been used in literature to describe the mountain environment such as elevation, volume, relief, steepness, spacing and continuity (Gerrard 1990). A universally accepted definition of mountains will always remain difficult. However, mountain regions can be defined as a conspicuous, elevated landform of high relative relief with steep slopes and variations in climate and vegetation zones (Price et al. 2013). The mountain definition applied in the current study was modified according to the most commonly used definition of mountains. This determination was developed by the (UNEP) World Conservation Monitoring Centre (WCMC) based on Kapos et al. (2000), with the following three criteria:

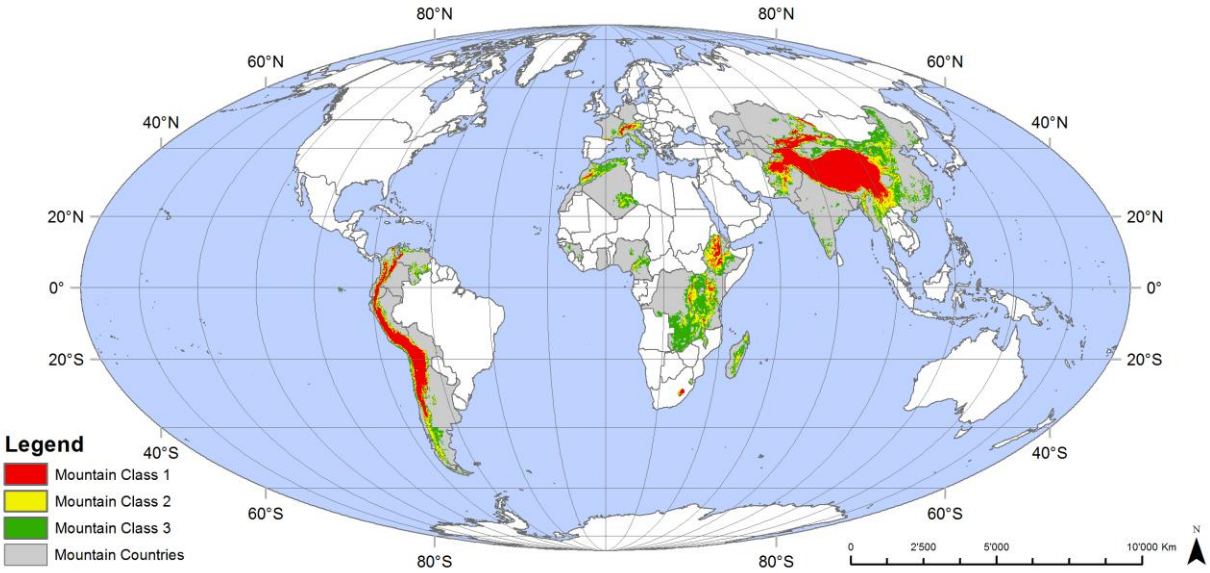

Figure 7: Mountain regions based on the three mountain classes with the five study regions (in grey): Andes, Africa, Alps, Central Asia and Hindu Kush-Himalaya

Mountain Class	Criteria
1	Elevation > 2,500 m a.s.l.
2	Elevation 1,500 – 2,500 m a.s.l. and slope ≥2°
3	Elevation 1,000 – 1,500 m a.s.l. and slope ≥5°, or
	Elevation 1,000 – 1,500 m a.s.l and local elevation range > 300 m a.s.l.

Initially, the mountainous regions were defined by elevation and slope. Local elevation range was added by Kapos et al. (2000) as a third criterion to generate a more adequate extraction of mountain areas. The definition used is based on altitude and slope. To generate a mountain map of the study area based on the three mountain classes, therefore a global SRTM DEM with a resolution of 1 km was loaded into the geographical information system ESRI ArcGIS. Afterwards, the slope and the local elevation index, as well as the topographic roughness index (TRI), were calculated in ArcGIS. Figure 7 show the mountain regions based on the three mountain classes. The lower limit of 1,000 m a.s.l. for mountain areas was determined, to exclude hilly and shallower regions.

4.2.2 Mountain Disaster Data Extraction

The main objective of the extraction of data for mountain disasters was to exclude all events based on the spatial locations from the map (Figure 7). In general, all entries in disaster databases refer to different countries and, with a few exceptions, to specific locations. These locations are either geo-referenced with coordinates (NatCatSERVICE) or with an X/Y-centroid (Dartmouth), or they are described with specific spatial information such as province, region, city or a geographical location such as North, West, South and East (EM-DAT and

DesInventar). Because of variations in structure and organization of the disaster data used in the study, all events in mountain regions had to be extracted in a different way for each database.

NatCatSERVICE

Upon data request, with a written description of the ongoing studies and the usage of the data, Munich RE provided information about landslides, avalanches and rockfalls in an Excel table. To obtain only the weather- and climate-related disasters such as landslides and avalanches, these data were filtered. As the NatCatSERVICE data contain coordinates, they could be uploaded into ArcGIS. To extract only events in mountain regions, the mountain layer from Figure 7 was overlaid by the point event features from NatCatSERVICE. With the ArcGIS function “select by location”, all landslides and avalanches which occurred in mountain regions could be selected and saved as a new layer (Figure 8 right).

Dartmouth

Dartmouth provides a flood event download from 1985 to present via their website in an Excel file. The spatial positions of the individual entries are described with an X and Y centroid. As was the case with the NatCatSERVICE database, the mountain layer could be overlayed by the centroid of each event with a further extraction of all floods which occurred in mountain regions (Figure 8 left).

EM-DAT

Upon raw data request, EM-DAT provided information about natural disasters from the requested countries in an Excel table. These data were filtered to obtain only the climatological, meteorological and hydrological events, whereas the geophysical and biological events were not taken into account. The EM-DAT database entries provide no geo-referenced spatial information. Therefore, the mountain layer from Figure 7 in 4.2.1 was overlaid in ArcGIS with a layer of all states (departments, provinces, zones, etc.) for all countries. For each state, ArcGIS calculated the ratio of mountainous areas. The threshold was defined as a minimum mountain area of about 50%. Thus, if the mountain layer covered more than fifty per cent of the area of a state, this region was selected as a mountain region. Out of using this threshold, each state of every country could be extracted either as a mountain state or not (Figure 8 left). In a second step, all disaster entries from EM-DAT had to be checked precisely to determine whether they occurred in the defined mountain states. In cases where there were more than just one location mentioned, the selection was based on the majority principle. For instance, if an entry referred to three locations, two locations in mountain regions and one outside, this entry was included as a mountain area (Table 2). If the amount of mountain location and non-mountain location was equal, the entry was extracted as a mountain location. One major limitation of this approach is the lacking capture of events that may have originated in a single mountain state, but where the majority of losses are recorded in non-mountain states. Thus, disaster originated in mountain regions may be underestimated with the methodological approach used in this study. The data for which the exact location of the event was not available through the Excel file were excluded from the analysis. As different regions and countries have different spatial notations such as states, provinces, regions and departments, they will all be categorized as states, for the sake of convenience of the present study. The percentage of mountain areas of all states was calculated in ArcGIS for all countries (Appendix A.1).

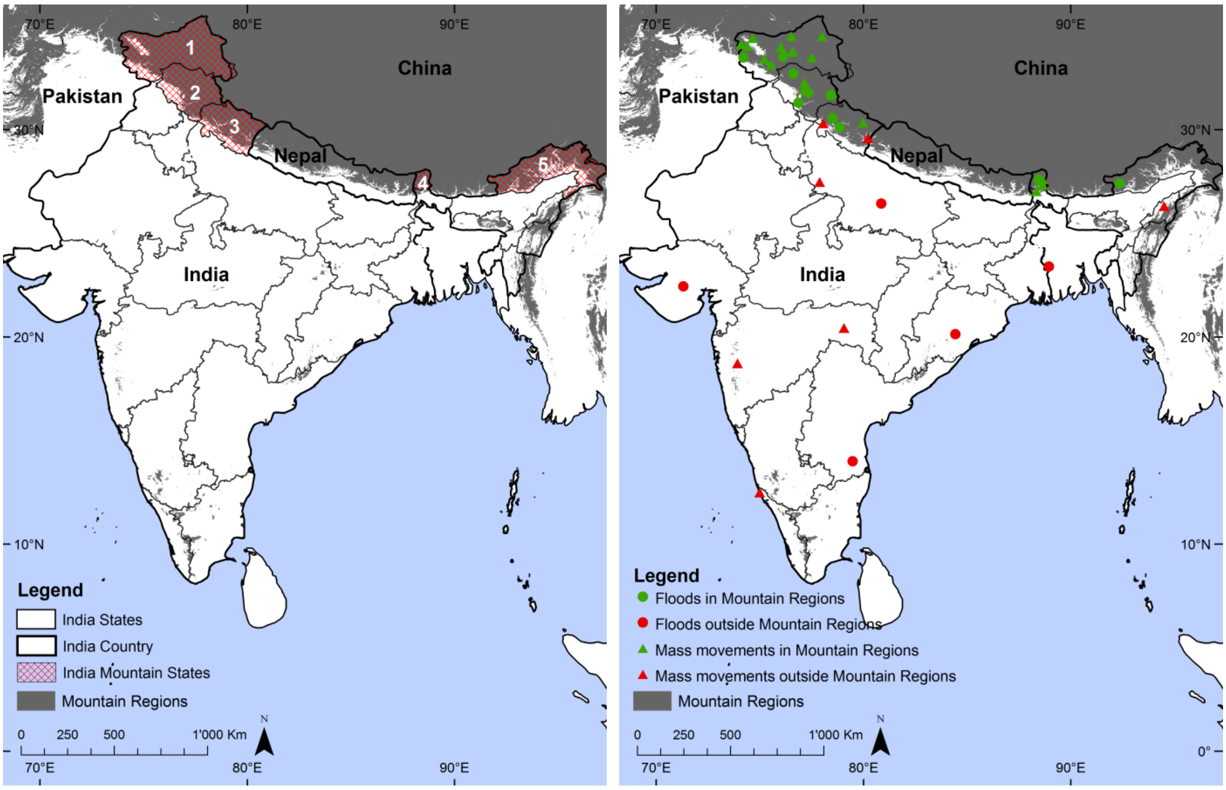

Figure 8: Comparison of approaches for assigning weather- and climate-related disasters to mountain regions in India. Left: For EM-DAT exact geo-referenced information is lacking, and mountain disasters are assigned at the state level. Mountain states: (1) Jammu and Kashmir, (2) Himachal Pradesh, (3) Uttarakhand, (4) Sikkim, (5) Arunachal Pradesh. Right: For NatCatSERVICE and Dartmouth, geo-referenced disaster locations can be overlayed with the mountain classification scheme. Green labels signify disasters in mountain regions, red labels signify disasters outside mountain regions.

Table 2: Disaster entry example registered in the EM-DAT database (generalized). (Source: EM-DAT database).

Year	Disaster Group	Country	Location	Total killed	Number affected	Total damage
2005	Flood	India	Himachal Pradesh, Uttaranchal, Uttar Pradesh	23	150	4000

DesInventar

DesInventar database provided an analysis module with an individual data query through their website. After selecting the requested country, various query definitions such as the disaster type, department, province etc. could be chosen. The data query allowed data extraction based on selectable criteria regarding social loss such as people killed, victims, injured, affected and missing. As the definition and meaning of people killed and affected is not the same as in EM-DAT (LA RED 2002), the criteria for DesInventar were adapted to EM-DAT for a more credible comparison of the two databases. Thus, “people affected” in EM-DAT is similar to “people affected” + “number of victims” in DesInventar. Whereas “people killed” in EM-DAT include “missing people”, DesInventar adds up “people killed” + ”people missing”. Consequently, the entry criteria for DesInventar are 10 or more people killed/missing, and/or 100 people affected/victims. Unfortunately, there was no opportunity to have the criterion for a call for international assistance/declaration of a state of emergency. After selecting all criteria, DesInventar provided a data download in an Excel table for the required date range and selectable disaster types.

4.2.3 Classification of Disaster Types

The entries of EM-DAT and NatCatSERVICE are based on the same hierarchy and terminology of natural disasters. They distinguish between geophysical, meteorological, hydrological and climatological disasters (Below et al. 2009). The following study includes only meteorological, hydrological and climatological disasters with the corresponding disaster types. Biological and geophysical disasters are not considered. Dartmouth only contains information about flood events. Since the disaster types and natural processes in the disaster databases used were not all exactly the same, the following six categories were generated:

Storm (including tropical storm, strong wind, snow-, wind-, hail-, and thunderstorm)
Flood (including spate)
Mass movement wet (including landslide, avalanche and debris flow)
Extreme temperature (including cold and heat wave)
Drought
Wildfire

Although various definitions may be found in the scientific literature, within the EM-DAT and NatCatSERVICE databases the different disaster types are defines as follows (Below et al. 2009):

Storm

A tropical storm, extra tropical cyclone (winter storm) or a local/convective storm including orographic storm (local strong winds), thunderstorm/lightning, snowstorm/blizzard and generic (severe) storm.

Flood

A significant rise of water level in a stream, lake, groundwater or coastal region due to high rainfall or snowmelt rates. It includes general floods caused when a river or a lake overflows its normal confines due to rising water levels. Furthermore, inundations by melting snow and ice and backwater effects can cause outburst of a glacial lake or the breaching of a dam. Flash floods originated due to intense rainfall are described as sudden flooding with short duration and are typically associated with thunderstorms.

Mass movement wet

Any type of downslope movement of earth materials (snow and debris avalanches). A snow avalanche is a rapid downslope movement of a mix of snow and ice, whereas a debris avalanche is characterized as a sudden and very rapid downslope movement of an unsorted mass of rock and soil. A landslide is the movement of soil or rock controlled by gravity, including mudslides and debris flow.

Extreme temperature

A heat wave is a prolonged period of excessively hot and sometimes also humid weather relative to normal climate patterns of a certain region. In contrast, a cold wave can be defined either as a prolonged period of excessively cold weather or as a sudden invasion of very cold air over a large area. Low temperatures associated with frost can cause damage to agriculture, infrastructure, and property.

Drought

A long-lasting event triggered by a lack of precipitation. A drought is an extended period of time characterized by a deficiency in a region's water supply that is the result of constantly below average precipitation. A drought can lead to losses in agriculture, affect inland navigation and hydropower, plants, and cause famine and a lack of drinking water.

Wildfire

An uncontrolled fires burn, usually in wild lands, which can cause damage to forestry, agriculture, infrastructure and buildings.

In general, the different disaster entries contain no information about the reason for their occurrence. For instance, when a flood is registered, there is no additional information available about the course of this event. Hence, a flood could be triggered due to a lake outburst or due to a heavy precipitation event. In some cases, the disaster entries contain information about the disaster subtype, for example, for flood events EM-DAT distinguishes between riverine floods and flash floods.

4.3 Disaster Data Analysis

4.3.1 Analysis of regional Disaster Occurrence

In order to obtain an overview of the five mountain regions, the regional analysis aimed to investigate disaster trends with respect to disaster types and their occurrence in time and space. The region analysis was based on the five mountain regions characterized according to geographic location, vulnerability, population and climate conditions. All records of natural disasters over a period from 1980 to 2014 were extracted from the EM-DAT database. The reason of the data selection lies in the free accessible EM-DAT database with a global coverage including all six disaster types. All three other data sources are either with a regional focus or including only one specific disaster type or do not provide an open access. The study indicates the frequency and occurrence of a number of disaster types in the time period 1980-2014 with information about the social and economic loss. Further analysis of trends in disaster occurrence across time and space, also based on data from the EM-DAT database, was carried out for the three decades 1985-1994, 1995-2004 and 2005-2014. First analyses considered all events based on a country level. Furthermore, for the most disaster-prone regions such as East Africa, the Andes and the HKH, a more precise analysis on a state level was conducted. The mountain countries and mountain states extracted from the EM-DAT database were integrated into a geographic information system, referenced to the respective administrative spatial unit in the countries concerned and illustrated with maps. Additionally, a human and economic loss analysis was carried out for the HKH region. Therefore, loss data from EM-DAT were used to investigate the most affected, the deadliest and the most costly states of the region. As EM-DAT sometimes mentioned more than one location for a certain event, loss information was assigned only to the first listed state. Thus, the generated maps may be somewhat differing from the reality but will be consistent in the current study, as the number of events per state were also based on the same principle.

4.3.2 Comparative Disaster Loss Analysis

In order to estimate the significance of disaster losses, data about human, physical, and economic losses as well as social and environmental impacts had to be analyzed. However, the absence of internationally agreed definitions and homogenous accounting practices has an influence on the disaster loss data collection. This circumstance leads to incomplete and unreliable statistics on a national and global scale (De Groeve et al. 2014).

For the national-scale comparative disaster analysis, data from the global EM-DAT database together with data originated from the regional DesInventar database were compared for the Andes (Peru, Colombia, Ecuador and Bolivia) and the HKH region (Nepal, India, Pakistan, Afghanistan and China). The comparative analysis considered three decades 1981-1990, 1991-2000 and 2001-2010. The main fields are the number of events and people killed and affected. Additionally, the total population was calculated for all mountain states for the analyzed countries for the three periods of time. Population data was retrieved from various statistical institutions in the analyzed countries. The disaster loss analysis illustrates the percent change for the number of events, people killed and affected, and population change. The changes are measured in relation to the percent of the first period between 1981 and 1990, which was set to 100 percent. The disaster mortality ratio and the ratio of affected population were calculated with the formulas (1) and (2):

$$\text{Disaster Mortality Ratio} = \frac{\text{Total People Killed}}{\text{Total Population}} \tag{1}$$

$$\text{Ratio of Affected Population} = \frac{\text{Total People Affected}}{\text{Total Population}} \tag{2}$$

4.3.3 Database Comparison for Flood and Mass Movement Disasters

A comparative disaster database analysis is a crucial approach for an assessment of the reliability of disaster data, based on different sources. In order to conduct a comparative analysis of disaster databases, disaster events from the HKH regions and the Andes were analyzed through data from the EM-DAT, Dartmouth and NatCatSERVICE databases. The focus lies on floods and mass movement events, as they represent a high frequency of disasters in both regions. All recorded flood events were extracted from the EM-DAT and Dartmouth databases for the time period 1985-2014. For a comparative analysis, all flood events were uploaded and plotted into R to generate comparative flood trends for both databases. Additionally, the number of people killed, people affected/displaced and the economic losses were compared. The same procedure was used for the comparative assessment of mass movement disasters, based on data from the EM-DAT and NatCatSERVICE databases for the time period 1980-2014. The agreement and the discordance of the output graphics helps to generate predications about the reliability of the databases and their base elements. Calculation of the coefficient of determination (R^2) indicates the relationship between two datasets, whereby an R^2 of 1.0 indicates that the regression line perfectly fits the analyzed data.

4.3.4 The Importance of Mountain Regions for Natural Disasters

Mountain regions are high-risk areas, where hazards can cause damage, destruction, injury and death at any time. Mountain regions are more frequently affected than other environments by destructive natural processes including dam burst or glacial lake outbursts. Additionally, hazards such as avalanches and landslides occur almost exclusively in mountain regions (Kohler & Maselli 2009). The hydrological processes in mountains are strongly influenced by specific characteristics of mountainous regions such as temperature, precipitation, soil, vegetation, slope and windward/leeward effects. A study by Weingartner et al. (2003) of the European Alps indicates that there is a far greater likelihood of intense floods with high discharges in

catchments above an altitude of 1,000 m with an upper limit of around 2,000 m. At higher altitude, short-term snow storage of precipitation reduces the hazard of floods.
For an evaluation of the importance of natural disasters in mountain regions, data from floods and mass movement disasters were compared for mountain and non-mountain regions. As Dartmouth and NatCatSERVICE provide geo-referenced data, the coordinates were uploaded into ArcGIS. The defined mountain layer from Figure 7 in 4.2.1 was overlaid with all floods and mass movement events from both databases. With the *select by location* function, all events occurring in mountain regions, as well as outside these regions could be generated and illustrated in a survey map.

4.3.5 Case Example Kedarnath Disaster North India 2013

For a detailed and comparative overview of an extreme event, the Kedarnath flood in north India, June 2013, was analyzed. The global landslide catalogue (GLC) reported landslide activity from 2007 to 2013. The highest recorded peak of fatalities was in 2013 due to this devastating event in Kedarnath in India, on June 16th, 2013 which killed an estimated 5,000 people (Kirschbaum et al. 2015). Disaster data from EM-DAT and Dartmouth databases indicate numerous entries and make reference to the diverse information regarding geographical location and human and economic losses. The analysis highlights distinctions between different socio-economic losses, reveals divergences of the registered spatial resolution and illustrates the impact of the results. The affected location was extracted and marked on a map in ArcGIS then overlaid with the defined mountain area. Furthermore, to explore the unusual or extreme climatic factors contributing to this disaster, climate data from nearby meteorological stations were analyzed. These monthly and daily precipitation and temperature measurements will be compared with reanalysis data of precipitation and temperature anomalies. These data are based on observation data (station data from the past) in combination with a meteorological forecast models. These data contain a temporal resolution of a few hours with a special scale between 80 and 100 meters. The advantage of the combination of both climate data is the completeness. Thus, the reanalysis data may fill in the gaps and give a complete coverage, whereas the station data (if and where available) should generally be more accurate and can also be used to validate the reanalysis data. Therefore, mean daily and monthly temperature and precipitation data from meteorological stations near Kedarnath indicate the heavy precipitation event in June 2013 in comparison with the mean annual precipitation anomalies from the past (1980-2014) with reference period 1961-1990 for the month of June. The reanalysis data of mean precipitation and temperature anomalies cover an area between 25.5–34°N and 75.5–84.5°E for the region of Central Himalaya, whereas the data were generated from following six meteorological stations: Shiquanhe (China), 4,232 m a.s.l., Haryana (India), 221 m a.s.l., Mukteshwar (India), 2,311 m a.s.l., Jaipur (India), 390 m a.s.l., Beluri Shantipur (Nepal), 159 m a.s.l. and Muskiot (Nepal), 1,280 m a.s.l..The time series were filtered with a 10-year low-pass filter (Gauss).

5 Results

This section includes the results of the analysis of the disaster database quality and completeness, the regional analysis and spatiotemporal trends of disaster occurrence and the comparative disaster loss analysis. Furthermore, a detailed database comparison for floods and mass movement events for the HKH and the Andes indicates trends and investigates the reliability of different database entries. This section also makes reference to the importance of mountain regions regarding natural disasters and sustainable development and provides a case example of the catastrophic Kedarnath flood disaster in northern India in 2013.

5.1 Disaster Database Quality and Completeness

5.1.1 Quality Assessment

The following section presents overall results based on the quality assessment table (Appendix A.2). The completed table was rectified by Regina Below for the EM-DAT database and by Petra Löw for the NatCatSERVICE database. Information about the DesInventar database was acquired from a study by Below (2010). The Dartmouth database information could not be rectified by the persons responsible and therefore contains some missing fields.

Methodology

All four databases use a standard definition for their disaster types as well as a standard form for collecting information and data entry with database-specific data elements. However, the entry criteria are only defined explicitly by the EM-DAT and NatCatSERVICE database, whereas the latter registers events if there is any property damage and/or person dead. Dartmouth enters large floods with damage to structures/agriculture, and/or fatalities. DesInventar has no minimum threshold for an event registration but uses a standard data collection format to capture the data from a range of sources and subsequently to enter it into the DesInventar system. All databases, except Dartmouth which considers only flooding events, have a hierarchical disaster classification from broad categories to tailored disaster types. Each database provides a data analysis, as for instance, the NatCatSERVICE database with annual statistics from 2004 onwards and informative maps. EM-DAT also provides interactive graphs and maps throughout their database. DesInventar enables a data analysis through DesConsultar software and separate analysis in Excel. Dartmouth also provides charts and maps via their website. All datasets use different disaster identification numbers for their entries. The unique ID from the EM-DAT database includes the year and the sequential number, e.g. 2015-0005. The NatCatSERVICE database has a unique MR-Number for each loss event including the year, month, disaster group and a 3 digit cat-number, e.g. MR2009-01-A-005. Dartmouth uses different archive numbers for the identification of events. DesInventar entries contain serial numbers to identify the data card, using a number, an acronym or code for the record. EM-DAT and DesInventar are based on a SQL-database system, whereas NatCatSERVICE uses an Oracle database system.

Accuracy and Reliability

Data sources for the nationally-based DesInventar database are national newspapers and government information releases without source checking. In the case of Nepal, sources of information are originated from the two newspapers Gorkhapatra and Kantipur of Nepal. DesInventar provides a standard compilation procedure without standard validation procedures but with random checking. However, priority is given to the media. Entries for the global EM-DAT database are mainly based on information from UN agencies, governmental and non-governmental sources and agencies, reinsurance companies, IFRC, research institutes and press agencies. For a verification of data entries, EM-DAT has a monthly validation process and an internal error cross checking. In contrast, the global NatCatSERVICE database generates disaster information from national insurance companies, international agencies (e.g. UN, EU, Red Cross), NGOs, scientific sources and weather and warning services. The NatCatSERVICE database provides a systematic evaluation of daily press reports from local to international levels. The global Dartmouth database generates information mainly from news, governmental, instrumental and remote sensing sources. Information about possible validation procedures is not available. A guideline or explanatory notes are obtainable for all databases used for the study with descriptions and definitions of the various data entry fields.

Serviceability

As outputs and functions, DesInventar enables online data querying with data extraction. The interactive web-based system comprises a comprehensive selection of maps, data, charts, statistics and reports options. The EM-DAT database also provides data querying and data extraction with different tools such as country and disaster profiles, disaster list, advanced searches, maps and trend figures via their website. Additionally, EM-DAT generates regular publications such as the annual statistical review, CRED Crunch and statistical annex of the World Disasters Report (IFRC). NatCatSERVICE provides annual statistics reports, lists of significant natural disasters, focus analyses and catastrophe portraits. Dartmouth database supplies maps and associated global and regional analyses with explanatory notes.

Accessibility

The EM-DAT database provides access to disaster data without cost and restrictions through their website. However, it offers only limited access to raw data through data request for selectable countries. Contact details are available and further information may be obtained upon written request. DesInventar allows a query of disaster data through an online analysis module without any cost or restrictions for obtaining the data. DesInventar data for Nepal are accessible from 1971 – 2011. NatCatSERVICE disaster data are partially accessible to the public, whereas more information is available to clients. For the current study, NatCatSERVICE supplied limited disaster type data, as only mass movement data were provided. Contact details are also available and further information may be obtained upon written request. Dartmouth provides an open data download for flood disasters from 1985 to the present via their website. Contact details are available but without successful response upon written requests for further information.

Credibility

The EM-DAT database provides information concerning the institute, database goals and methodology. They have 35 years of experience in data collection and database management. They undergo a yearly quality data control process and promise impartiality. Information for the DesInventar database is marginally available on the website with indications of the goals, objectives and sources of information. The NatCatSERVICE provides information through their website and possesses 35 years of experience in data collection and database management with a complete global data record since 1980. NatCatSERVICE provides a continuous data quality assessment and promises objectivity, as part of the finance industry. Information about quality management and impartiality are not available for Dartmouth.

Prerequisites and Sustainability

The EM-DAT database is maintained by CRED and exhibits a large collaboration network such as the IFRC, UNISDR, UNDP and the World Bank. They have a long experience in data collection and management. The basic functions of the DesInventar database are maintained independently without collaboration networks. They have a long-term objective of institutionalizing disaster inventory at local and national levels. The NatCatSERVICE is developed and maintained by Munich RE and uses a vast array of resources with more than 60 offices worldwide, clients in over 150 countries and contacts with national and international insurance associations. They have a collaboration network with a number of NGOs, weather services and other global databases for natural disasters. They have a long experience in data collection and management, from 1980 until today for all natural loss events. The Dartmouth database is linked with numerous collaboration networks such as water organizations (e.g. Geological Survey) and global flood partnership (GFP). They possess a long experience in flood data collection and management from 1985 until today, with good data reliability after 1995.

5.1.2 Completeness of Contents

The results of the completeness of contents analysis of the four databases for the five mountain regions are illustrated in Figure 9. See Appendix A.3 for a more detailed overview of the specific content in the five mountain regions analyzed in the study.

Data from the EM-DAT database include all weather- and climate-related disasters for the time period 1985-2014, independent of occurrence in mountain areas or not. Information about the geographical location (e.g. state, region, city, etc.) is mentioned for 85.2% of all registered events. Information about the exact start and end date is given for 80.0% of all disasters. Economic loss data, as total damage in USD, are provided for 32.5% of the events. Additionally, 3.6% of registered events include zero values without any information regarding economic or social losses (Figure 9 A)

The analysis of the DesInventar database only refers to the seven Andean countries between 1985 and 2011. DesInventar data only include data from defined mountain states of the countries concerned. The geographical location of all Andean countries is 100%, as DesInventar allows a query analysis for requested geographical regions. Economic loss information (in USD or local currency) is only provided for 7.6% of all registered events. DesInventar provides no indications of start date for the database entries, but provides information about the duration of an event (in days) for approximately 26.9% of all data entries. Through the DesInventar query function, only entries without zero values are listed.

Dartmouth database provides flood events information from 1985-2014. The total number of records only refers to mountain regions. The geographical location for all regions is equal to 100%, as Dartmouth provides geo-referenced locations. Twenty-two percent of all listed events contain information about economic loss (damage in USD). Each entry in Dartmouth provides a start and end date. Zero values represent 4% of all registered disasters.

The NatCatSERVICE database includes avalanche and landslide disasters in the time period 1985 to 2014. As NatCatSERVICE registers geo-referenced events, the geographical location of all disasters is equal to 100%. For each event in all regions, the economic loss is given as a direct overall loss (in USD), as well as the exact start and end dates. No entries with zero values exist in all registered disasters.

The distribution of registered events per mountain regions and databases are shown in Figure 9 B. Data records from the EM-DAT database include weather- and climate-related events in mountain regions in the time period 1980-2014. EM-DAT registers the region with the highest frequency of disasters as the HKH with 339 events, followed by Africa (169 events), the Andes (164 events), the Alps (45 events) and Central Asia (39 events).

Data from the Dartmouth database include only flood events between 1985 and 2014. The highest number of registered floods is in the HKH region with 126 events, followed by Africa (94 events), the Andes (61 events), Central Asia (17 events) and the Alps (10 events).

The reinsurance database NatCatSERVICE registers mass movement events between 1980 and 2014. The highest number of events occurs in the Alps with 160 events, followed by the HKH (119 events), the Andes (95 events), Central Asia (33 events) and Africa (14 events).

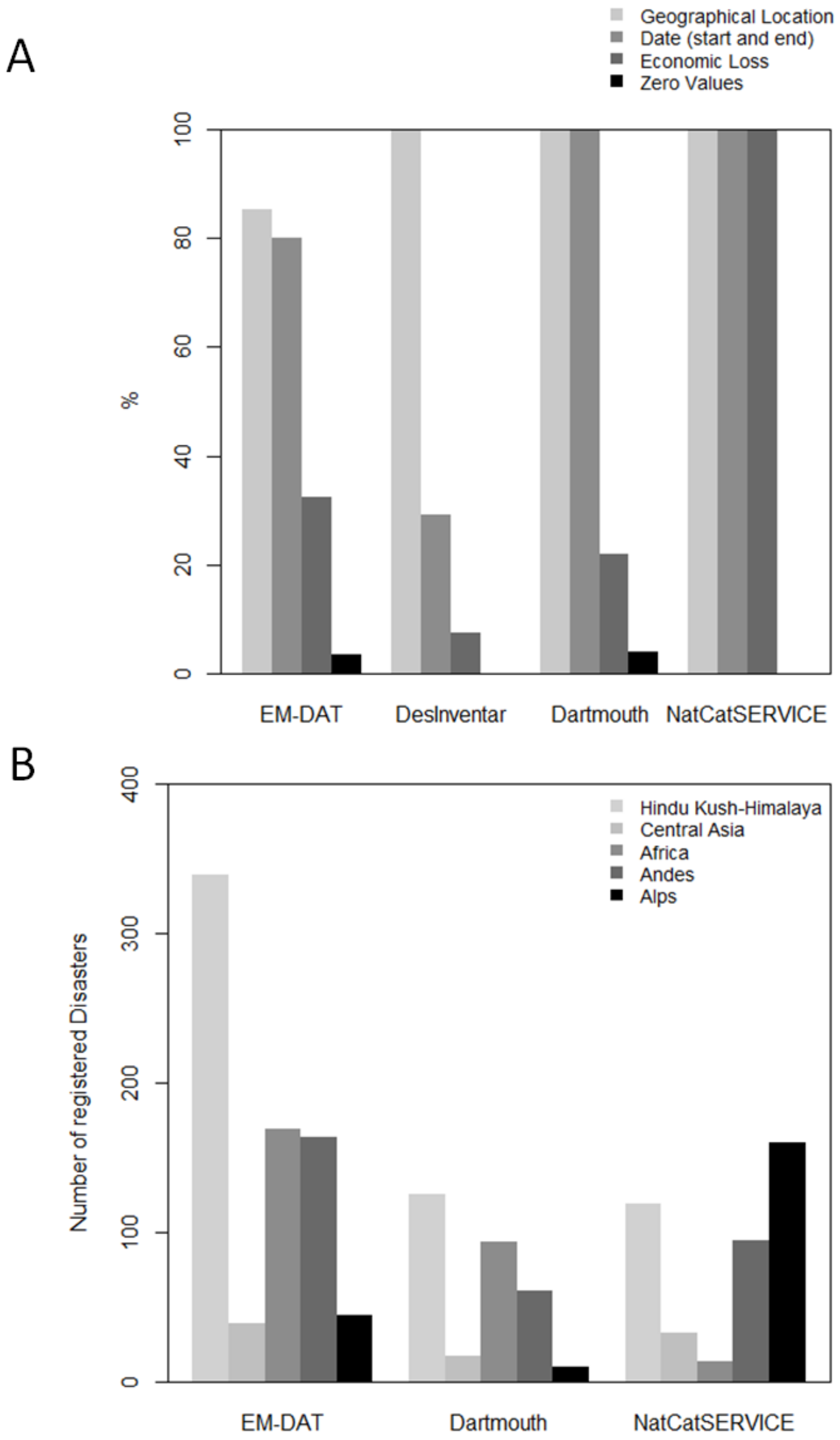

Figure 9: Analysis of disaster databasescompleteness of contents (A) and number of registered disasters per database and mountain region (B) for weather- and climate-related events the time period 1980/1985 - 2011/2014. (Source: EM-DAT, DesInventar, Dartmouth and NatCatSERVICE databases).

5.2 Analysis of regional Disaster Occurrence

The regional analysis and the spatiotemporal changes of disaster occurrence of the five mountain regions are based on data from the EM-DAT database.

5.2.1 Regional Analysis

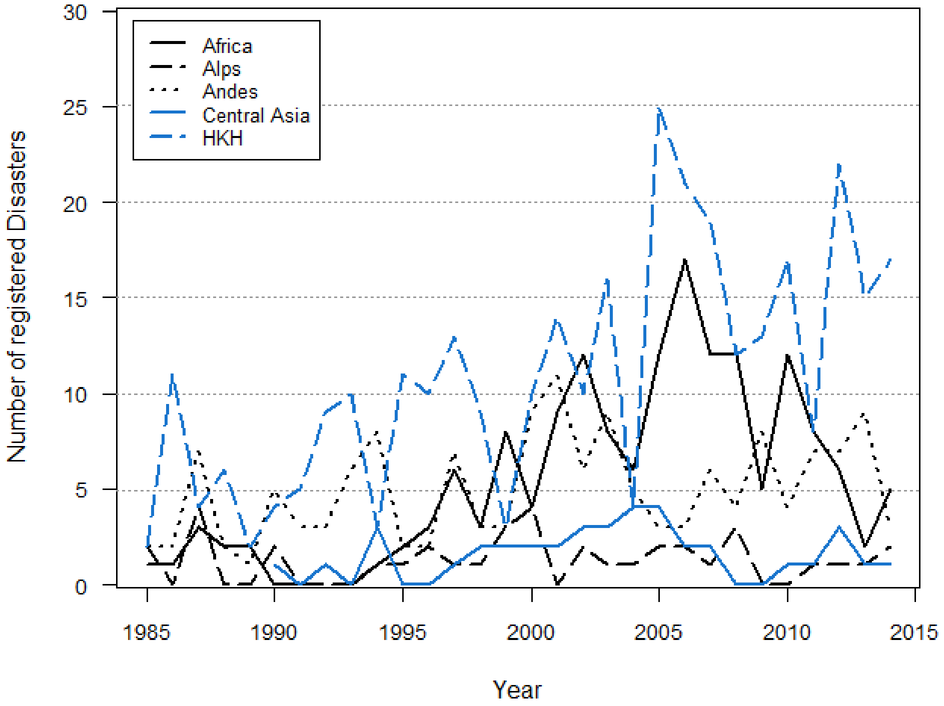

Figure 10: Number of weather- and climate-related disasters in the five mountain regions for the time period 1985 (Central Asia from 1990) to 2014. (Source: EM-DAT database).

The temporal trends of weather- and climate-related disasters in the five mountain regions from 1985, 1990 for Central Asia, until 2014, are illustrated in Figure 10. Data for all disaster entries are generated from the EM-DAT database. The African countries (solid black line) exhibit a low number of disasters in the first ten years with a fluctuation between one and three events. After 1995, the line indicates an irregular increasing trend until the peak in 2006 with 17 disasters. Afterwards, there is a decreasing trend until a lower level is reached again in 2014. The disaster trend in the Alps (black dashed) during the 35 years period exhibits a very low disaster fluctuation between zero and four disasters per year, the latter occurring in the years 1987 and 2000. The Andes (black dotted) indicates a discontinuous fluctuation over the whole time period with the highest number of disaster occurrences in 2001. There is a minimum number of disasters in the Andes of two events per year. In Central Asia (blue solid line), the relatively low disaster frequency fluctuates between zero and four events per year, the latter occurring in the years 2004 and 2005. The HKH-region (blue dashed) indicates a gradually increasing trend over the whole time period with a maximum of 25 disasters in the year 2005.

The total number of 38 reported natural disasters in the Alps (Austria, France, Italy and Switzerland) between 1985 and 2014 is shown in Figure 11. Flood disasters represent the highest rate of occurrence with 44.7%, followed by mass movement events (28.9%) and storms (21.1%). The mass movement disasters are divided into five landslides and six avalanches. Only one wildfire (2.6%), and one extreme temperature (2.6%), as a cold wave, was registered. No drought disaster occurred in the European Alps. The two years 1987 and 2000 were impacted by the greatest frequency of events with four disasters. The 38 disasters in the 30 years cost a total of 607 people killed and 33,011 people affected. The estimated damage in the Alps was 7,245.0 million USD.

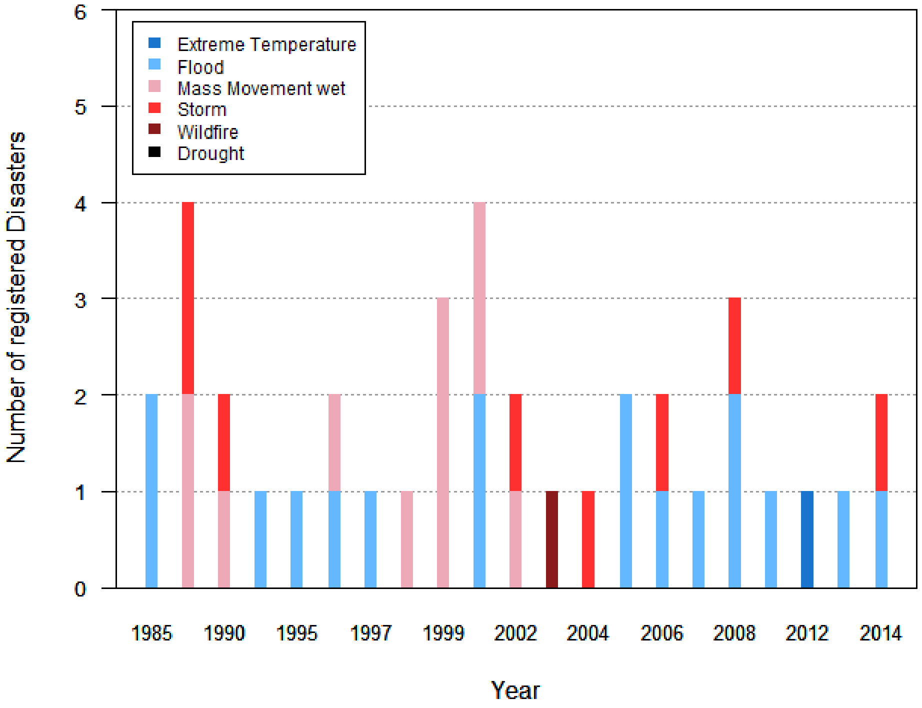

Figure 11: Number of weather- and climate-related disasters in the Alps according to the type of disaster for the time period 1985 to 2014. (Source: EM-DAT database).

In the time period 1985-2014, a total of 150 natural disasters occur in the Andes (Colombia, Ecuador, Peru, Bolivia, Argentina, Chile and Venezuela) (Figure 12 A). Flood disasters (50%) and mass movement disasters (28.7%) occur most often, followed by extreme temperatures (8.0%), droughts (9.0%), storms (5.3%) and wildfires (2.0%). The mass movements appear as 41 landslides and two avalanches, whereas extreme temperatures consist of nine cold waves, two severe winter conditions and two heat waves. In the 30 years, a total of 6,674 people were killed, whereas 13,006,871 people were affected. Disaster damage in the Andes cost 3,138.4 million USD.

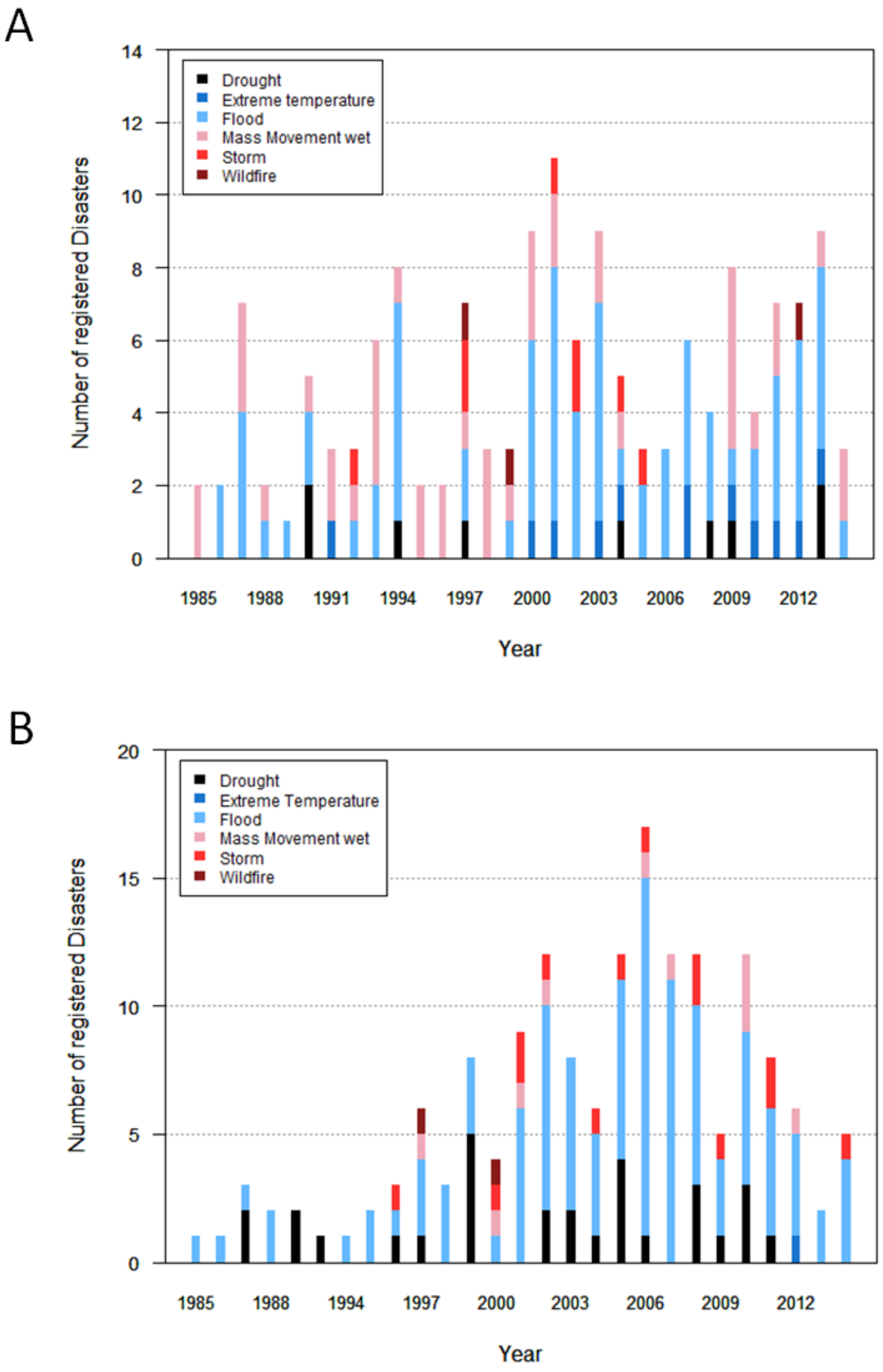

Figure 12: Number of weather- and climate-related disasters in the Andes (A) and Africa (B) according to type of event for the time period 1985 to 2014. (Source: EM-DAT database).

A total of 163 natural disasters occurred in Africa (Malawi, Madagascar, Tanzania, Uganda, Zambia, Algeria, Ethiopia, Kenya, Lesotho, Burundi and Rwanda) between 1985 and 2014 (Figure 12 B). More than half of all disasters were floods (65.0%), followed by droughts (18.4%), storms (8.6%), mass movement events (6.1%), wildfires (1.2%) and one extreme temperature event (0.6%), as a cold wave. The mass movements comprised ten landslides. Over the 30 year period, Africa reported a total of 4,881 people killed and 76,127,779 people affected. The estimated economic loss in Africa was 1,246.8 million USD.

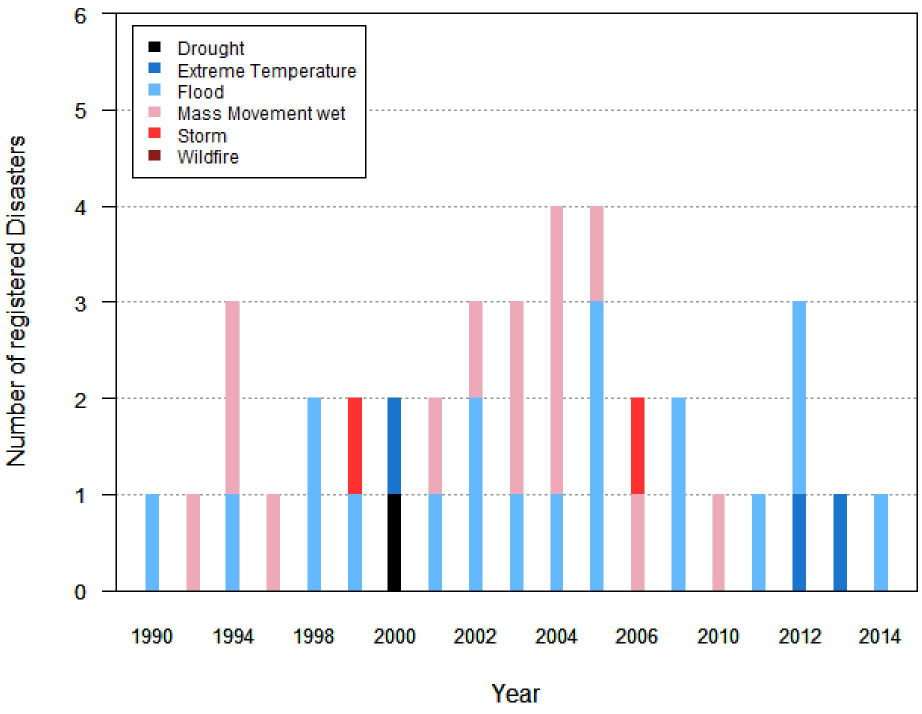

Figure 13: Number of weather- and climate-related disasters in Central Asia according to type of event for the time period 1985 to 2014. (Source: EM-DAT database).

In the 25 year period 1990-2014, Central Asia (Kyrgyzstan, Tajikistan) suffered from 39 natural disasters (Figure 13). Flood disasters (48.7%) and mass movement disasters (35.9%) occurred most often, followed by disasters of extreme temperatures (7.7%), storms (5.1%) and droughts (5.1%). Mass movements constituted ten landslides and four avalanches, whereas the extreme temperatures comprised two cold waves and one severe winter conditions. No wildfire occurred in the analyzed time period. A total of 700 people were killed, with 3,518,763 people affected. Disaster damage in Central Asia cost 257.4 million USD.

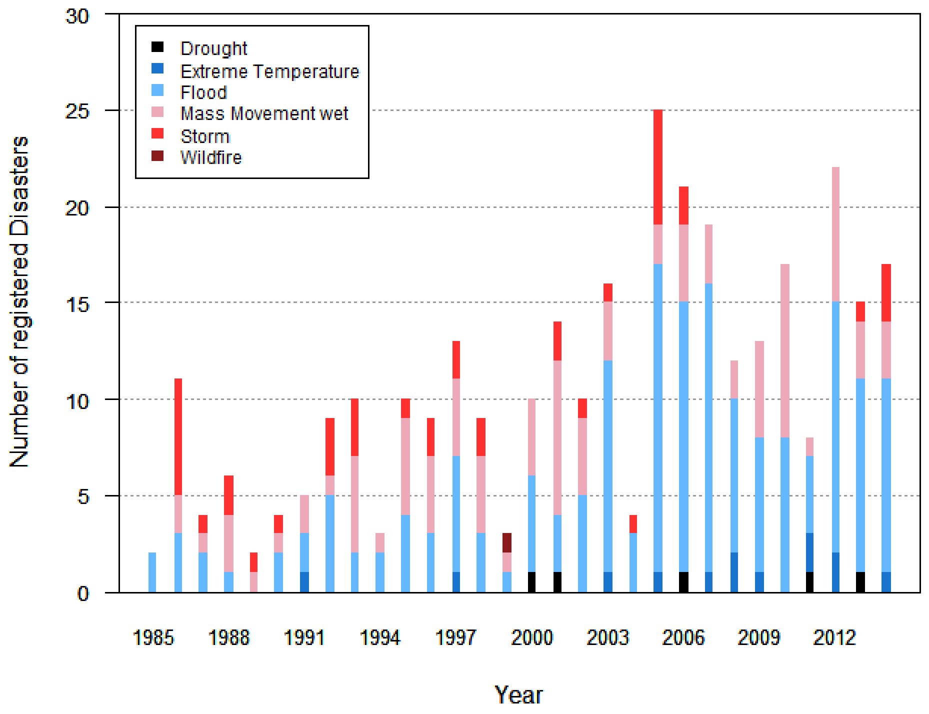

Figure 14: Number of weather- and climate-related disasters in the HKH region according to type of event for time period 1985 to 2014. (Source: EM-DAT database).

The Hindu Kush-Himalaya region (Afghanistan, Bhutan, China, India, Nepal and Pakistan) (Figure 14) reported a total of 323 natural disasters in 30 years, in time period 1985-2014. The HKH region was most frequently affected by flood disasters (52.6%), followed by mass movement disasters (28.5%), storm disasters (13.0%), extreme temperature disasters (4.0%), droughts (1.5%) and wildfires (0.3%). The mass movement disasters constituted 63 landslides and 29 avalanches, whereas the extreme temperatures comprised nine cold waves and four severe winter conditions. Totals of 26,818 people killed and 165,694,879 people affected were registered. The economic damage in the HKH region cost 44,690.4 million USD.

5.2.2 Spatiotemporal Trends of Disaster Occurrence

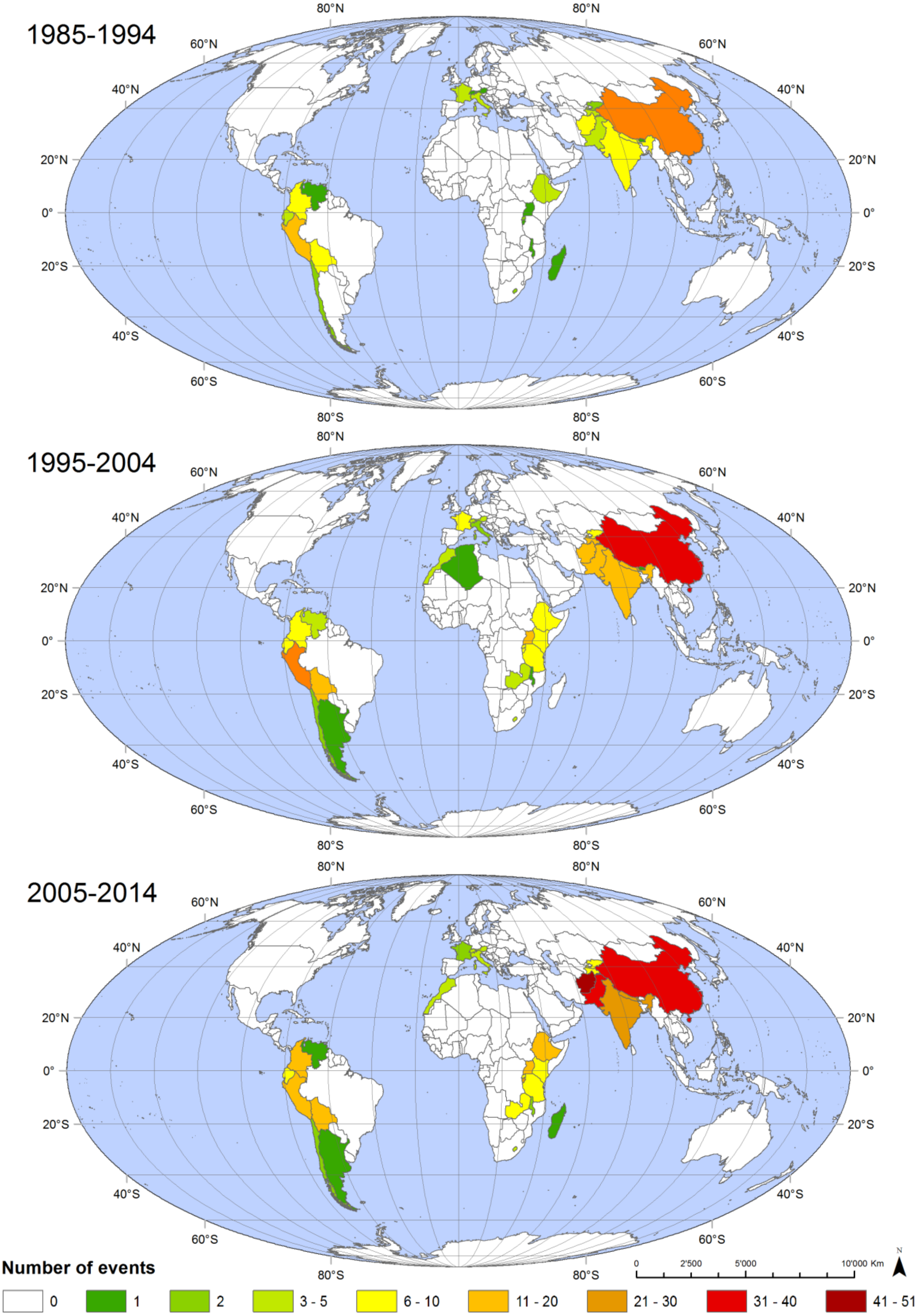

Figure 15: Spatiotemporal trends of disaster occurrence in the five mountain regions at the level of countries over the time period 1985-2014. (Source: EM-DAT database).

The spatiotemporal trends of disaster occurrence in the five mountain regions on a country level over the time period 1985-2014 are illustrated in Figure 15. During the first decade 1985-1994, the frequency of disasters per country in the regions of Africa, the Alps and Central Asia fluctuated between three events in Central Asia and four in eastern Africa and the Alps. The Atlas region of northern Africa was not affected by any disaster. The number of disasters in the Andes exhibited on a higher level with 19 disasters occurring in Peru, eight in Colombia and six in Bolivia. In contrast, the frequency of disasters in the HKH region ranged from one event in Bhutan to eight in Afghanistan and India, ten in Nepal and as high as 24 in China. In the second decade from 1995-2004, the frequency of recorded disasters was higher in most of the regions, compared to the prior decade. The Atlas ranges and the Alps suffered between one and six disasters, whereas the eastern parts of Africa were affected by twelve disasters which occurred in Uganda. The Andes registered 15 disasters in Bolivia and 23 in Peru. Once more, the most disaster-prone region was represented by the HKH with 34 disasters in China, 18 events each in Afghanistan and India, 14 in Pakistan and 13 disasters in Nepal. The reported disaster occurrence in the last decade 2005-2014 was low for the mountains of the Atlas and the Alps with five events each and higher in East Africa with 23 disasters in Burundi, 14 Uganda and 13 Ethiopia. Central Asia suffered from nine events. The highest disaster frequencies in the Andes were 17 in Peru, 16 in Bolivia and 11 in Colombia. Nevertheless, the majority of events occurred in the HKH region, with 21 events in India, 28 in Nepal, 32 in Pakistan, 37 in China and 51 in Afghanistan. The results of the spatiotemporal occurrence of disasters indicate that the three most disaster-prone regions are the Andes, the mountainous parts of East Africa and the HKH region.

For a more comprehensive and detailed analysis of these three regions, the disaster occurrences were evaluated on a state-based level (Figure 16), During the first decade 1985-1994 the most disaster-prone state of the HKH region was the Sichuan (1) state of China with a total of 16 disasters. The second most disaster-prone regions with five events each were registered in the Yunnan (2) state of China and the Jammu and Kashmir (3) state of India, followed by four events in the Badakhshan (4) state of Afghanistan and four events in the Bagmati (5) state of Nepal. The highest frequency of disasters in the second time period 1995-2004 also occurred in China with 14 disasters in the state of Sichuan (1), and 13 in the Yunnan (2) state. The Khyber Pakhtunkhwa (3) state in Pakistan suffered from ten disasters, followed by seven events in the Himachal Pradesh (4) state of India. The last decade between 2005 and 2014 indicated an increase of natural disasters twice as high as in the previous years in the Khyber Pakhtunkhwa (1) state of Pakistan with 21 events. In each of the two states of China, Sichuan (2) and Yunnan (3), 16 disasters occurred. The Badakhshan (4) state of Afghanistan suffered from 13 disasters in the last decade. The state-based disaster analysis indicated that the most disaster-prone mountainous regions were located in the HKH. Hence, the Badakhshan state of northern Afghanistan, the Khyber Pakhtunkhwa state in northern Pakistan, the Jammu and Kashmir state of India and the two states of China in the eastern parts of the HKH, Yunnan and Sichuan, were most affected by natural disasters in recent years.

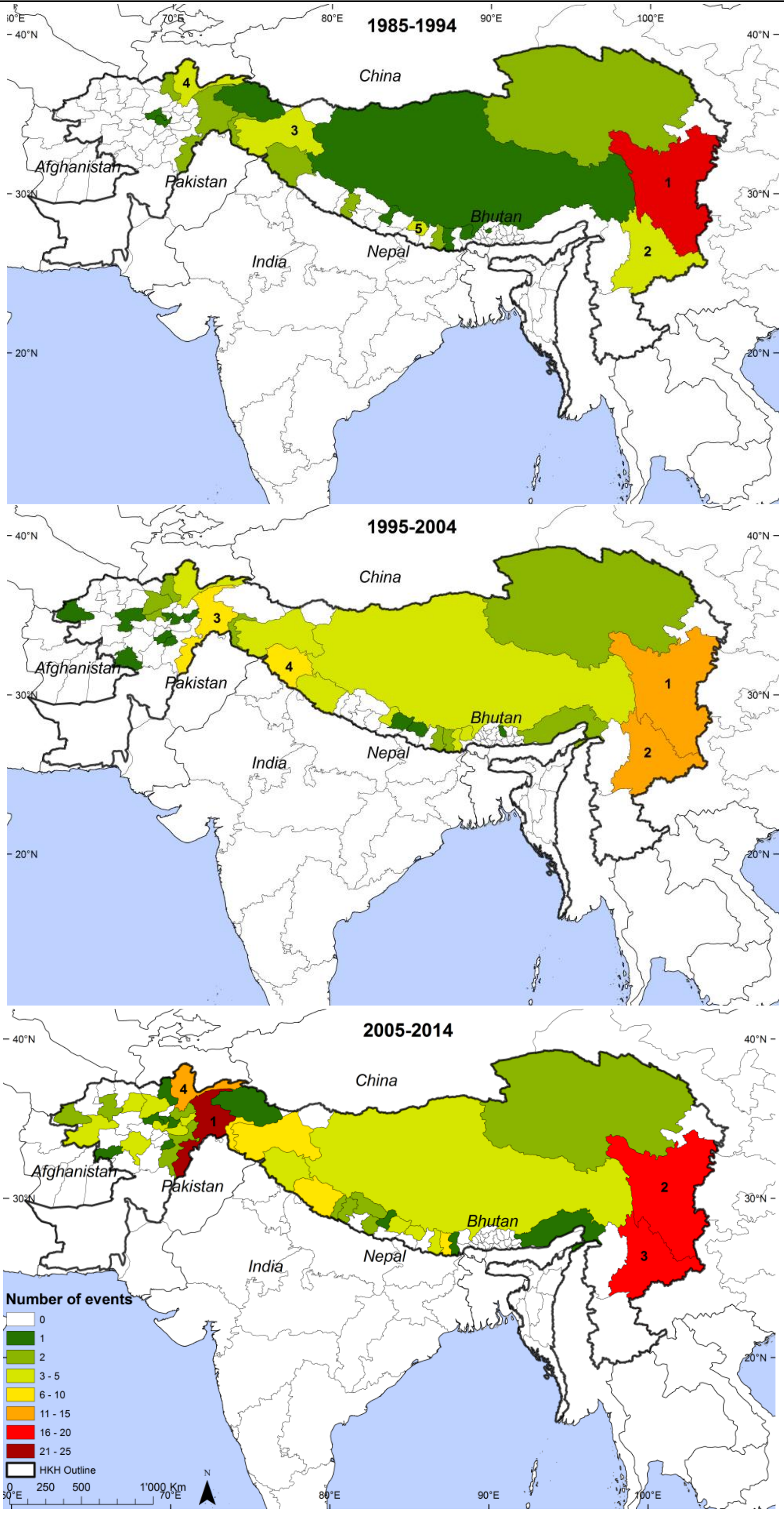

Figure 16: Spatiotemporal trends of disaster occurrence in the HKH region at the level of states over the time period 1985-2014. The numbers indicate the most affected states. 1985-1994: (1) Sichuan, (2) Yunnan, China; (3) Jammu and Kashmir, India; (4) Badakhshan, Afghanistan; (5) Bagmati, Nepal. 1995-2004: (1) Sichuan, (2) Yunnan, China; (3) Khyber Pakhtunkhwa, Pakistan; (4) Himachal Pradesh, India. 2005-2014: (1) Khyber Pakhtunkhwa, Pakistan; (2) Sichuan, (3) Yunnan, China; (4) Badakhshan, Afghanistan. (Source: EM-DAT database).

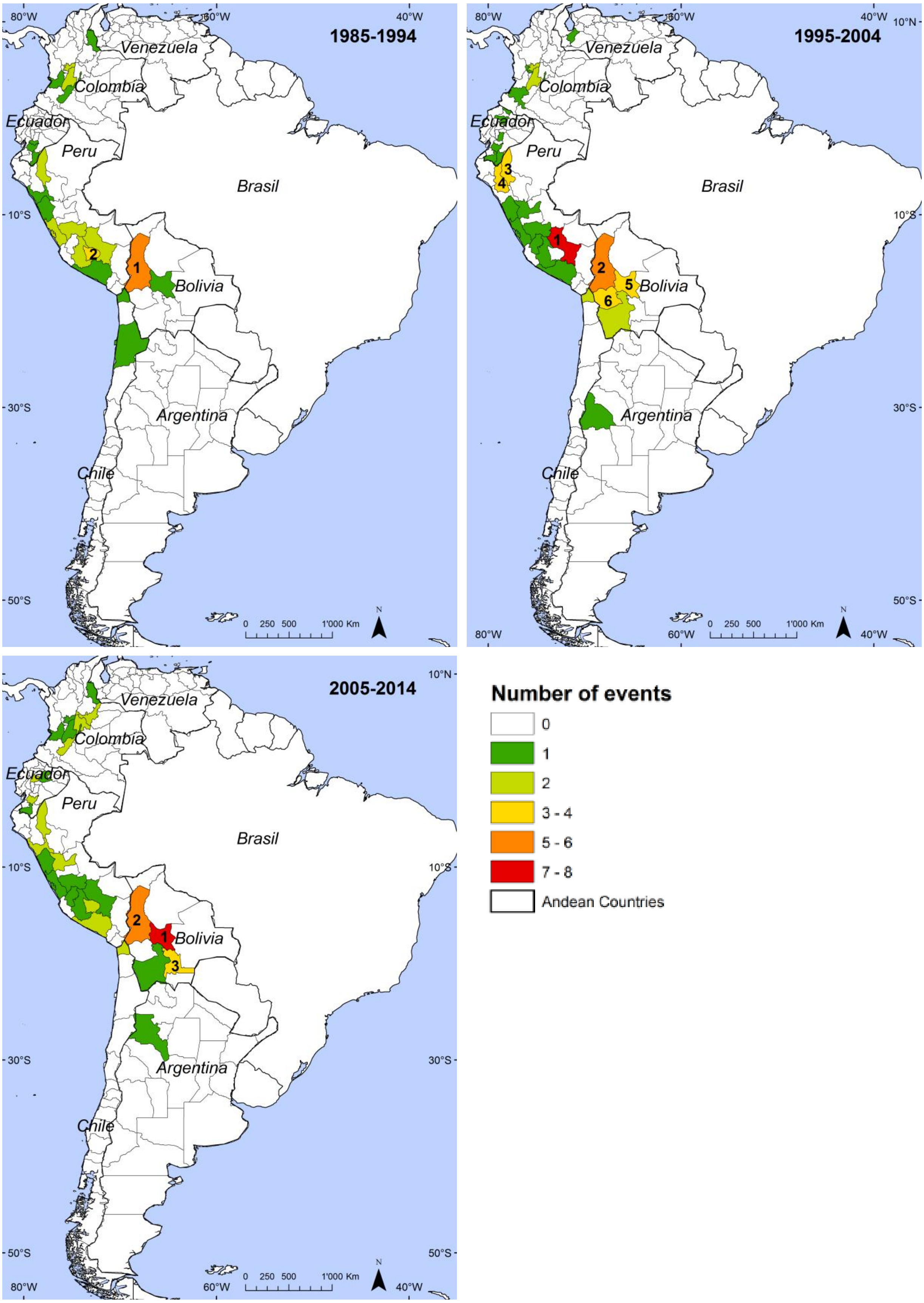

Figure 17: Spatiotemporal trends of disaster occurrence in the Andean region at the level of states over the time period 1985 to 2014. The numbers indicate the most affected states. 1985-1994: (1) La Paz, Bolivia; (2) Apurimac, Peru. 1995-2004: (1) Cusco, Peru; (2) La Paz, Bolivia; (3) Amazonas, (4) Cajamarca, Peru; (5) Cochabamba, (6) Oruro, Bolivia. 2005-2014: (1) Cochabamba, (2) La Paz, (3) Chuquisaca, Bolivia. (Source: EM-DAT database).

The spatiotemporal trends of disaster occurrence in the Andes on a state-based level over the time period from 1985-2014 is shown in Figure 17. During the first decade, the most affected area was the Bolivian state of La Paz (1) with five natural hazards, followed by the Peruvian state of Apurimac (2) with three disasters. All other mountainous states of the Andes were affected by between zero and two disasters. In the second decade, the Cusco (1) state of Peru registered seven disasters, followed by La Paz, Bolivia (2) with five disasters, the Peruvian states of Amazonas (3) and Cajamarca (4) each with three disasters, and Cochabamba (5) and Oruro (6) in Bolivia each with four disasters. In the last decade, in the time period 2005 to 2014, the most natural disaster-prone states were all located in Bolivia, where Cochabamba was affected by seven, La Paz by five and Chuquisaca by three natural disasters. The analysis emphasized that the states of the Central Andean regions in Bolivia and Peru are most affected by natural disasters. The analysis at the level of states in the Andes with data from the EM-DAT database does not show a clear pattern of changes over the three decades. However, the frequency of recorded disasters in the first decade was lower, compared to the two following decades which experienced a higher registration of adverse natural events.

The analysis of the spatiotemporal changes of disaster occurrence in the mountainous parts of East Africa (Figure 18) indicate a low number of events in the first decade from 1985-1994. The maximum of two disasters per state was documented in the Tigray state of Ethiopia. Two other states in Ethiopia, two in Uganda and two in Rwanda were each also affected by one disaster. All other mountain states were not impacted by any natural disaster. The most disaster-prone states in the second decade were the Nyanza state in Kenya with four disasters, followed by Mbeya state of Tanzania with four disasters, Mbale state of Uganda with three disasters, and Bubanza state of Burundi also affected by three natural disasters. In the last decade, the Bujumbura Rural state of Burundi suffered from eight adverse natural events. The second most disaster-prone region was the Western state of Kenya which was affected by six events. The Oromiya state of Ethiopia, the two states of Zambia, North-Western and Southern and the Western state of Rwanda were all affected by four adverse natural events. The analysis indicated an increasing trend of disaster occurrence in East Africa, with the most affected regions being located in Ethiopia and Kenya.

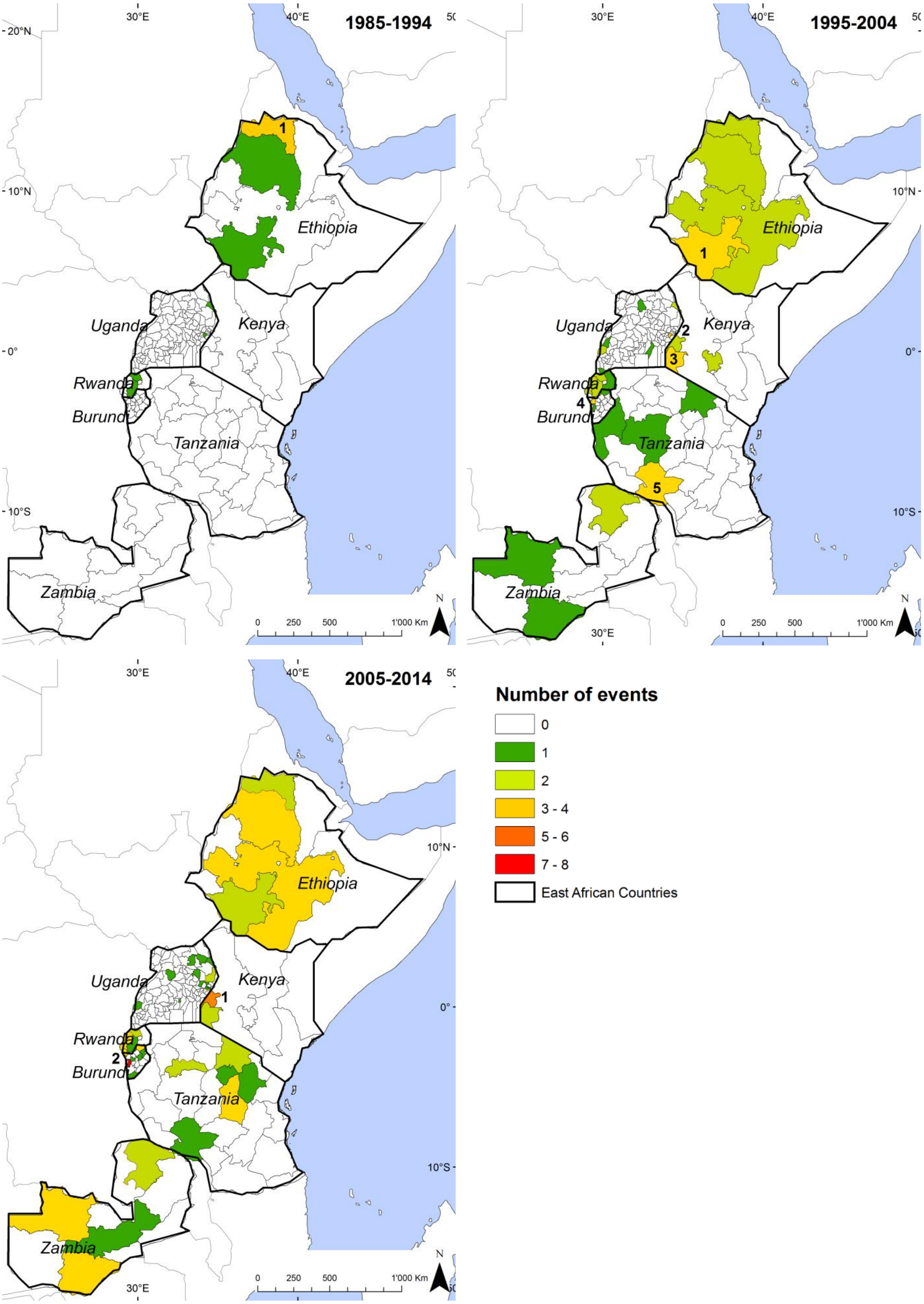

Figure 18: Spatiotemporal trends of disaster occurrence in Eastern Africa at the level of states over the time period 1985 to 2014. The numbers indicate the most affected states. 1985-1994: (1) Tigray, Ethiopia. 1995-2004: (1) Southern Nations, Ethiopia; (2) Mbale, Uganda; (3) Nyanza, Kenya; (4) Bubanza, Burundi; (5) Mbeya, Tanzania. 2005-2014: (1) Western, Kenya ; (2) Bujumbura Rural, Burundi. (Source: EM-DAT database).

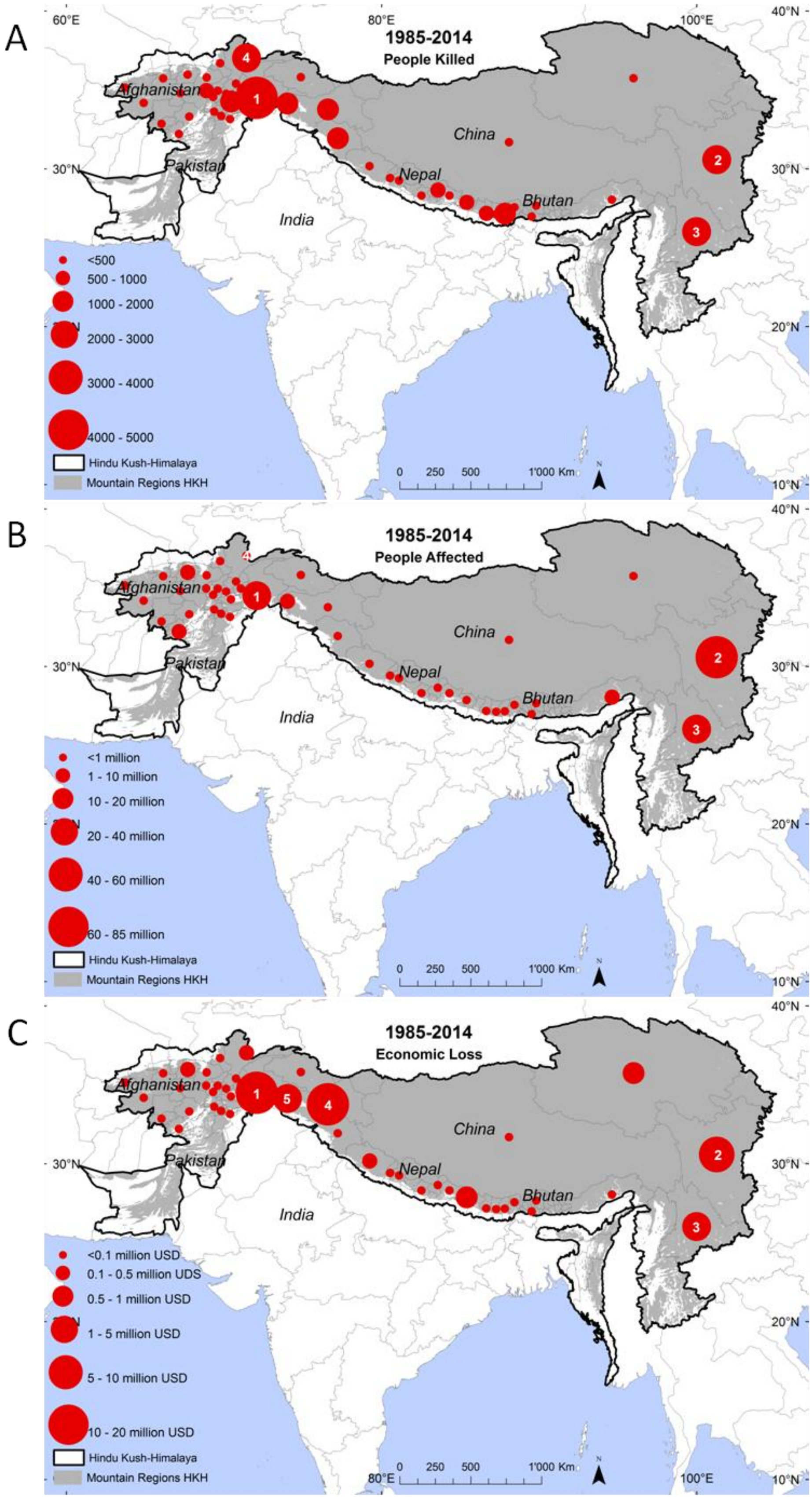

Figure 19: Number of people killed, affected, and economic loss in the HKH region at the level of states over the time period 1985-2014. (A) The numbers indicate the most deadly states: (1) Khyber Pakhtunkhwa, Pakistan, (2) Sichuan, (3) Yunnan, China; (4) Badakhshan, Afghanistan. (B) The numbers indicate the most affected states: (1) Khyber Pakhtunkhwa, Pakistan, (2) Sichuan, (3) Yunnan, China. (C) The numbers indicate the most costly states: (1) Khyber Pakhtunkhwa, Pakistan; (2) Sichuan, (3) Yunnan, China; (4) Jammu and Kashmir, India; (5) Kashmir, Pakistan. (Source: EM-DAT database).

The maps of the HKH region (Figure 19) refer to the human and economic losses from natural disasters at the level of states over the time period 1985-2014. Figure 21 (top) indicates the total number of people killed. The highest number of fatalities was recorded in the Khyber Pakhtunkhwa (1) state of northwestern Pakistan. Khyber Pakhtunkhwa state, which is the smallest state of Pakistan with an area of 74.5 km^2, registered 4436 people killed in the 30 year time period. The second deadliest state is located in the eastern part of the HKH region in the Yunnan (2) state of China with 2615 dead, followed by the Sichuan (3) state of China with 2423 people killed. The Badakhshan (4) state of northeastern Afghanistan listed 2033 dead. The spatial occurrence of affected people (Figure 21 middle) follows a similar distribution to the number of people killed. Khyber Pakhtunkhwa (1) state registered over 33.5 million affected people, Yunnan (2) state listed nearly 26 million people, whereas more than 81 million people affected were registered in the Sichuan state of China. Also the amount of economic damage follows similar spatial patterns to the human losses (Figure 21 bottom). Hence, Khyber Pakhtunkhwa (1) state recorded economic damage greater than 12 million USD, whereas the China states Yunnan (2) listed an economic loss of about 2.9 million USD, and a loss of 8.2 million USD was recorded in the Sichuan (3) state. The Jammu and Kashmir (4) state of northern India listed a 16 million USD loss and Kashmir (5) state in Pakistan 3 million USD. The results indicated a significant occurrence and interdependence of human and economic losses for the northern parts of Pakistan and Afghanistan, the northwestern part of India and the two states of China in the eastern part of the HKH. However, the mountainous regions of Nepal and Bhutan, the southern parts of Afghanistan and Pakistan and the Tibetan plateau in the middle of the HKH region were less prone to human and economic losses in the 30 years time period.

5.3 Comparative Disaster Loss Analysis

The number of events and human losses in the time period 1985-2014 based on data from the EM-DAT database with indications of the mountain population living in these regions is illustrated in Table 3. The HKH suffered from most events with a high resulting number of affected and killed people. However, the HKH is home for the greatest number of people with a population of up to 210 million. The total number of events for Africa and the Andes is similar, with comparable numbers of people killed. However, there are many more people affected in Africa than in the Andes, corresponding to the higher population density in Africa. The number of disasters, people killed and the mountain population density for Central Asia and the Alps are also comparable, although there is a significantly higher registration of people affected for the Central Asia region.

Table 3: Total number of natural disasters, people killed and affected per mountain region for the time period 1985-2014. (Source: EM-DAT database).

Region	Number of events 1985-2014	Number killed 1985-2014	Number affected 1985-2014	Mountain Population (in millions)
Africa	163	4,881	76,127,779	183
Alps	38	607	33,011	7
Andes	150	6,664	13,006,871	58
Central Asia	39	700	3,518,763	9
HKH	325	26,991	165,694,879	210

The national-scale comparative disaster analysis for the Andes (Peru, Colombia, Ecuador and Bolivia) and the HKH (Nepal, India, Pakistan, Afghanistan and China) are compared with global data from the EM-DAT database (Table 4) and national data from the DesInventar database (Table 5). The disaster trend from 1981 to 2010 indicates a considerably greater number of events reported by DesInventar than by EM-DAT. The largest disparity appears in the data of Colombia, where DesInventar registered 1,544 events in the last decade, compared to EM-DAT with only ten disasters in the same time coverage. However, in both databases, the lowest number of events registered was for the 1980s, whereas the highest number of events occurred in the last decade, with a few exceptions such as for Peru (DesInventar) and for Ecuador (EM-DAT) with a peak in the second decade. The number of disasters therefore indicates a visible increasing trend over the three decades in both databases. Comparing the numbers of people killed and affected, there are no clear patterns visible over the 30 years time period. There is a better correspondence between the two databases for the number of people killed than there is for people affected. Nevertheless, the number of people killed varies between similar results e.g. for Bolivia and Ecuador, and unequal results e.g. for Peru, with more than double the number of people killed per decade registered in DesInventar than in EM-DAT. Generally, there are more decades with a higher registration of people killed for the DesInventar database. Concerning the affected people, no clear patterns and correlations between the two databases are recognizable. Numbers of affected people from EM-DAT are highest in the last decade for six out of the total of nine countries. The disaster mortality ratio for both databases does not indicate clear trends. EM-DAT registers the lowest ratio for six out of nine countries for the 1980s, whereas according to DesInventar, the ratio is lowest in three out of five countries for the 2000s. By contrast, the ratio of affected population indicates the highest rate in EM-DAT for six out of the nine countries in the last decade, whereas DesInventar registers the highest ratio of people affected for the first and second decades.

Table 4: A comparison of metrics of disasters in the Andes and the HKH (1981-2010). The percentages refer to the reference state of the first decade (1980s) (Source: EM-DAT database).

EM-DAT	No. of Events	People killed	People affected	Total population	% No. of Events	Disaster mortality ratio	Ratio of affected population
Peru[1]							
1981-1990	21	1,406	2,485,300	11,050,747	-	1.27E-04	0.225
1991-2000	14	1,146	952,200	13,065,863	66.7	8.77E-05	0.073
2001-2010	24	1,704	3,634,937	14,245,978	114.3	1.20E-04	0.255
Colombia[2]							
1981-1990	3	171	800	17,801,756	-	9.61E-06	0.000
1991-2000	10	160	90,714	21,251,775	333.3	7.53E-06	0.004
2001-2010	10	407	426,550	24,008,005	333.3	1.70E-05	0.018
Ecuador[3]							
1981-1990	2	200	6,000	4,454,182	-	4.49E-05	0.001
1991-2000	7	555	121,057	5,444,872	350.0	1.02E-04	0.022
2001-2010	4	90	397,240	6,424,355	200.0	1.40E-05	0.062
Bolivia[4]							
1981-1990	5	54	2,149,209	5,438,582	-	9.93E-06	0.395
1991-2000	10	228	434777	6,591,660	200.0	3.46E-05	0.066
2001-2010	15	455	1,628,930	6,358,350	300.0	7.16E-05	0.256
Nepal[5]							
1981-1990	11	510	611,500	11,441,231	-	4.46E-05	0.053
1991-2000	11	2,457	219,115	14,184,328	100.0	1.73E-04	0.015
2001-2010	16	1,326	1,077,498	16,144,736	145.4	8.21E-05	0.067
India[6]							
1981-1990	12	901	250,200	21,330,000	-	4.22E-05	0.012
1991-2000	12	1,393	3,075,000	26,349,768	100.0	5.29E-05	0.117
2001-2010	18	1,432	40,300	31,486,590	150.0	4.55E-05	0.001
Pakistan[7]							
1981-1990	2	177	0	15,302,395	-	1.16E-05	-
1991-2000	11	1,621	6,655,650	24,362,590	550.0	6.65E-05	0.273
2001-2010	32	4,116	29,795,225	37,359,247	1600.0	1.10E-04	0.798
Afghanista[8]							
1981-1990	1	0	161,000	15,003,100	-	-	0.011
1991-2000	15	1,828	2,704,200	16,426,900	1500.0	0.0001	0.165
2001-2010	45	2,927	651,874	18,254,512	4500.0	0.0002	0.036
China[9]							
1981-1990	16	1,462	37,571,619	132,147,677	-	1.11E-05	0.284
1991-2000	30	2,158	8,468,310	135,013,182	187.5	1.60E-05	0.063
2001-2010	40	1,591	52,576,300	136,834,300	250.0	1.16E-05	0.384

Table 5: A comparison of metrics of disasters in the Andes and the HKH (1981-2010). The percentages refer to the reference state of the first decade (1980s) (Source: DesInventar database).

DesInventar	No. of Events	People killed	People affected	Total population	% No. of Events	Disaster mortality ratio	Ratio of affected population
Peru[1]							
1981-1990	121	580	1,980,237	11,050,747	-	5.25E-05	0.179
1991-2000	383	703	649,427	13,065,863	316.5	5.38E-05	0.050
2001-2010	201	738	505,249	14,245,978	166.1	5.18E-05	0.035
Colombia[2]							
1981-1990	246	793	2,020,007	17,801,756	-	4.45E-05	0.113
1991-2000	744	637	2,809,386	21,251,775	302.4	3.00E-05	0.132
2001-2010	1,544	465	2,373,737	24,008,005	627.6	1.94E-05	0.099
Ecuador[3]							
1981-1990	12	267	276,917	4,454,182	-	5.99E-05	0.062
1991-2000	44	776	92,481	5,444,872	366.7	1.43E-04	0.017
2001-2010	67	239	47,188	6,424,355	558.3	3.72E-05	0.007
Bolivia[4]							
1981-1990	18	97	12,057	5,438,582	-	1.78E-05	0.002
1991-2000	42	192	305,494	6,591,660	233.3	2.91E-05	0.046
2001-2010	360	377	1,821,229	6,358,350	2000.0	5.93E-05	0.286
Nepal[5]							
1981-1990	93	688	45,201	11,441,231	-	6.01E-05	0.004
1991-2000	405	1,201	956,191	14,184,328	435.5	8.47E-05	0.067
2001-2010	410	1,684	658,427	16,144,736	440.9	1.04E-04	0.041

Information on total population was derived from following sources:

[1] Peruvian National Institute of Statistics and Informatics (INEI) for the years 1993, 2007, 2012

[2] Colombian National Department of Statistics (DANE) for the years 1993, 2005, 2014

[3] Ecuadorian National Institute of Statistics and Census (INEC) for the years 1990, 2001, 2010

[4] Bolivian National Institute of Statistics (INE) for the years 2001, 2010, 2012

[5] (CBS) Nepal Central Bureau of Statistics for the years 1991, 2001, 2011

[6] Indian Statistical Institute (ISI) for the years 1991, 2001, 2011

[7] Pakistan Bureau of Statistics for the years 1981, 1998, 2011

[8] Afghanistan Central Statistics Organization (CSO) for the years 2006, 2009, 2015

[9] National Bureau of Statistics of China for the years 2000, 2010, 2013

5.4 Database Comparison for Flood and Mass Movement Disasters

In order to evaluate the reliability of disaster databases, a number of base elements such as the year of occurrence of the events, the number of people killed and affected and the economic loss have been analyzed within this thesis. The focus of the comparison lies on flood and mass movement disasters in the HKH region and the Andes. The flood data are stem from the global Dartmouth database and the global EM-DAT database. Mass movement data are generated from the two global NatCatSERVICE and the EM-DAT databases. For the comparative flood and mass movement trends for Africa, the Alps and Central Asia see Appendix A.7.

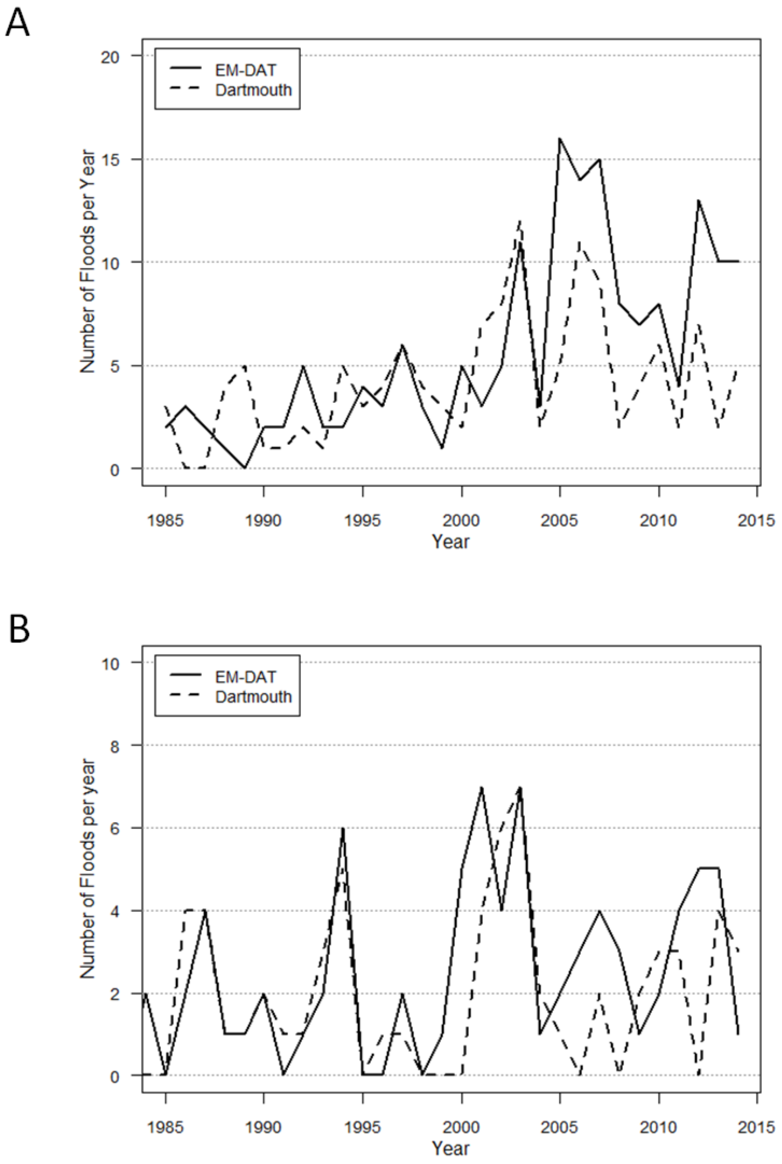

Figure 20: Number of registered flood disasters per year in the HKH region (A) and the Andes (B) for the time period 1985 to 2014. (Source: EM-DAT and Dartmouth databases).

The number of register floods for the HKH region (A) and the Andes (B) are illustrated in Figure 20 for the time period 1985 to 2014. The development of floods for the HKH region show a relatively high disparity between the EM-DAT and Dartmouth databases for the period 1985-1995 with a fluctuation between zero and five floods in both databases. There is a higher degree of accordance of the two traces after 1996 with a significant increase of flood events after 2000. However, the greatest number of floods in the EM-DAT database is in 2005 with 16 floods per year. The maximum number of floods in Dartmouth occurs two years earlier, in 2003, with twelve flood events. After 2005, the two lines decreases, with EM-DAT registering a greater number of floods compared to Dartmouth for the last decade. The calculated R^2 value is 0.3484 for the two databases for flood events in the HKH. In contrast, the flood trends in the Andes (B) indicate a good accordance in the first years with higher disparity in the last decade with a higher event registration from the EM-DAT database. The Andean flood trend seems to be variable without any significant increasing or decreasing indications over the time period, with a high number of disasters in 1994 and around 2003 being registered in both databases. Despite apparent differences in the absolute number of events in the two databases for the HKH and the Andean regions, the disaster trends show a relatively good agreement with exceptions of some visible divergences and shifts. EM-DAT registered a total of about 170 floods for the HKH and 76 for the Andes, whereas Dartmouth listed 126 floods for the HKH and 61 for the Andes. The calculation of the R^2 value for the two flood trends is 0.3484 for the HKH region, whereas the two flood trends for the Andes indicate a value of about 0.3520.

The number of people killed due to flood events in the HKH region is shown in Figure 21 (A), for the Andes in Figure 21 (B) with data from EM-DAT and Dartmouth databases for the time period 1985 to 2014. EM-DAT registers a fluctuation of killed people in the first five years between zero people (1988 and 1989) and 329 people in 1985. There is a first peak in 1992 with 2,070 people killed, followed by smaller peaks in 1996 (1,014), 2000 (548), 2003 (793), 2005 (818) and 2007 (856). However, the maximum peak of fatalities is registered in the year 2010 with 2,547 people killed due to a monsoon triggered flash flood in northern Pakistan with 1,985 people killed. In the first five years, Dartmouth database registers people killed between zero people (1986 and 1987) and 373 people in 1985. A maximum of fatalities is recorded in 1992 with 3,012 people killed, followed by smaller peaks in 1997 (597) and 2002 (607). Nevertheless, the maximum of people killed in the 30 years was reached due to the catastrophic Kedarnath flood disaster in northern India in summer 2013 with up to 5,828 people killed. In general, the number of the recorded dead is slightly higher in the EM-DAT database with a total of 16,465 people killed in the HKH region, compared to Dartmouth with 15,427. Despite the differences in the number of events registered, the number of people killed seems to be a robust element with a relatively good correlation of both databases. Compared to the HKH region, the Andean region (B) includes more years without any indication of people killed for both databases as in the years 1985, 1992, 1995/96 and 1998/99. There is a first peak of fatalities in the Andes in 1987 with 219 people killed in EM-DAT and 374 in Dartmouth. The latter registers the highest number of people killed in 2011 with 517 dead. However, the number of people killed is fairly stable over the 30 years period with some peaks. The EM-DAT database registers a total of 2,209 people killed for the Andes, whereas Dartmouth only lists 1,965 people dead in the Andes without any significantly alternating trends.

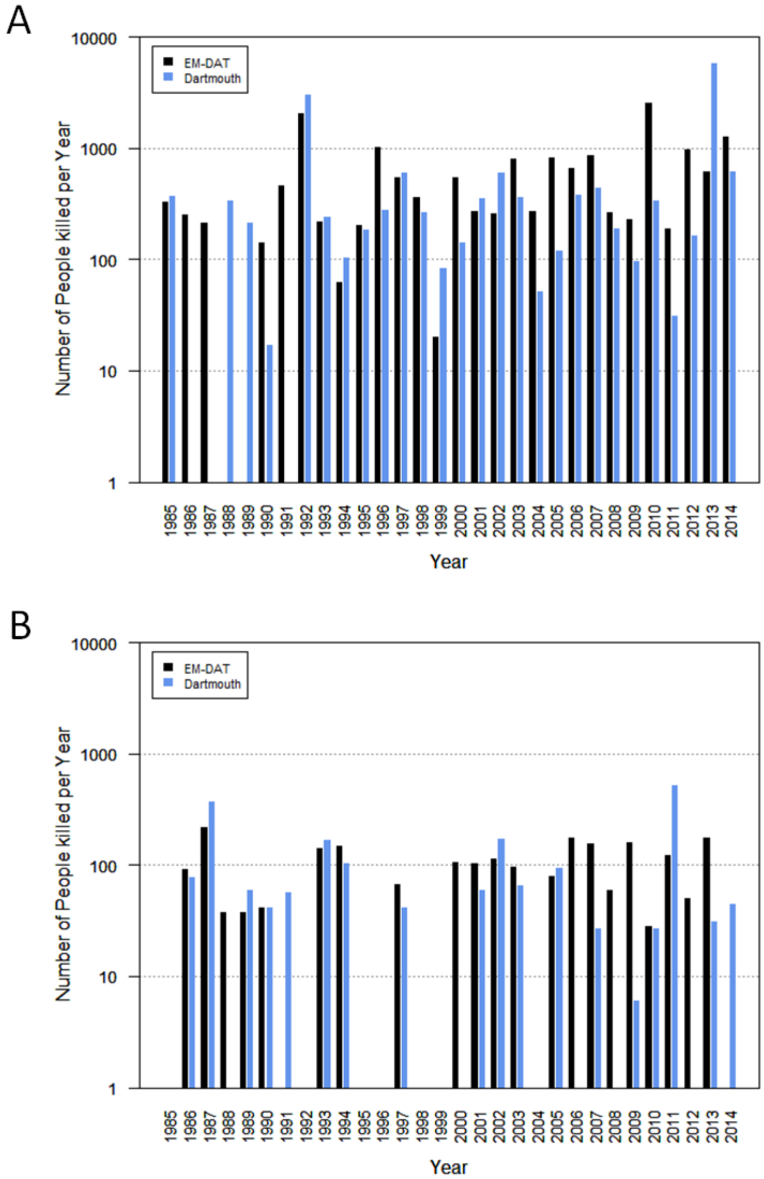

Figure 21: Number of people killed per year due to flood disasters in the HKH region (A) and the Andes (B) in the time period 1985 to 2014. (Source: EM-DAT and Dartmouth databases).

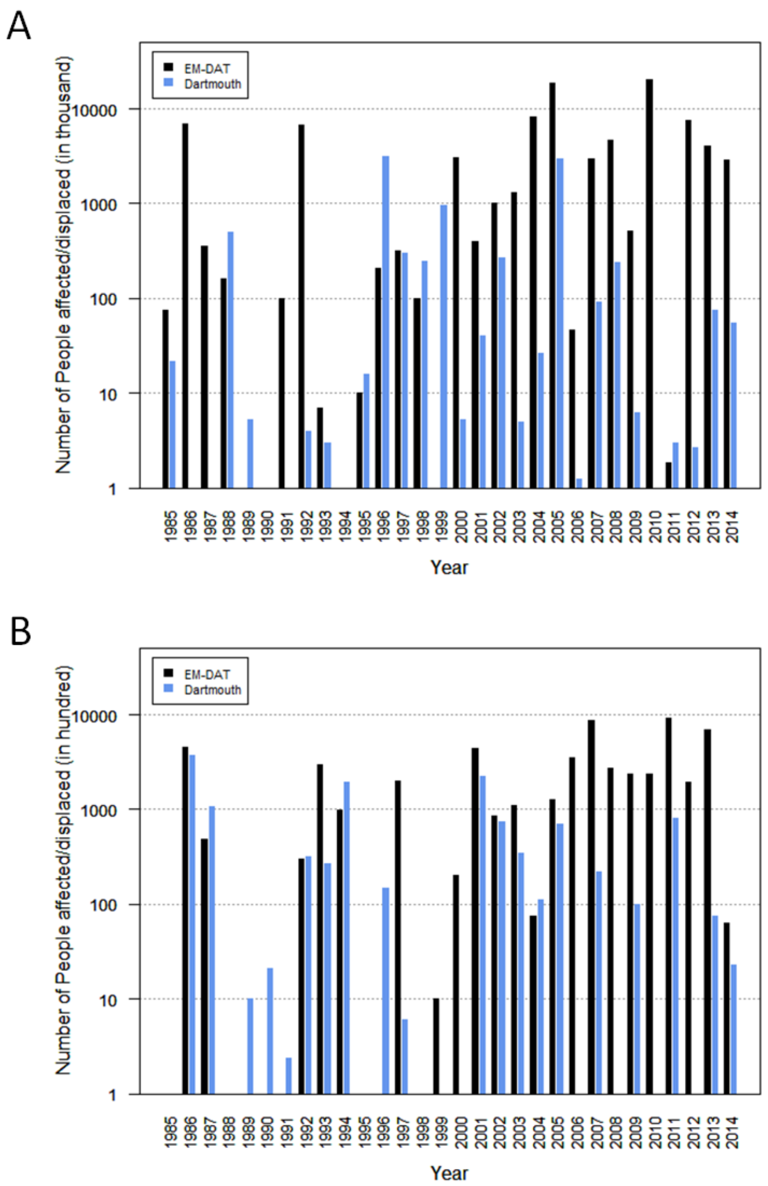

Figure 22: Number of people affected and displaced due to flood disasters per year in the time period 1985 to 2014. A: Affected in HKH region (in thousands); B: Displaced in the Andes (in hundreds). (Source: EM-DAT and Dartmouth databases).

The number of people affected (EM-DAT) and people displaced (Dartmouth) for the years 1985-2014 are indicated in Figure 22 (A) for the HKH region and in Figure 22 (B) for the Andes. EM-DAT registered three significant instances with high numbers of people affected between 1985 and 2000 in the years 1986 with 7 million affected, in 1992 with 6.7 million affected and in the year 2000 with 3.1 million people affected. However, the two maximum numbers of people affected were recorded in 2005 (18.7 million) and 2010 (20.4 million). In the years 1989, 1990 and 1999 no affected people were registered. In contrast, Dartmouth database indicates a peak in the first ten years in 1988 with 0.5 million people displaced. The highest registered number of people displaced was in the years 1996 (3.1 million) and 2005 (3.0 million). In the years 1986, 1987, 1990 and 1994, Dartmouth did not register any people as displaced. For the Andes region, EM-DAT did not record any people affected for the years 1985, 1988/89, 1991, 1995/96 and 1988. The Andean region was affected especially in the last decade, when the 1 million mark was exceeded often in the EM-DAT database. Dartmouth also registered no people displaced for the same decade. Generally, the patterns and trends for the number of people affected/displaced indicate high variations over time in both data sources without a clear tendency. However, EM-DAT register more people affected than Dartmouth with evidence of a higher number of people registered in the last decade for both regions. The EM-DAT database for the HKH reports a total of 90.7 million, with 57.1 million people affected for the Andes. In contrast, Dartmouth registers 9 million people as displaced for the HKH region and 1.3 million for the Andes. The total number of registered people affected and displaced confirms a high disparity between the two data sources, resulting in diminished reliability of these data elements.

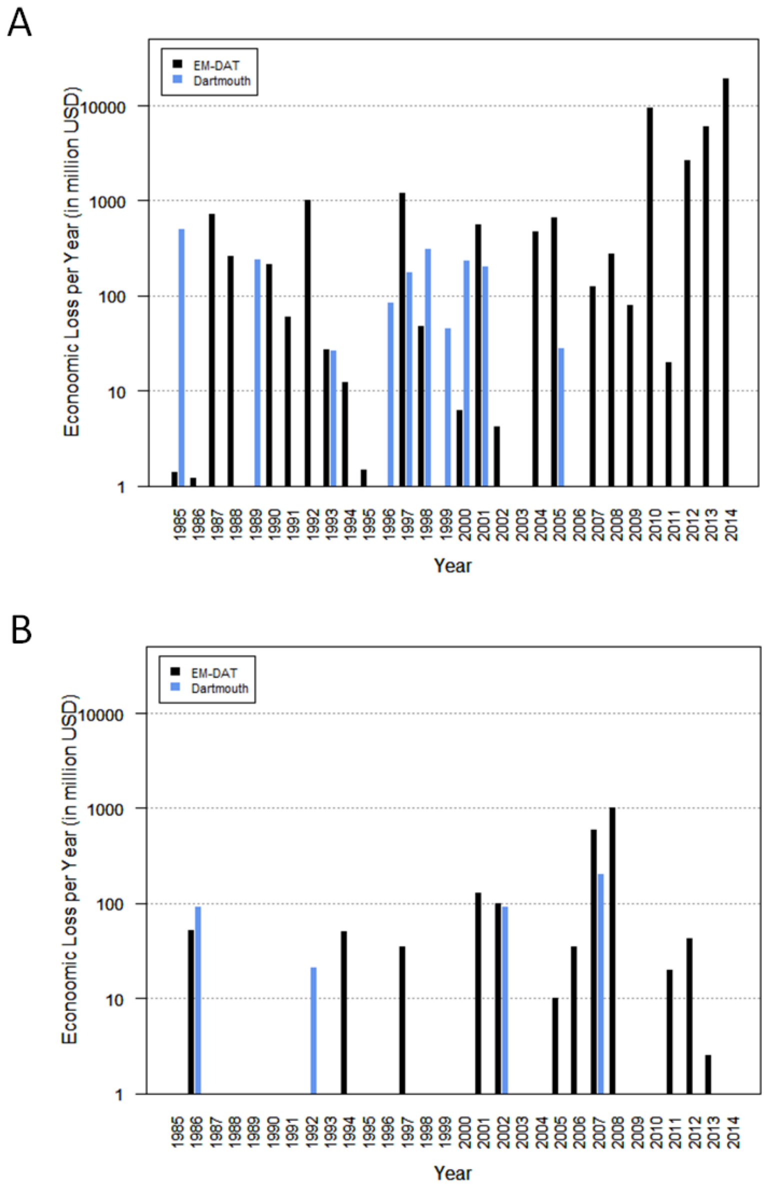

Figure 23: Economic loss (in million USD) per year due to flood disasters in the HKH region (A) and the Andes (B) in time period 1985 to 2014. (Source: EM-DAT and Dartmouth databases).

Economic losses estimations for flood events in the HKH regions are shown in Figure 23 (A) for the Andes in Figure 23 (B) in the time period 1985 to 2014. More and higher economic damage values were listed in EM-DAT, compared to Dartmouth for the HKH region. The highest economic damage with values greater than 1 billion USD was registered in the last few years in EM-DAT. Dartmouth only provides information for the first two decades without any indication of economic damage from recent events. The discrepancy between EM-DAT and Dartmouth is rather high, as Dartmouth registered economic damage of about 500 million USD for the year 1985, whereas EM-DAT only listed an economic value of about 1.4 million USD. EM-DAT registered total economic damage of about 43 billion USD for the HKH region and 2.1 billion USD for the Andes. Indications of economic damage values for the Andes are very incomplete with missing values for many years. Dartmouth only provides data for four years for the Andes (405 million), while EM-DAT supplies data for twelve years (1.8 billion) of the 30 years time period. The economic loss data indicate no significant trends over time. Due to the high divergence of loss data between the two databases in combination with the incomplete data recording, assessments of economic loss are rather unreliable.

The mass movement trends in the time period 1980 to 2014 are illustrated in Figure 24 (A) for the HKH region and (B) for the Andes. Disaster data are generated from the two global databases EM-DAT and NatCatSERVICE. The fluctuation of the registered mass movement events in EM-DAT fluctuate between zero events in the years 1980, 1981, 1982 and 1985 and three events in 1988 for the first decade. There are two peaks in the years 1993 and 1995 with five mass movement disasters. Between the two higher peaks with eight in 2001, and nine events in the year 2010, there is a year with no registered disaster in 2004. The NatCatSERVICE trend indicates a fluctuation between zero disasters (1984, 1986 and 1987) and three events (1982) in the first ten years. In 2004, no mass movement disaster is registered in correspondence with the EM-DAT data. The number of mass movement events increases with time, with three significant peaks in 2008 (twelve events), 2010 (ten events) and 2012 (14 events). The correlation of mass movement trends for the two datasets is relatively weak in the first and the last decades, with a better agreement between 1993 and 2000. However, the NatCatSERVICE registers events on a higher level in the last few years, resulting in a total of 119 events over the 35 years of observation. In contrast, EM-DAT records a total of 96 mass movement disasters for the same time period. Despite divergence in the absolute number of recorded events, both trends indicate a similar increasing trend of mass movement disasters for the HKH region. The calculated R^2 value for this region is about 0.4196. The discordance for the Andean region is observed as a general discrepancy throughout the entire time period, with NatCatSERVICE reporting consistently higher event figures for most of the period covered by the study. Thus, the reinsurance database includes nearly twice as many disasters (95 events) compared to EM-DAT with only 48 events. The R^2 value for the two mass movement trends is 0.0042 for the Andes.

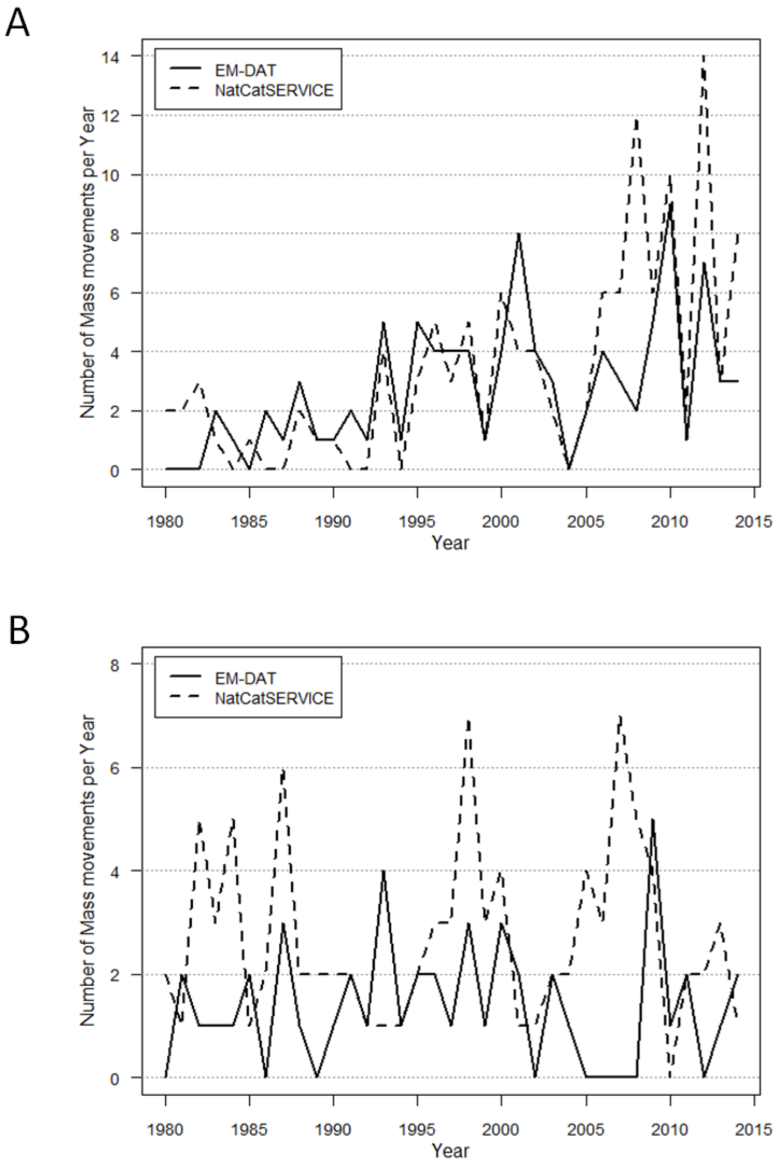

Figure 24: Number of mass movement disasters in time period 1980 to 2014 for the Hindu Kush-Himalaya region (A) and the Andes (B). (Source: EM-DAT and NatCatSERVICE databases).

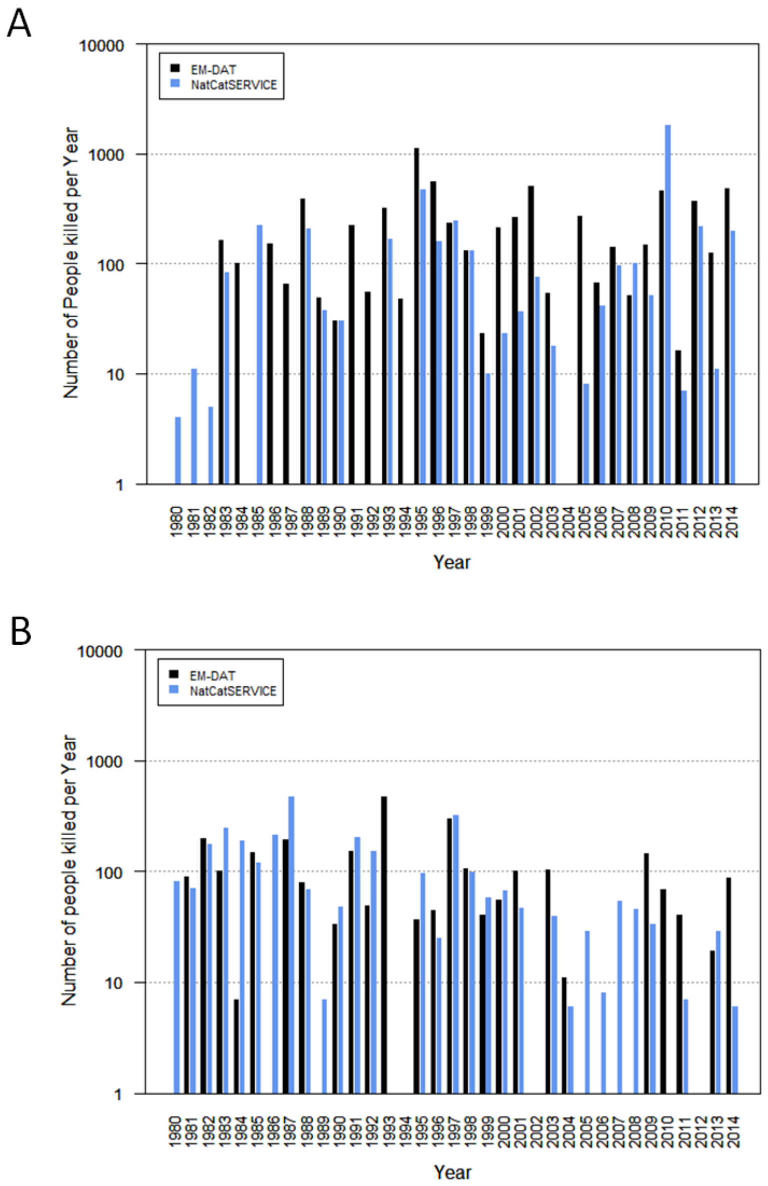

Figure 25: Number of people killed due to mass movement disasters per year in the HKH region (A) and the Andes (B) in time period 1980 to 2014. (Source: EM-DAT and NatCatSERVICE databases).

The number of people killed due to mass movement disasters in the time period from 1980 to 2014 are indicated in Figure 25 (A) for the HKH region and in Figure 25 (B) for the Andes. EM-DAT registers no person killed in the HKH for the years 1980, 1982, 1982 and 1985 in the first ten years with a peak in 1988 with 391 people killed. The maximum of people killed is registered in 1995 with 1,134 people deaths. In the last 15 years, there are three smaller peaks of people killed in the years 2002 (508), 2010 (461) and 2014 (484). Data for number of deaths from NatCatSERVICE show a relatively low rate with a fluctuation between no person killed (1984, 1986, 1987) and 225 people killed (1985) in the first ten year period. There is a peak in 1995 with 474 people killed. However, there is a significant maximum of fatalities in 2010 with

1,831 people killed, due to a catastrophic landslide event in the Gansu state of China. This severe event is not included in the EM-DAT database, as a result of the defined data extraction procedure for non geo-referenced data from the EM-DAT database. The number of registered people killed is generally on a higher level in the EM-DAT database than in the NatCatSERVICE database, wherein EM-DAT registers a total number of 6,860 dead compared to NatCatSERVICE with 4,506 people killed. However, disregarding the few discrepancies, the accordance of the data is on a relatively high level for the HKH region without clear pattern regarding increasing or decreasing numbers of events. The EM-DAT database trend of people killed for the Andes (B) indicates some years without any fatalities (1980, 1986, 1989, 2002, 2005-2008, 2012). The highest peak of people killed is registered in 1993 with 470 dead. The NatCatSERVICE database registers no people killed for 1993/94, 2010 and 2012 with a maximum of registered dead in 1987 with 477 killed. The accordance of both trends is relatively inconsistent, with some higher disparities such as for the year 1993, where the EM-DAT database registers the highest number of killed people compared to NatCatSERVICE where no deaths are recorded. The figures indicate that the number of people killed generally decreases for the last decade in the Andes. The EM-DAT database lists a total of 2,682 fatalities, compared to the 3,018 fatalities of the NatCatSERVICE database.

The economic losses per year are shown in Figure 26 (A) for the HKH region and in Figure (B) for the Andes for mass movement disasters in the time period 1980 to 2014 with data from the NatCatSERVICE and EM-DAT databases. NatCatSERVICE registers economic losses for each event in the HKH region with exceptions in the years 1984, 1986, 1987, 1991, 1992, 1994 and 2004, when no disaster occurred. The economic losses of NatCatSERVICE indicate an increasing trend from 1980 to 1997, including the second highest peak in 1988 with a damage of about 35.05 million USD. In the following years, the economic loss is smallest in 1999 with 10,000 USD. However, the highest peak is registered in 2010 with total damage of about 655.77 million USD due the severe landslide event in the Gansu state of China. Figure 26 indicates a higher rate of damage occurrence in the last ten years with losses greater than 1 million USD. In contrast, the EM-DAT database registers economic damage only for five years - 2000 (2,400 USD), 2001 (60,000 USD), 2005 (50,000 USD), 2009 (139,000 USD) and 2010 (18,000 USD). Due to this lack of information, no clear trend may be identified. The EM-DAT database registers total economic damage of about 270,000 USD compared to the reinsurance database with up to 745 million USD. The economic loss data from NatCatSERVICE for the Andes are available for all events occurring in the period studied, with relatively stable values over time, especially for recent years. The highest economic damage is registered in the year 1993 with 54 million USD. The complete data series of the NatCatSERVICE is relatively consistent over time, with a high degree of reliability. The total economic damage for the Andes region is 108 million USD. The economic loss indications from EM-DAT are less complete as economic damage information is only provided for five years - 1984, 1991-1993 and 2014, with the highest amount being registered in 1993 at 0.5 billion USD. In total, an economic loss of 1 billon USD is registered in EM-DAT. Nevertheless, the economic loss indications from the EM-DAT database are less trustworthy due to the incomplete registration and the comparatively high amount of loss for the registered years for which losses are recorded.

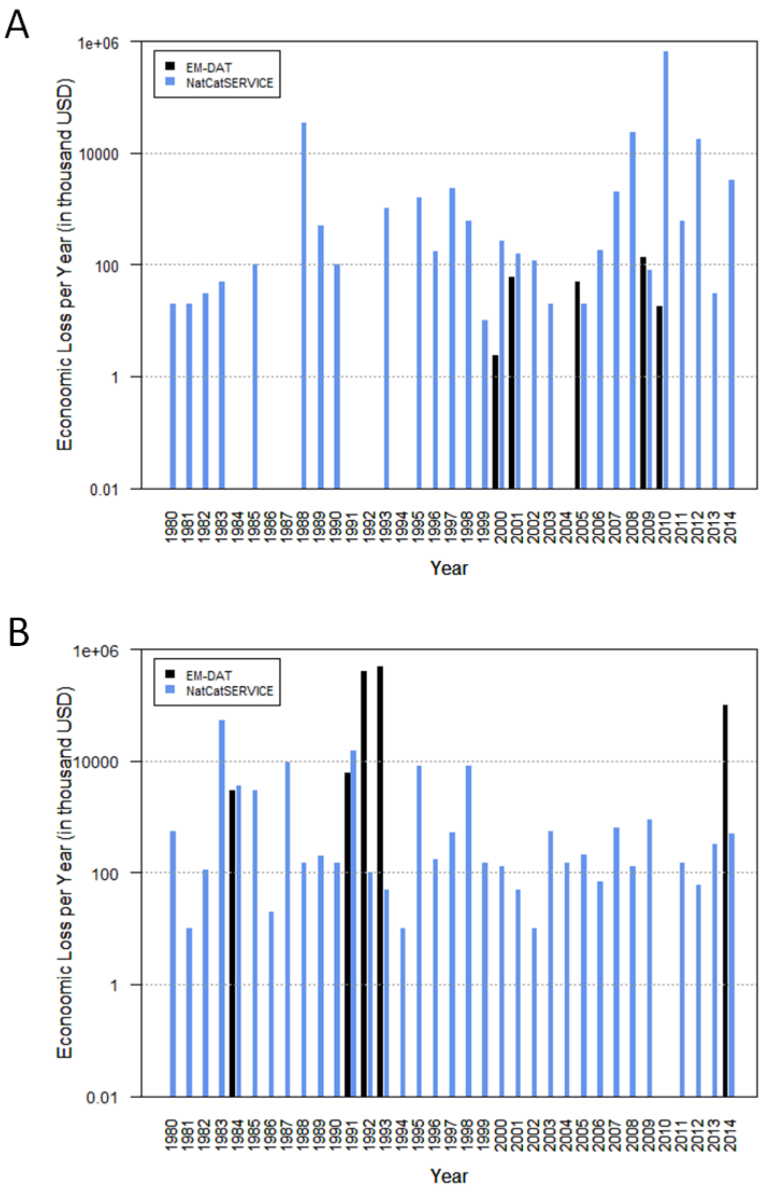

Figure 26: Economic loss (in thousands) per year due to flood disasters in the HKH region (A) and the Andes (B) in time period 1985 to 2014. (Source: EM-DAT and NatCatSERVICE databases).

5.5 The Importance of Mountain Regions for Natural Disasters

For the analysis of the occurrence of natural disasters, the mountain regions map (Figure 7) was overlaid with the geo-reference mass movement data from the NatCatSERVICE database. The geo-referenced flood events from the Dartmouth database were analyzed to determine whether they occurred in mountain regions or at lower altitudes.

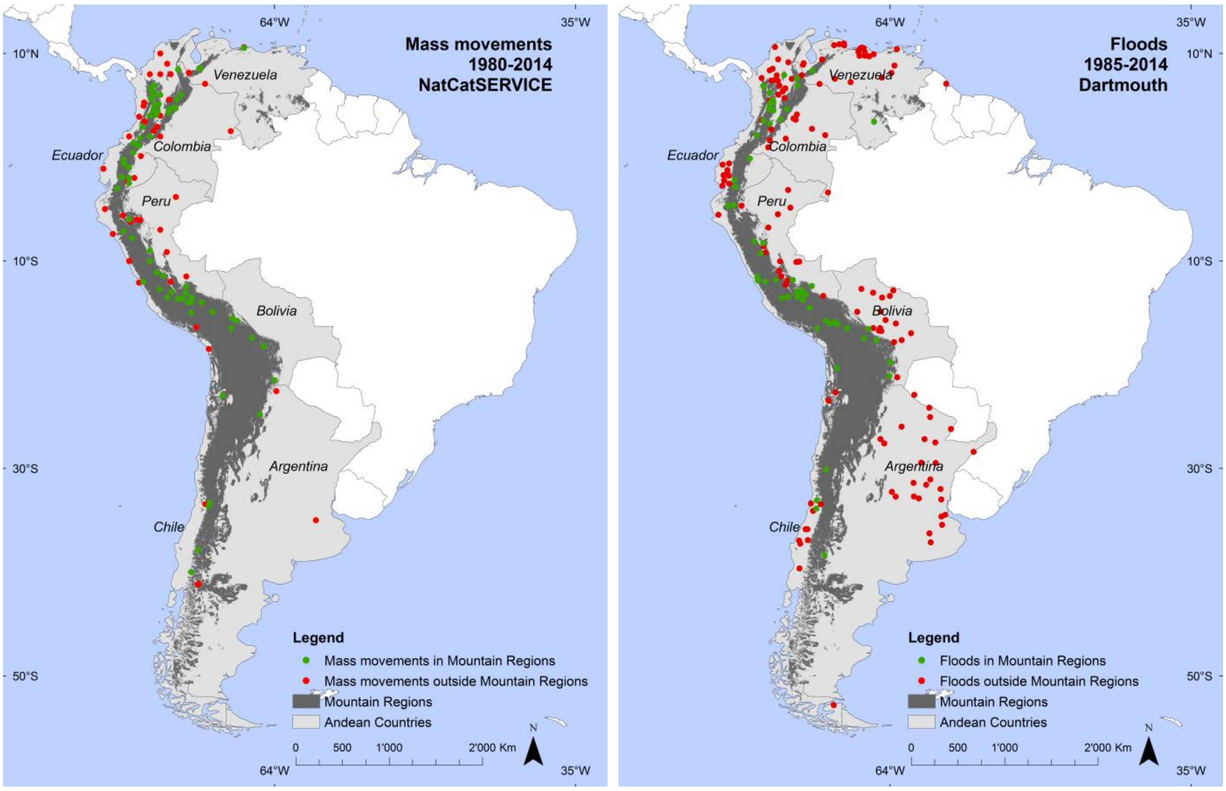

Figure 27: Mass movement and flood disaster in the Andes. Left: Number of registered mass movement disasters in the Andes in the time period 1980 to 2014, based on data from the NatCatSERVICE database. Right: Number of registered flood disasters in the Andes in the time period 1985 to 2014, based on data from the Dartmouth database. Green points indicate disasters within mountain regions and red points represent disasters outside mountain regions.

Mass movement events are illustrated in Figure 27 (left) and flood disasters in Figure 27 (right) in the Andes with occurrence within mountain regions (green points) and outside mountain regions (red points) between 1980/85 and 2014. A total number of 144 mass movement disasters affected the Andes, with 95 events (66.0%) occurring in mountain and 49 events (34.0%) in non-mountain regions. The mountain events appeared as 3 avalanches, 11 mudslides and 81 landslides, whereas the non-mountain regions were affected by 5 avalanches, 2 mudslides and 42 landslide events. In the non-mountainous parts of the Andes 1,755 people were killed with economic damage of 3,393.4 million USD. In mountains, the number of fatalities was 3,018 with an estimated economic loss of about 108.3 million USD. There is a remarkable distribution of disasters incidents in the mountainous country of the Andes with an accumulation of events in the central and northern parts of the Andes, whereas only a few events were registered in the southern Andes, in Chile and Argentina. The majority of non-mountain events occurred very close to the Andean Cordillera with a few locations in lower areas and foothills of the Andes.

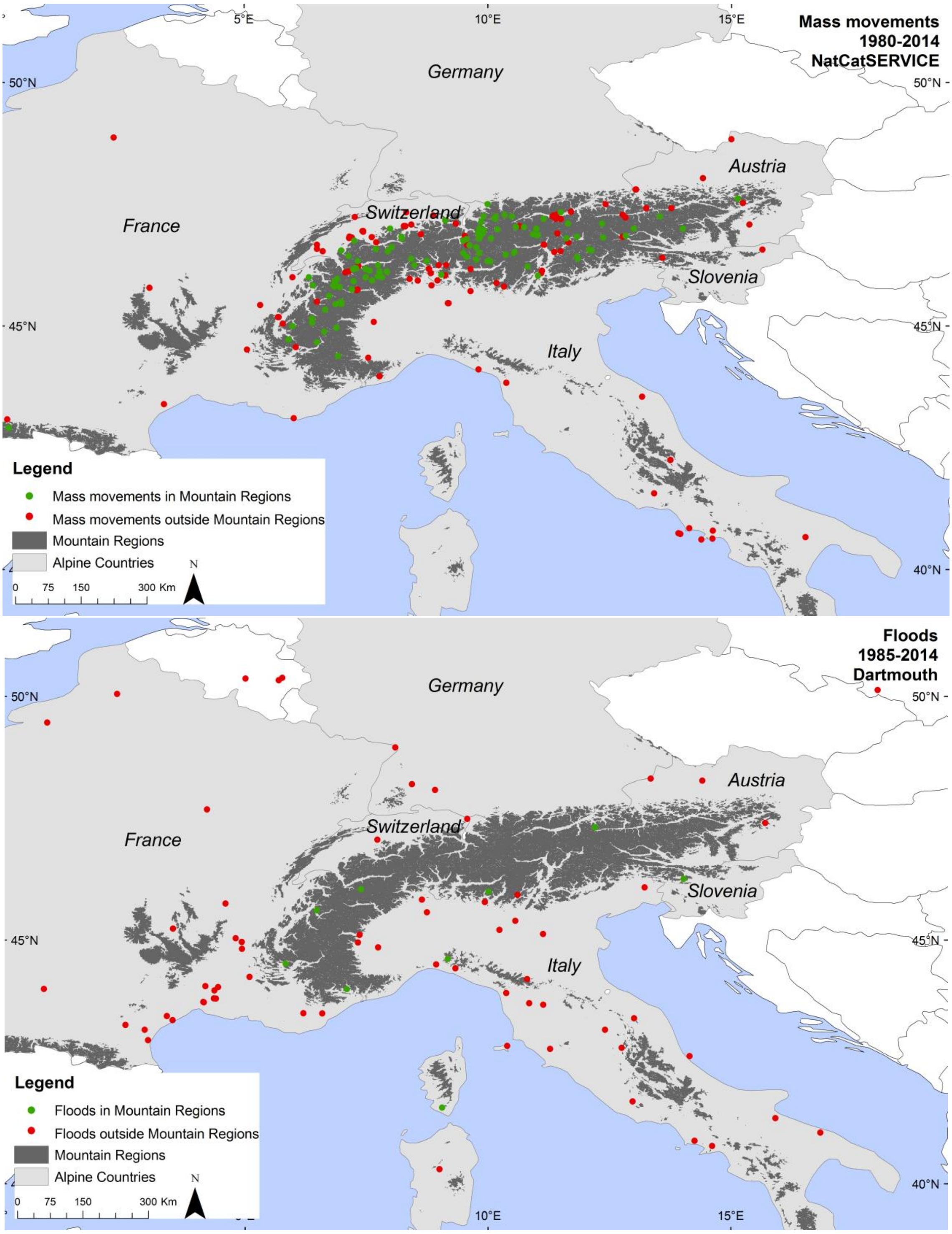

Figure 28: Mass movements and floods in the Alps. Above: Number of registered mass movement wet disasters in the Alps in the time period 1980 to 2014, based on data from the NatCatSERVICE database. Below: Number of registered flood disasters in the Alps in the time period 1985 to 2014, based on data from the Dartmouth database. Green points indicate disaster within mountain regions and red points are disaster outside mountain regions.

With respect to flood disasters in the Andes region, a total of 201 events were registered, with 61 (30.3%) appearing in mountain, and 140 (69.7%) in non-mountain regions. The latter registered 23,819 people killed and 9,407,234 people displaced. The estimated economic loss was 11,470.2 million USD. In mountainous regions of the Andes, 1,963 people were killed, 1,285,839 people were displaced with an economic loss of 404.7 million USD. The distribution of flood events in non-mountain regions exhibits a different spatial distribution compared to the mass movement disasters. The floods appear more widespread, with occurrence in all Andean countries. There is a significantly high occurrence of floods in the eastern parts of the Andes Cordillera at lower altitudes. However, the floods occurring in mountain regions are also concentrated in the northern and central parts of the Andes with little occurrence in the southern part.

The Alps (Figure 28) were affected by a total of 306 mass movement disasters, with 160 events (52.3%) occurring in mountains (5 landslides, 27 mudslides and 128 avalanches), and 146 (47.7%) in non-mountain regions (63 landslides, 7 mudslides and 76 avalanches). The latter suffered 573 people killed with an estimated economic loss of 874.6 million USD. In mountain regions, 525 people were killed with economic damage of about 254.3 million USD. The distribution patterns are similar to those of the Andes, where the non-mountain events were dependent on mountain processes of the Alps and most of them occurred close by.

In contrast to the flood disasters, a total of 82 floods affected the Alps in the 35 years time period, with 9 (11.0%) occurring in mountain regions and 73 (89.0%) in non-mountain regions. The latter suffered 746 people killed and 475,240 people displaced. The economic loss was 15,045.2 million USD. Eighty-one people were killed in mountainous regions and 6,700 were affected with economic damage of 276.0 million USD. Flood events in non-mountainous regions were mostly widespread over all alpine countries at lower altitudes without significant evidence of an influence of mountain processes and characteristics.

5.6 Case Example Kedarnath Flood Disaster North India 2013

In June 2013, exceptionally heavy and continuous rains caused unprecedented damage to life and property in the Uttarakhand state of northern India and some parts of western Nepal. The maximum severity of the floods and damage occurred in the Kedarnath region (3,553 m a.s.l.) (Figure 29), which is the site of a very famous Hindu pilgrimage (Sati & Gahalaut 2013).The torrential rainfall between 15th and 17th June 2013 flooded the area causing excessive gulley erosion and sediment deposition. Due to continuous precipitation, large volumes of water transported a huge amount of sediments and debris from glacial moraines and surrounding areas to Kedarnath town. The main reason for the voluminous flow was the breach of Chorabari Lake (3,960 m a.s.l.), which was dammed by the moraines deposited by the Chorabari glacier. The high pressure of the water caused a breach in the loose-moraine dam resulting in a glacial lake outburst flow (GLOF) (Uniyal 2013). This event killed and affected thousands of local people and pilgrims and destroyed infrastructure including highways and bridges. Socioeconomic factors such as heavy deforestation, road construction, unplanned extension of settlement, mining and hydropower development may have increased the damage (Shrestha et al. 2015)

Figure 29: Kedarnath valley after severe flood and landslide events in June 2013. (Source: Retrieved August 22, 2015 from http://dvi-forensic.blogspot.ch/2014/06/17-more-skeletons-found-near-kedarnath.html).

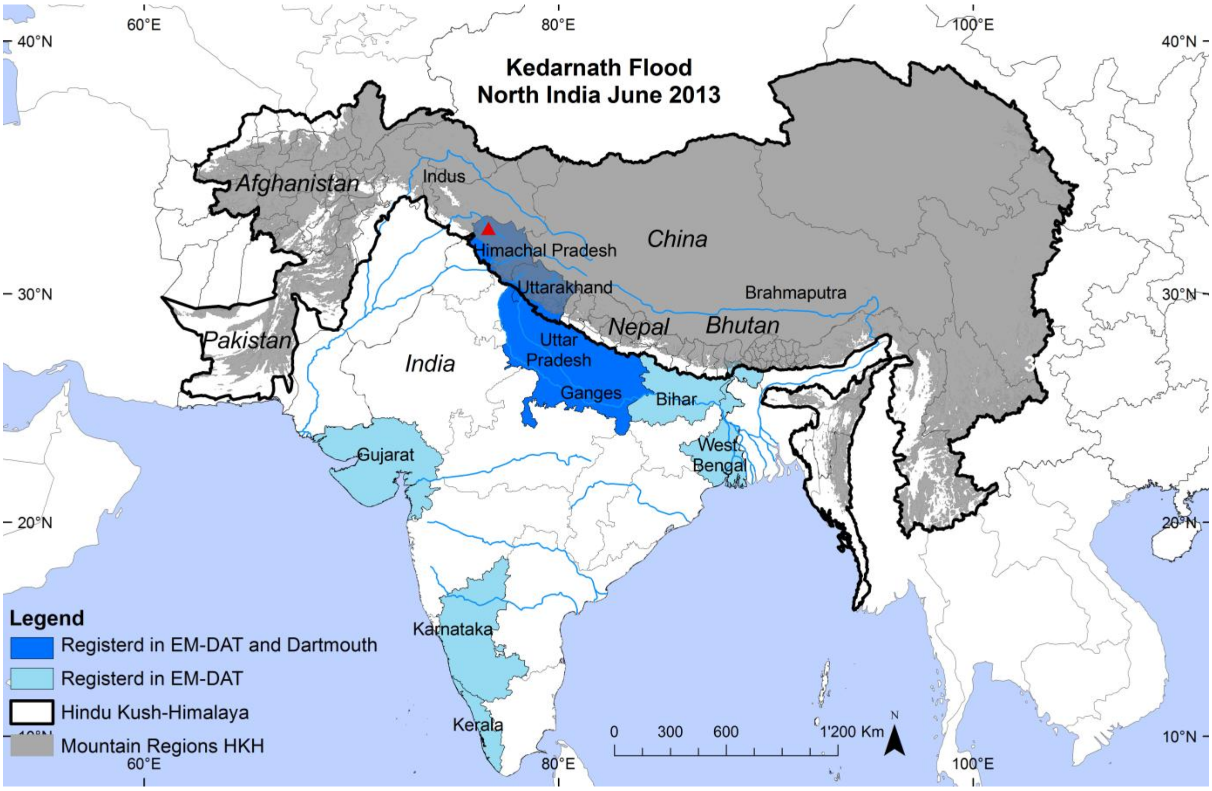

Figure 30: Kedarnath Flood North India in June 2013. Dark blue indicates the affected states registered in the EM-DAT and the Dartmouth databases, whereas the light blue indicates the affected states registered only in the EM-DAT database. Red triangle signifies the geo-referenced location recorded in the Dartmouth database.

The affected areas of the Kedarnath flood disaster in June 2013 in northern India is mapped in Figure 30. The two global databases EM-DAT and Dartmouth register three states which were equally affected by the flood such as – Himachal Pradesh, Uttarakhand and Uttar Pradesh states. Additionally, the EM-DAT database registers five further states affected by the flood - Bihar and West Bengal states in the north-northeast of the country and Gujarat, Karnataka and Kerala states located on the west coast of India. The red triangle represents the geo-referenced position of the registered flood in the Dartmouth database.

Table 6: Data elements comparison from Kedarnath flood India in June 2013. (Source: EM-DAT and Dartmouth databases).

EM-DAT	Data elements	Dartmouth
Flood	**Disaster Type**	Flood
Riverine flood	**Disaster sub-type**	-
Uttarakhand, Himachal Pradesh, Uttar Pradesh, Bihar, Karnataka, Kerala, Gujarat, West Bengal	**Location**	Northern India, Uttarakhand, Himachal Pradesh, Uttar Pradesh
Monsoonal rain	**Origin/main cause**	Monsoonal Rain
Slide (land, mud, snow, rock)	**Associate Disaster**	-
12.6.2013 – 27.6.2013	**Date (start and end)**	12.6.2013 – 27.6.2013
-	**Duration**	16 days
6,054 people	**Deaths**	5,748 people
4,473 people	**Injured**	-
500,000 people (affected)	**Affected/Displaced**	75,000 people (displaced)
1,100,000 million USD	**Total damage**	-
500,000 million USD	**Insured damage**	-
-	**Severity**	1.5
-	**Affected km^2**	131,743.41 km^2
-	**Magnitude**	6.5
-	**Centroid X**	76.6135
-	**Centroid Y**	32.7135
-	**Notes and Comments**	A total of 5,748 people missing after last month's floods in northern India are presumed dead. Heavy monsoon rains in mid-June caught thousands of pilgrims visiting Hindu shrines in the Himalayan region, tourists and locals, triggering devastating landslides and flash floods (...)

A comparative overview of the Kedarnath flood registration is given in Table 6 with entries from the two databases EM-DAT and Dartmouth. Both databases register the event as a flood, with EM-DAT declaring the disaster sub-type as a riverine flood with associated disasters of land-, mud-, snow-, and rock slides. The start and end date of the flood is the same, 12.6.2013 – 27.6.2013 for both databases. The three affected states Uttarakhand, Himachal Pradesh and Uttar Pradesh are listed in both sources, with the EM-DAT location referring to five additional states such as - Bihar, Karnataka, Kerala, Gujarat and West Bengal. The origin, namely the main cause is a monsoonal rain for both of them. The number of people killed in EM-DAT is 6,054 fatalities, whereas Dartmouth registers 5,748 people killed. Additionally, EM-DAT registers 4,473 people injured and 500,000 people affected. In contrast, Dartmouth only considers people displaced and registers a total of 75,000 people. Indications of economic loss only appear in the EM-DAT database with total damage of 1,100,000 million USD, and an insured damage of 500,000 million USD. As specific information about the flood, Dartmouth registers the event with a severity of 1.5 with an affected area of about 131,743.41 km^2 and a magnitude of 6.5. For the exact geographical location, Dartmouth registers coordinates for the centroid X (76.6135), and Y (32.7135). Additionally, the DFO provides some additional notes and comments about the Kedarnath flood disaster.

Daily precipitation measurements from June 2013 and mean daily precipitation measurements (1980-2014) at the Dehradun station (682 m a.s.l.) in the Uttarakhand state of northern India are shown in Figure 31 (A). Exceptionally heavy rainfall was recorded in June 2013 on the 11th (57.9 mm), 16th (220 mm) and 25th (119.9 mm), compared to the mean daily precipitation measurements from the past. The station registered a total of 724.3 mm for the entire month of June. This high precipitation amount is almost 5.5 times higher than the normal rainfall in this region measured at Mukteshwar station (2,311 m a.s.l.) (Figure 31 B) between 1980 and 2014 with a monthly precipitation mean of about 134.39 mm in June.

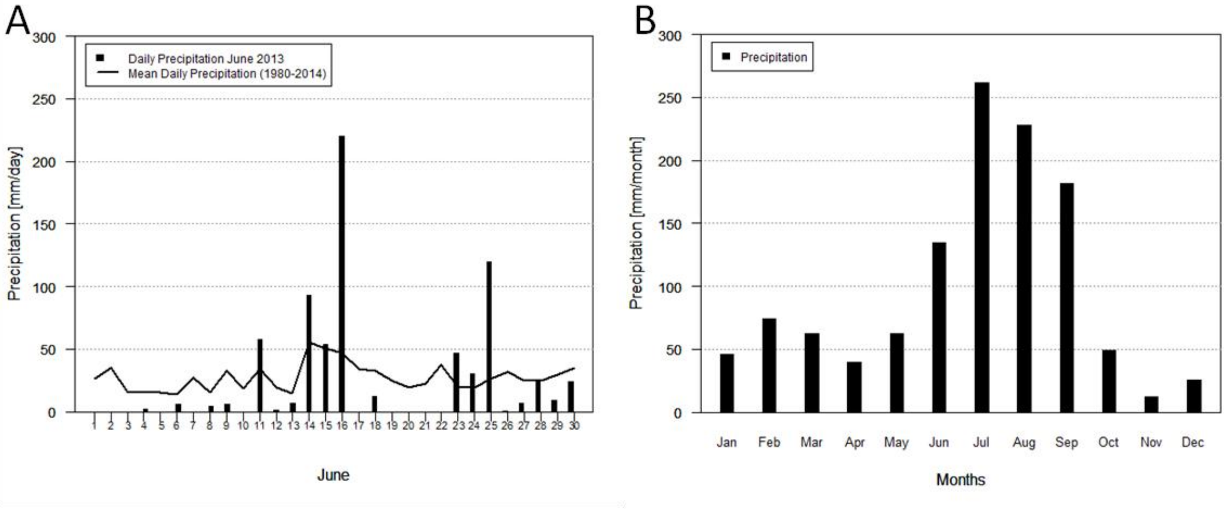

Figure 31: Precipitation in Dehradun and Mukteshwar. A: Daily and mean precipitation records for June 2013 at Dehradun station (Uttarakhand) India (682 m a.s.l.), about 100 km southwest of Kedarnath (Uttarakhand) India. B: Monthly precipitation record at Mukteshwar station (Uttarakhand) India (2322 m a.s.l.) based on mean precipitation data from 1980-2014. (Source: KNMI Climate Explorer).

Mean precipitation anomalies data from six stations in Central HKH (Figure 32 A) and reanalysis data (Figure 32 B) for the same region indicate no significant increasing or decreasing tendencies over the time period from 1980-2014. However, significantly higher measured precipitation amounts were registered for the years 1993, 2011 and 2013, with lower anomalies for the last decade. Higher precipitation anomalies from the reanalysis data were calculated for the years 1988, 1994, 2000, 2008 and 2013. Thus, both data sources indicated enhanced precipitation anomalies for the year 2013, the year in which the Kedarnath disaster in India occurred.

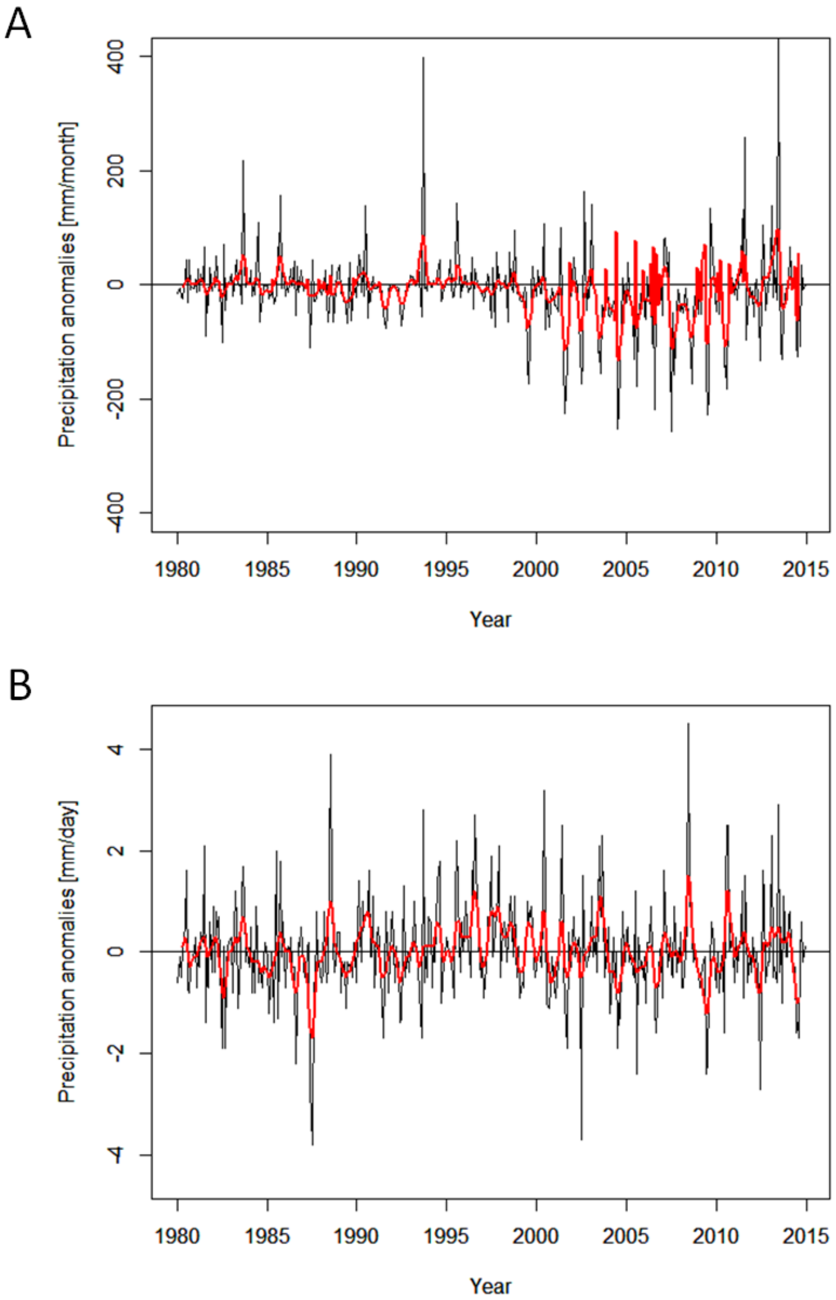

Figure 32: Mean measured (A) and Reanalysis (B) precipitation anomalies for the Central HKH region from 1980-2014 with reference period 1961-1990. Red line indicates the 10-years low-pass filtered time series of the precipitation model inputs. (Source: KNMI **Climate Explorer).**

Concerning the mean temperature anomalies from the six meteorological stations in the region of Central HKH (Figure 33 A) and the reanalysis temperature data (Figure 33 B) for the same region, non-significant increasing trends are visible. However, there are some noticeable years with higher anomalies. Thus, in the first years of registration between 1981 and 1983 there are some negative anomalies, followed by significant positive anomalies in 1988, registered in both temperature data source. There is clear evidence of lower measured and calculated temperature around the year 1997 registered in both temperature graphs. The last decade is characterized by more positive temperature anomalies in both data sources.

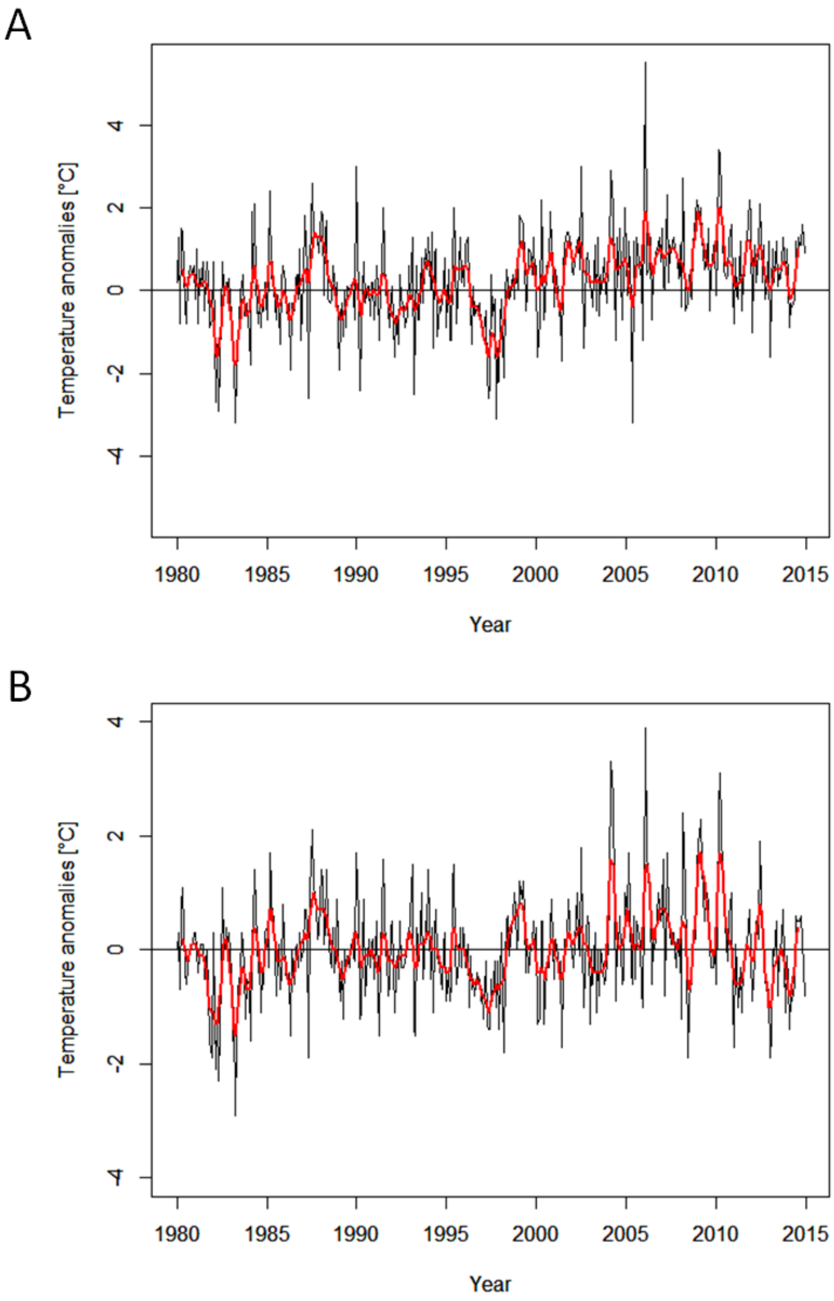

Figure 33: Mean measured (A) and Reanalysis (B) temperature anomaliesfor the Central HKH region from 1980-2014 with reference period 1961-1990. Red line indicates the 10-years low-pass filtered time series of the temperature model inputs. (Source: KNMI Climate Explorer).

6 Discussion

In this section, the most important results regarding loss database quality and reliability of database entries are analyzed and discussed with an investigation of the strengths and weaknesses of the four datasets used in the study. Furthermore, the five mountain regions are examined regarding local specific disaster types and climate impacts with indications of the significance of mountain regions regarding natural disasters and sustainable mountain development.

6.1 Database Quality and Reliability

6.1.1 Disaster Database Quality Assessment

The results of the disaster quality assessment (Chapter 5.1.1) indicate the strengths and weaknesses of each database according to six main topics: methodology, accuracy and reliability, serviceability, accessibility, credibility and prerequisites and sustainability.

- The strengths of the methodology are the standard definitions for data entry and disaster types of all databases applied in the study. However, the lack of similar definitions of data entries such as people affected or killed hindered an accurate comparison of different datasets. All databases include an internal unique disaster identification number for each disaster entry. However, the serial number of record cards in DesInventar is not helpful for a classification by disasters and follows different standards among the different countries (De Groeve et al. 2013). One main difficulty exists in the absence of entry criteria or impact threshold for entering a disaster event, except for the EM-DAT database. Nevertheless, DesInventar methodology allows the collection of historical disaster losses data in a systematic and homogeneous way at a low administrative level based on pre-defined definitions and classifications (UNDP 2013). Entry criteria for DesInventar are redundant, as the small-scale losses are recorded on a local or municipality level. An advantage for comparing disaster data is the use of the same disaster type classification by the EM-DAT and the NatCatSERVICE databases, as their entries are based on an identical disaster category classification (Below et al. 2009).

- The accuracy and reliability of disaster data sources is highly influenced by the purposes of each database which results in different registered data entries (Menoni & Margottini 2011). For instance, DesInventar and Dartmouth disaster entries are primarily based on newspaper information and media. However, data from journalists often do not come from proven sources and there is an unequal distribution of recorded information in different regions (Brauch et al. 2011). Thus, for example, more centrally located districts in the Andes would have a higher probability of being reported in newspapers than more marginally located districts. These circumstances may cause potential bias in the two databases (Glave et al. 2009). All four databases used in the study provide a country-, or global-wide data range, including all important human and economic indicators such as killed and affected people and information concerning economic damage. However, quality and completeness highly depend on the database purpose and data sources.

- The serviceability of the four databases, all accessible in English, is mostly comparable, as they all provide additional information such as annual statistics, catastrophe portraits or analytical reports. With the exception of DesInventar, they all compile pre-results as tables, charts and maps and provide user documentation such as archive notes, database methodology or guidelines. DesInventar provides a comprehensive user guide for the online data query and analysis tool. The three global databases update their entries daily, whereas the DesInventar database for Nepal has yearly updates, but without providing data from recent years. The main weakness of the data collection system is the absence of a global identification number for all databases. Thus, for better linkage and interoperability between records in these databases, CRED, Relief/Web, ADRC and LA RED propose a unique identifier number for a disaster; as a unique external disaster number, the GLIDE Number (Global Disaster Identifier Number) is proposed (Guha-Sapir & Hoyois 2012). However, EM-DAT includes the GLIDE number but does not really use it.

- The strengths of the accessibility for EM-DAT, DesInventar and Dartmouth are the access to disaster data without any restrictions or charges. Data access to NatCatSERVICE is limited and only partially available, as only mass movement data were supplied for the current study.

- The strengths of the credibility of the databases are the information generated from user guides or websites about the aim, objectives, methodology of the databases used in the study. The main weaknesses are the limited information about the quality management and quality control of the data as for instance would be provided by a cross-checking procedure or validation process.

- The main strengths of the prerequisites and sustainability are the long temporal experience in data collection and management of all databases combined with the wide-ranging collaboration networks (humanitarian agencies, NGOs, Red Cross etc.), excluding DesInventar. Information about changing methodology for data registration is rare, but has a large influence on the data outputs.

6.1.2 EM-DAT

The value of the EM-DAT database lies in the fact that it is the most complete recorded disaster database with a global coverage and encompasses natural and technical (man-made) disasters. EM-DAT provides raw data upon request for selectable countries in an Excel file. The main interest of the EM-DAT database is the humanitarian focus, where the primary sources are governments and UN agencies (UNEP, OCHA, WFP and FAO), NGOs (IFRC) and data generated from research and insurance institutions and press agencies are only secondary sources (Menoni & Margottini 2011). Thus, the EM-DAT database registers only events with clearly defined entry criteria namely 10 people killed, and/or 100 people affected, and/or there is a state of emergency or call for international assistance. The relatively high thresholds of inclusion into the database indicate a clear emphasis on humanitarian impacts, rather than economic loss and environmental damage (Smith 2013). Concerning the results of the analysis of contents (Chapter 5.1), the indications of economic loss confirm the low rate of information. Here, Africa only has a rate of 12.4%, compared to the Andes (25.6%), Central Asia (38.3%), HKH (43.4%) and the Alps with 71.6%. EM-DAT generates loss data (overall and insured losses) mainly from information from UN agencies, government offices, IFRX, research organizations and reinsurance publications (Wirtz et al. 2014). EM-DAT releases only official figures without any of its own estimations of economic damage. There is a relatively low quality in the specification of geographical location, whereby indications of location are not always precise or even available, with values between 65.8% for the Alps and 93.3% for the HKH region. The main limitation of data from the EM-DAT database is the absence of geo-referenced data, whereby location indications are mainly based on a state level. Because of the missing coordinates, it is more difficult to focus on a specific field, such as mountains. The data extraction procedure for mountain regions is also highly influenced by the resolution of states of the countries studied. Thus, countries with more states (e.g. Uganda with 111 states) can be more accurately divided into mountain and non-mountain areas than countries with only a few states (e.g. Kenya with 8 states). Therefore, there will always be a higher error rate for extracting mountain regions from EM-DAT compared to geo-referenced data available from other databases. Hence, data from the EM-DAT database are more reliable for a country- or state-based analysis, rather than specific purposes. Clearly defined start and end dates are provided for 71.7% of events in Africa with a maximum rate of about 85.6% for the Alps. The zero values are lowest in Central Asia with 1.7% and highest in the Alps with 9.3%. In general, EM-DAT reports relatively high numbers of affected people compared to NatCatSERVICE. Because EM-DAT data are generated mainly from humanitarian agencies and development organizations, the information related to human impact may be better reported and more completely than in other databases (Guha-Sapir & Below 2002).

6.1.3 DesInventar

The value of the DesInventar database lies in the national spatial resolution with the main objective of the identification of disasters on a regional, district and municipality level. The free, publicly available database (open source software) concentrates on developing countries, especially in South America, and is a tool for disaster risk mitigation strategies for the respective countries. Thus, a main purpose lies in the use of local and national management of risk. DesInventar enters events without any thresholds, whereby all events with any social losses are registered. Thus, DesInventar contains detailed information of every type of effect that a disaster may have, independent of its impact and size, and at a high level of resolution. This quality is important when accessing global datasets, as small disasters are certainly relevant and should not be ignored by policy makers and planners. Although there is an absence of clearly defined entry criteria, DesInventar allows a data query based on user defined entry thresholds. Therefore, only requested events can be extracted based on individual entry criteria. Thus, the analysis of disaster database completeness of contents (Chapter 5.1.2) shows a clear geographical indication for all events, although no coordinates are available. There are no registered disasters which include zero values. Nevertheless, economic loss indications are only provided for an average of about 7.6% of all registered events with a lack of transparency of the monetary value calculations. All data sources for DesInventar databases in different countries are varied and of national origin for each database. In general, only daily newspapers are used as sources, sometimes in combination with official data from governments (Guha-Sapir & Hoyois 2012). A main weakness of DesInventar is the origin of information and the representation of different data sources. As the disaster entries are mainly derived from newspaper information, the representation is not always homogenous and reliable and is highly dependent on the newspaper quality and distribution in different countries. Thus, disaster loss in outlying areas and smaller isolated regions may be underestimated compared to more centrally situated locations with denser information distribution from newspapers (Brauch et al. 2011). Another weakness is the temporal period covered by the database, whereby data from most countries of the Andes is only provided until 2012, with no data update until the present. This circumstance hinders data analysis for recent years with a deficit of accurate information.

6.1.4 Dartmouth Flood Observatory

The Dartmouth database provides flood disaster data without any restriction through their website with data from 1985 until the present in an Excel file. Dartmouth Flood Observatory (2004) provides good data reliability from 1985-1995, and even better after 1995. Based on the method used, data from Dartmouth are comparable between 1985 and 1995 and between 1996 and 2015 (Dartmouth Flood Observatory 2004). The advantages of the Dartmouth database are additional flood-specific data along with common social information (killed, displaced, economic loss) such as the severity class, the geographic flood extent and the magnitude of the event. The results from the analysis of content from Chapter 5.1 provide an indication of the geographical location for all registered flood events, as all events are geo-referenced. Also clear statements of the start and end dates for all entries are provided. The results of the database comparison of flood events with data from the EM-DAT and the Dartmouth databases (Chapter 5.4) indicate similar patterns which tend to be a robust number of registered events. Also the number of people killed exhibits similar patterns in both databases. Disaster data are derived from a variety of news and governmental sources, consequently the quality and quantity of information is not always in proportion to its magnitude, and the intensity of news coverage varies from country to country. Generally, information about floods in developing countries tends to arrive later and be less detailed than information about flood events from developed nations (Dartmouth Flood Observatory 2007). Thus, registered flood disasters are underrepresented in low income regions, which are generally most affected. Dartmouth does not have clearly defined entry criteria for registration of flood events. Hence, Dartmouth includes large floods with damage to structures, agriculture, and/or fatalities without any thresholds. Referring to the analysis of content results (Chapter 5.1.2), Dartmouth only contains information about an economic loss for between 11.1% of events for the Alps and 47.1% for Central Asia. Dartmouth Flood Observatory (2004) state that damage caused by floods is very difficult to evaluate and loss information quality is highly dependent on reports from different countries and is presented from the perspective of the data source such as an insurance company or local government (Dartmouth Flood Observatory 2004). The number of zero values without indications of any social or economic loss varies between 0% in the Alps and 6.6% in Africa.

6.1.5 NatCatSERVICE

The value of the NatCatSERVICE database lies in the assessment of financial loss, representing the most important parameter for the reinsurance database. The magnitude of each loss (insured loss and economic loss) is registered for each event. NatCatSERVICE is a private international level reinsurance disaster database where the main focus lies in providing accurate number for material losses. NatCatSERVICE provides limited accessibility, whereas more data are available for insured clients. Compared to EM-DAT, the entry criteria are lower, whereby an event will be registered if harm to humans (fatality, injury, homelessness) or property damage occurs. NatCatSERVICE classifies events in six catastrophe classes, depending on the severity of the monetary and humanitarian impact (Wirtz et al. 2014). An important advantage is the fact that all locations of natural disasters are geo-referenced, whereby their exact geographical position is expressed in latitudinal and longitudinal coordinates. Thus, the analysis of contents (Chapter 5.1) indicates a clear geographical location for all registered events for all regions. The main source of the NatCatSERVICE database is insurance industry information with priority given to client reports, branch offices and insurance press, with secondary consideration given to the press and media, UN agencies, NGOs and weather services (Menoni & Margottini 2011). As the main focus of NatCatSERVICE lies in the economic loss, the quality of economic damage information is very high. Thus, NatCatSERVICE provides information about insured and uninsured damages for each disaster entry. Also the start and end data are indicated for all events, with no zero values registered, as every event contains information regarding either social or economic loss. Consequently, the total number of recorded losses in the Alps (160), HKH (119), Andes (95), Central Asia (33) and Africa (14) differs from the EM-DAT and the Dartmouth databases, where the highest number of events is registered in the HKH, followed by Africa and the Andes. The fact that loss of life is not included in the economic loss calculations of NatCatSERVICE, leads to an underestimation of the loss in poor countries, where values of physical assets are low and numbers of lives lost are high. In countries and communities where ownership and value of economic assets are low, reported economic damage and insurance awareness are generally low (Guha-Sapir & Hoyois 2012). Referring to a comparative loss study on developing countries, the limited information of NatCatSERVICE from countries with low insurance density is illustrated. Nevertheless, economic loss information is much more detailed compared to non-reinsurance databases (Menoni & Margottini 2011).

The detailed comparative analysis of the three global and one regional disaster databases indicates a variety of strengths and weaknesses regarding their purpose, data sources, data reliability and organization. Discrepancy between data entries can be explained by the different methodologies, spatial resolution and base element definitions. The ambiguities among the four databases indicate the relevance and the importance of comparing data from different sources (global and national databases) for a more reliable and comprehensive assessment of natural disasters. Therefore, database sources and structures, methodologies, purposes and history have to be analyzed carefully. However, there is a necessity for more standardized data entries, more homogenous and comparable loss data definitions and enhanced completeness of human and economic loss information.

6.2 Comparative Disaster Loss Analysis

The comparative disaster loss analysis of events from the EM-DAT and DesInventar databases (1981-2010) (Chapter 5.3) indicates a strong increasing trend in the number of registered events in mountainous regions in the Andes and the HKH, for both databases. However, the analysis reveals that the absolute number of events as recorded in DesInventar is roughly 1 to 2 orders of magnitude greater than in EM-DAT, but indicates a relatively robust and similar trend over time. This can be caused due to the fact that the DesInventar database contains information of effects by municipality as a bottom-up process and not by the trigger event itself, as a top-down approach as employed by global databases such as EM-DAT. Thus, a severe flood event, for instance, will be registered as one triggered disaster entry in EM-DAT, whereas DesInventar will register four events if four regions are affected. The higher numbers of registered events for recent decades may be influenced by more accurate registration of events, compared to past observations in the initial phase.

The patterns of people killed signify a more robust and comparable category than people affected, but also demonstrate considerable differences between the two data sources. In line with various studies e.g. (Huggel et al. 2015; Fuchs et al. 2013) they also indicate an increasing trend of registered events and of people affected, but with a decreasing number of people killed. The stable, or even decreasing number of people killed can be explained by improvements in civil protections, enhanced capability in managing emergencies and provision of early warning systems (Menoni & Margottini 2011). The unclear and divergent trends of people affected can be explained by the various definitions of loss data indicators of the two databases, making a comparison of the data fields rather difficult (De Groeve et al. 2013).

A second reason may be due to diverse entry criteria, as for the EM-DAT database, a disaster is defined as a natural event with a negative influence of a minimum level of defined social losses such as people killed and affected. DesInventar, in contrast, includes events which may have any effect on life, property or infrastructure. For DesInventar, there is no need to define a minimum threshold for registration of a disaster and every event must be included if there are any social losses (LA RED 2002). The fact of having no minimum threshold gives DesInventar the advantage of registering very small events which can have a significant impact on a local scale. Because of the scale and the organization of global databases, minor and multi-site occurrences of disasters are often excluded (Menoni & Margottini 2011).

A further reason for the high discordance may be due to different sources of information and their handling in the two databases. Whereas EM-DAT draws information from international aid bodies (OCHA), national foreign aid bodies (OFDA) and insurance companies, DesInventar uses sources of national origin such as newspapers in combination with data from governments. Furthermore, an important difference could be the spatial resolution of the two databases. EM-DAT provides large-scale disaster information on a country level, for example in terms of spatial location of the data (states, regions, orientation e.g. north, south etc.), whereas DesInventar provides detailed information on a local resolution level (municipal, districts etc.). Thus, the mountain disaster extraction in DesInventar is more reliable due to the ability to extract data from selectable mountain states. However, one of the most important distinctions of both databases may originate in the different definitions in terms of people affected, killed and victims, which significantly inhibits the interoperability of global and regional data sources (Appendix A.6). Although the entry criteria from DesInventar were adjusted to those of EM-DAT, there are still several uncertainties.

6.2.1 Database Comparison for Flood Disasters

The database comparison for flood and mass movement disasters (Chapter 5.4) indicates several patterns and divergences for the HKH region and the Andes. Flood events from EM-DAT are compared to events registered in the Dartmouth database for the time period 1985 to

2014. The two flood trends of the HKH region (Figure 20 A) indicate a divergent occurrence of floods from 1985 to 1995, with a fluctuation between zero and five events. The high disparity of the two databases is also visible in the number of registered fatalities in the first years (Figure 21 A). For instance, EM-DAT reports 2,070 people killed in 1992, whereas Dartmouth registered 3,012. This non-parallel trend of registered events and fatalities in the first eleven years can be explained through a lower accuracy of event registration in the initial phase. This is especially true for the Dartmouth database, which first began to register flood events in the year 1985. The accuracy of the flood trend lines increases after 1996, with a higher accordance of the increasing number of registered floods for the HKH. However, this trend is not visible for the flood trends in the Andean regions (Figure 20 B), where the number of registered events demonstrates good accuracy from the beginning of data registration. However, there is a shift in the trend lines in recent years for the HKH and the Andes with a higher number of flood registrations for the EM-DAT than for the Dartmouth database. This observation is contrary to expectations, as the EM-DAT database maintains high thresholds for entering events and only floods with more extensive damage to property and human losses are registered. The quantification of the coefficient of determination (R^2), which measures the relationship between two datasets, indicates similar values for both regions with 0.3484 for the HKH and 0.3520 for the Andes. Thus, there is an approximately 35% match between the two datasets. Comparable results were calculated for flood disasters in Africa (0.3307) and Central Asia (0.3628), whereas the R^2 for the Alps indicated a very low consistency with a value of about 0.0308.

The overall higher registration of EM-DAT events also influences the accounting for the number of people killed, as this figure is generally higher in EM-DAT than in Dartmouth. One possible reason for the disparity in the absolute number of events can be the various spatial resolutions of listed events. As Dartmouth provides geo-referenced information for each event, data could be simply categorized in ArcGIS into mountain and non-mountain disasters. In contrast, EM-DAT provides spatial information in general only on a state-based level without any coordinates. The distribution in mountain and non-mountain areas appears with a lower credibility and may overestimate the occurrence of floods for the HKH and the Andean region in the last decade.

This discrepancy in flood localization could also be seen in the analysis of the Kedarnath disaster where the two databases diverged in the identification of affected states, with EM-DAT registering more affected states than Dartmouth.

Another important influence is the question of how data are collected. The main data sources of the EM-DAT database are humanitarian agencies, whereas event data for Dartmouth are mainly originated from news reports. However, both flood trends of the HKH region indicate a correlated increasing trend of events with a maximum of twelve disasters in 2003 in Dartmouth and 16 in 2005 in EM-DAT database. The relatively well correlated trends for the Andes do not indicate a clear increasing or decreasing trend. The higher number of fatalities in EM-DAT seems to be caused by the higher registration of floods and the different definition of people killed. Whereas the EM-DAT database includes people missing in the term of people killed, Dartmouth database only considers people killed. Information about missing people is therefore not available in Dartmouth. Compared to the increasing trend of registered floods in the HKH, there are no significant indications of an increase in the number of people killed in the 30 years of observation contained in the two databases. This stable process is also observed in the Andes. Hence, the number of people killed per disaster over the analyzed time period is relatively stable for both mountain regions. This trend was also determined by (Huggel et al. 2015) for Peru. Data on disaster mortality are often more accurate than other loss information (Smith 2013). Nevertheless, considering the uncertainties regarding the distinction between deaths and missing people, the mortality indicator seems to be the most reliable assessment of disaster losses.

The pattern of people affected (EM-DAT) and people displaced (Dartmouth) (Figure 22) displays a higher discrepancy between both data sources for the two regions. In most of the years, the number of people affected as recorded in EM-DAT is higher than people displaced recorded in Dartmouth, over the whole time span. The lower agreement of affected people may be caused by the enormous variation of definitions and different reporting data sources (Guha-Sapir & Below 2002). As affected people in EM-DAT may include displaced and evacuated people, Dartmouth may include the number of people left homeless and the number of evacuated people in the assessment of number of displaced people. However, numbers of people affected for all databases should be regarded cautiously and considered as a proxy for disaster size rather than an accurate measure of the impact of a disaster (Guha-Sapir & Hoyois 2012).

The economic loss of flood events in the HKH region indicates that EM-DAT provides damage information over a 25 period, with significantly higher damage in the last five years and losses valued at more than 1 billion USD in 2014. Dartmouth only registers an economic loss in ten years out of the 30 year period. There is a lack of information about economic damage from Dartmouth in the last decade, with no loss registered. The registration of economic losses for the Andes are even worse, as the EM-DAT database only provides information for twelve years, and Dartmouth for four years of the observed time span. This high discordance originates in the lack of clear definitions and permanent registration of economic damage, especially for Dartmouth. As both global databases only use official numbers for their economic loss data without their own calculations of economic damage, the data seem to be deficient due to missing available information and data disposability.

6.2.2 Database Comparison for Mass Movement Disasters

Mass movement events were compared using data from the EM-DAT and NatCatSERVICE databases. In the first decade, the relatively low correlation and accordance of both lines of mass movements in the HKH region (Figure 24 A) indicate comparable patterns as those of registered floods in the same region and could originate in the lack of a standardized registration in the initial phase. These trends were also recognized by studies from Guha-Sapir & Below (2002), where records from the 1980s had greater discrepancies than those from the

1990s, due to an increasing similarity of data sources between the databases. The correlation of the shape of the two trend lines indicates an increasing accordance, whereas the two trends indicate an increasing number, especially for the data from NatCatSERVICE database. Registered absolute numbers of mass movements from the NatCatSERVICE are shifted to a higher level, with higher peaks of events in 2008 (12 disasters), 2010 (10 disasters), and 2012 (14 disasters). The progression of the two trends in the Andes is very inhomogeneous without significant similarities. Concerning the R^2 values, the HKH has a value of about 0.4194, whereas the Andes indicates a very low correlation with a value of about 0.0042. The calculated R^2 for the Alps is 0.0565, for Central Asia 0.0033 and for Africa 0.0006 (Appendix A.7).

In general, the absolute numbers of events are higher in the NatCatSERVICE database compared to the data from EM-DAT for both regions. The reason for the significant discordance, especially for the Andes, can be explained by different spatial resolutions. As NatCatSERVICE provides coordinates for each event entry, all disasters can be easily localized, compared to the data from the EM-DAT database with a spatial resolution based on a state level. Hence, the accuracy of mountain locations extracted from EM-DAT is at a lower level with possible higher error rates.

A second important issue is the influence of the different entry criteria and the specific purpose of the datasets. While financial loss represents the most important parameter for NatCatSERVICE, the main objective of the EM-DAT database is social losses. Therefore, EM-DAT entries are based on clearly defined criteria (at least 10 people killed and/or 100 affected), whereas NatCatSERVICE registers events if any property damage occurs and/or any person dies. These different thresholds of disaster registration have an influence on the database entries, resulting in higher numbers of events in the reinsurance database due to the absence of clear thresholds. Thus, NatCatSERVICE registers smaller disasters, as in 2008 and 2012 when only three out of twelve and four out of 14 events respectively have an entry with ten or more people killed. As a comparison, NatCatSERVICE registers eight out of ten disasters with ten or more people killed in 2010, which correlates to a significantly higher degree with the EM-DAT data trend. A third reason may result from the different sources of the respective entries. Whereas EM-DAT data originated mainly from humanitarian agencies, the reinsurance database obtains their information from the insurance industry such as branch offices and insurance associations. Concerning the trends of killed people (Figure 25 A) the EM-DAT database registers generally more fatalities compared to NatCatSERVICE, although the number of events is lower in EM-DAT. There is one exception in the year 2010, when NatCatSERVICE registered a landslide event in the mountains of China with 1,467 people killed and economic damage of about 500 million USD. The same disaster is also mentioned in EM-DAT with 1,765 people killed and 47,000 affected and an economic loss of about 759 million USD. However, because of the precise definition of mountain states, the Gansu province in China is not included as a mountain state in EM-DAT. Hence, this large disaster is not taken into account for the analysis of EM-DAT data.

Regarding economic damage in the mountains of the HKH region (Figure 26 A), there is a high disparity between registered losses in NatCatSERVICE and EM-DAT. The latter only registers five years with any economic loss after 2000. In contrast, NatCatSERVICE registers the magnitude of each loss for each disaster occurring between 1980 and 2014. The graphic illustrates an increasing trend from beginning to 1997, with a peak in 1988 with damage of about 35.05 million USD, followed by a decreasing trend until 2005. The last decade is characterized by high economic losses with a peak in 2010, and total damage of about 655.77 million USD, including the damage caused by the severe landslide in China 2010.

6.3 Regional Analysis and Climate Impact

6.3.1 Monsoon-triggered Floods in the HKH

The disaster trend in the HKH region (Afghanistan, Bhutan, China, India, Nepal, and Pakistan), based on data from EM-DAT database, indicates a noticeable discontinuous increasing trend of disaster occurrence over the 30-years period from 1985 to 2014 (Figure 14). More events were registered in recent decades compared to the beginning of data analysis. The region was most affected over the whole time period by floods (52.6%), followed by mass movement (28.5%) and storm disasters (13.0%). Shaw (2015) determined river and flash floods also as the most frequent hazard types in the HKH, causing damage to infrastructure such as houses and bridges, soil erosion and human and livestock casualties. One of the most devastating floods occurred in the Khyber Pakhtunkhwa state of Pakistan in 2010, which killed up to 2,000 people and affected more than 20 million people. About a fifth of Pakistan's land was submerged by the monsoon-triggered flash flood. The trend indicates a remarkable increase of flood disasters in the last decade with a maximum of 16 flood events in 2005. The analysis indicates strong evidence of a correlation of the Indian monsoon index with flood occurrence in the HKH region. The Indian summer monsoon (ISM) index is defined by the seasonally averaged precipitation over all the Indian subdivisions from June to September 1871-1995 (Wang & Fan 1999). Predictions of the Indian summer monsoon are important, as a deficit in ISM greater than one standard deviation will increase the risk of droughts, whereby positive ISM anomalies with larger than one standard deviation may have an adverse influence on hydrological processes (Surendran et al. 2015). Thus, with reference to this index, 2005 is the year most frequently affected by floods and storms, which correspond to the strongest monsoon signal in the last 20 years with remarkably strong ISM of about 1.01, followed by a value of 0.915 in 2006. The high incidence of disasters in 2007 may be the result of the La Niña conditions appearing together with an unusually strong summer monsoon in the Indian subcontinent with numerous floods and landslides, causing several million people to be rendered homeless (Smith 2013). In contrast, in 1999, only three disasters were registered, with the ISM indicating a weak value of about -0.649. The comparison of the frequency of disasters with the influence of the monsoon pattern is very important for the HKH region, as more than 80% of the annual moisture received by the southeastern part of the HKH is provided by the summer monsoon (Bolch et al. 2012). Thus, the climate in the HKH region is highly influenced by the Asian monsoon from the eastern part of the HKH and the westerlies from the western part with highest rainfall amounts during the summer months and July as the wettest month. Hence, the westerlies are an important moisture source in the northwest with snowfall due to westerly cyclones in winter, whereas the southeast HKH region is influenced by the summer monsoon (Bolch et al. 2012).

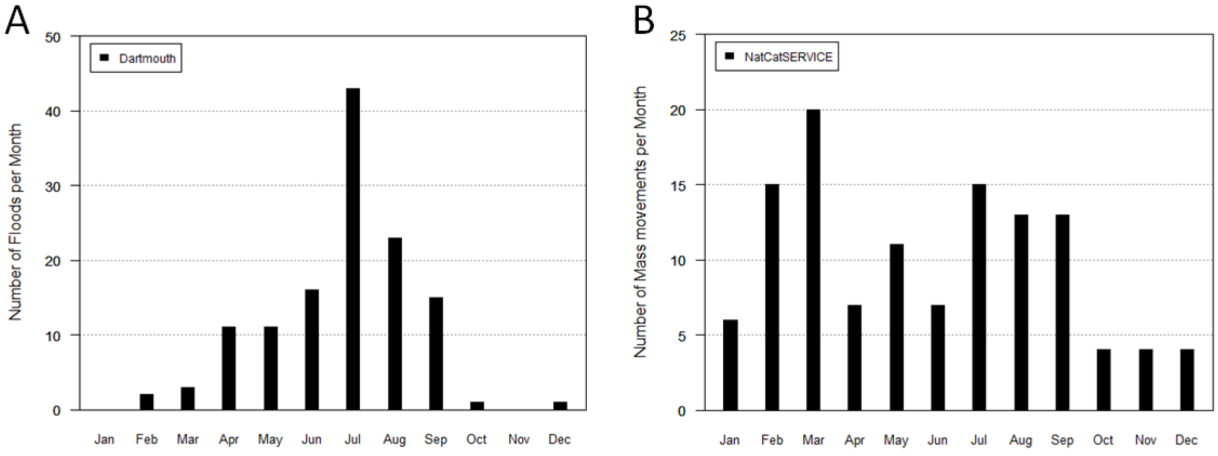

Figure 34: Time of occurrence of mass movement wet and flood disasters for mountain regions of the HKH in the time period 1980/85-2014. (Source: NatCatSERVICE and Dartmouth databases).

The two diagrams of the time of occurrence of mass movement and flood disasters in the HKH region (Figure 34) also verify the influence of the monsoon pattern on natural disasters. Thus, the number of registered floods in the mountainous regions of the HKH indicates a significant high frequency in July, registering numbers almost twice as high as for the second most frequently affected month in August. The number of registered mass movement events also exhibits a high occurrence in the summer months, but however, the highest numbers are listed in March. This high number of registered mass movement events is due to the large number of snow avalanches in February and March with up to 23 events which is equal to 50% of all listed avalanches during the observed time period. Thus, temperature seems to be the most important climate factor influencing mass movement events in the western region (Afghanistan) with increased glacier melt in spring, while precipitation and temperature are important for the rest of the HKH region (Elalem & Pal 2015).

Kulkarni et al. (2013) modelled the variability and change in seasonal precipitation and annual average temperature over three time periods 2011-2014, 2041-2070, and 2071-2098. They projected that annual average temperature will increase by 4-5°C for all three HKH regions (western, central, eastern Himalaya) until the end of the century, with the maximum temperature increase expected in the western Himalayan region. Precipitation may increase by 20-40% over the entire HKH region at the end of the century. Most glaciers in the HKH region have retreated and lost mass since the middle of the 19th century. Thus, future changes of monsoon intensity and temperature will have a significant influence on Himalayan glaciers (Bolch et al. 2012). However, future projections of regional monsoon patterns are still largely uncertain and need more careful investigation (Sharmila et al. 2015). Nevertheless, there is an expectation of a significant enhancement of heavy rainfall events during the Indian summer monsoon with a reduced number of low rain-rate events. There is an expected increase in seasonal mean rainfall intensity according to future climate models, and consequently in the sensitivity of the Indian Monsoon Index to global warming (Sharmila et al. 2015). The trend of the second most frequent disasters, the mass movement events, indicates a more stable tendency over the time period without a significant increasing trend. A study from Gabet et al. (2004) analyzed the rainfall thresholds for landslides in the Himalayas of Nepal with different slope stability models. They find two rainfall thresholds for a landslide initiation - a seasonal accumulation in combination with a daily precipitation total. Hence, landslides are not triggered until a minimum of about 860 mm of rain has fallen during the monsoon season, with additionally rainfall possible triggering landslides. These trends may be compared with studies of climate variability in the HKH region e.g. Singh et al. (2011). The findings indicate that climate change, land use change and population dynamics are the main drivers of environmental change in the HKH region, with an increased economic and environmental vulnerability for mountain people. One severe problem regarding temperature and precipitation measurements is the low density of meteorological stations in the HKH, especially for higher elevation areas. This could also be seen in the temperature anomalies data for the six stations in central HKH, where only one station included temperature measurements for the whole time period between 1980 and 2014. Also the numbers of storm, drought, wildfire and extreme temperature disasters seem to be more stable over time, without any noticeable pattern.

The three maps of the spatiotemporal trends of disaster occurrence in the HKH region between 1985 and 2014 (Figure 18) show the increasing number of disasters, with 56 events in the time period 1985-1994, 98 events between 1995 and 2004, and 169 events in recent decade between 2005 and 2014. From these investigations and localization of hazards, three main affected zones could be recognized: western Himalaya constituting the northern parts of Afghanistan (Badakhshan state) and Pakistan (Khyber Pakhtunkhwa state), central Himalaya comprising the northwestern Indian states Himachal Pradesh and Jammu and Kashmir and eastern Himalaya constituting the two China states Sichuan and Yunnan in the eastern HKH region. Similar patterns are also visible in the three maps of the analysis of the human and economic losses for the same region (Figure 19). Therefore, the three zones with most people killed, affected and with the highest economic damage correspond exactly with the areas with the highest frequency of registered disasters. A study from Elalem & Pal (2015) mapped the vulnerability hotspots of flooding disasters for the HKH region between 1951 and 2013. They found the highest spatial-temporal frequency of flood disasters to occur in northern Afghanistan and north-western Pakistan, as well as northern India and Nepal with some locations within

China in the east of the HKH. Hence, the main spatial distribution of disaster occurrence corresponds well to the results of the present study. The social and economic vulnerability distribution of the HKH region is extremely influenced by population pattern. Thus, the population density is highest in the northern part of Afghanistan and Pakistan, in the mountainous states of northern India, southern parts of Nepal and the eastern part of the HKH region within China. The majority of the flooding disasters occurred in the summer during active south-west monsoon season with increased cloudbursts and precipitation as well in the spring combined with, especially in Afghanistan, westerly weather systems and snow and glacier melt (Elalem & Pal 2015). Decadal patterns indicated that most disasters were reported in the recent decade (2005-2014) in both studies, as compared to the earlier decades. This fact may also be influenced by the availability of better and more accurate registration of events as a result of better communication systems.

Concerning the disaster risk statistics of the HKH region between 1985 and 2014 (Table 7), there is clear evidence that the highest relative vulnerability is for flood hazards with a value of about 2.613, followed by mass movement disasters with 1.047 and extreme temperature events with 0.334. The relative vulnerability measures the number of people killed per country due to natural hazards as a proportion of the number of people exposed (people killed/year/million population). There is strong evidence of enhanced flood disaster occurrence including high numbers of people killed.

Table 7: Disaster risk statistics HKH (1985-2014). (Source: EM-DAT database).

Disaster type	No. of disasters	No. of disasters/year	Total no. of deaths	Deaths/year	Relative vulnerability (deaths/year/million[1])
Drought	5	0.17	37	1	0.006
Extreme Temp.	13	0.43	2166	72	0.334
Flood	170	5.67	16465	529	2.613
Mass movement	93	3.10	6597	220	1.047
Storm	41	1.37	1553	52	0.247
Wildfire	1	0.03	0	0	0

[1] 210 million population of the HKH region (Singh et al. 2011)

A study from ICIMOD 2013 analyzed the flash flood risk in the Chitral District (14,800 km^2), one of the largest districts in the most disaster-prone state Khyber Pakhtunkhwa, located in Pakistan. The region is home to 450,000 people with a population growth rate of about 2.5% per year. The region is covered by 5% forest and 76% mountains including glaciers. The study found that short-duration intensive rainfall and cloudbursts are the main causes of flash floods in the study regions. Human activity and land use changes such as overgrazing and deforestation lead to lack of vegetation, whereas direct runoff may trigger flash floods. Extreme poverty and population growth in the study region lead to an increasing construction of infrastructure in the hazard-prone areas, and enhance their vulnerability and risk. Hence, changes in infrastructure and climate increase the frequency and magnitude of flash floods in the study area (Shrestha & Bajracharya 2013). Not only flood events occurred in Chitral, Pakistan, but also drought disasters. However, the overall impact on human population of drought is lower than for flood hazards. The reasons for droughts in these regions are variations in the frequency and duration of the rain pattern (Shrestha et al. 2015).

Thus, the increasing trend of registered disasters (Figure 16.) is influenced by several factors such as changing climate with enhanced temperature and changing precipitation patterns during the period studied. Population growth in the HKH region is higher than the national average and leads to an increased demand for food, shelter and infrastructure. It becomes apparent that landscape structure change with a significant decrease in forest areas for agriculture expansion leads to erosion and land degradation (Qasim et al. 2011). As a result of lack of land use regulation and enforcement, people and infrastructure are more exposed and prone to suffer injury or damage in the aftermath of natural disasters (Shaw 2015).

6.3.2 Central Asia with Mass Movements in Kyrgyzstan and Floods in Tajikistan

The disaster trends in Central Asia (Kyrgyzstan and Tajikistan) from 1990 to 2014 show a fluctuation between zero and four disasters per year, the latter in 2004 and 2005 (Figure 14.). However, the graphic does not indicate any significant trend over the time period. The region was most affected by floods (48.7%) and by mass movement disasters (35.9%). In Kyrgyzstan, landslides are the most widely distributed hazard type and about 5,000 potentially active landslides sites have been identified, especially in the southern part of the country (Gupta 2009). Landslides are predominantly concentrated in the foothills of the Fergana Basin and are mainly mobilized during the rainy season between fall and spring. Precipitation and hydrological processes are the main triggering factors of landslides in the mountainous regions studied (Goetz et al. 2011).

In April 1994, one major landslide in the Osh, Jalal-Abad Region killed 111 people, affected 45,000 people and caused economic damage of about 36 million USD. In contrast, Tajikistan is most exposed to flood disasters, due to its mountainous topography with a high rainfall pattern and large number of glaciers. Tajikistan is one of the most sensitive countries to natural hazards due to extreme poverty and lack of emergency management capacity (Pollner et al. 2010). A severe flood in July 2004 affected 400,000 people and caused an economic loss of about 12 million USD. Floods in Tajikistan are often caused by outburst from mountain lakes due to unstable natural barriers storing large volumes of water. Lake Sarez in Tajikistan (16 km^3 of water) is one of the world’s most potentially dangerous lakes (Gupta 2009). To reduce the risk of a possible outburst of Lake Sarez, a modern monitoring system coupled with an early warning system was recently installed to alert people living in the vicinity of Lake Sarez (Pollner et al. 2010). Also in Kyrgyzstan, more than 20 glacial lakes are in danger of outburst due to enhanced temperatures and glacial retreat (UNRCCA 2014).

The disaster risk statistics (Table 8) indicate a significantly higher relative vulnerability for people living in mountainous regions of Central Asia to mass movement disasters (2.537) compared to flood disasters (0.436). The table indicates that flood events appeared more frequently but with a lower impact on the mortality of people compared to mass movement disasters with a significantly higher number of fatalities.

Table 8: Disaster risk statistics Central Asia (1990-2014). (Source: EM-DAT database).

Disaster type	No. of disasters	No. of disasters/year	Total no. of deaths	Deaths/year	Relative vulnerability (deaths/year/million[1])
Drought	1	0.04	0	0	0
Extreme Temp.	3	0.12	27	1	0.12
Flood	19	0.76	98	4	0.436
Mass movement	14	0.56	571	23	2.537
Storm	2	0.08	4	0	0.018
Wildfire	0	0	0	0	0

[1] 9 million people from mountainous states of Kyrgyzstan and Tajikistan

In past decades, various climate-driven precipitation changes have been observed in Central Asia. The mean annual precipitation has increased in the outer and in the eastern ranges, but has decreased at higher altitudes in the inner ranges. In the future, winter precipitation in Central Asia is likely to increase by 4 to 8% by 2050, whereas summer precipitation is expected to decrease by 4 to 7%, which might result in more frequent dry summers. In contrast, the mean annual air temperatures have been more uniform with an increasing temperature trend since the 1970s of between +0.1 and +0.2°C. However, summer and winter temperatures are expected to increase to a higher level up to the 2050s, with temperature changes of between +3.1 and +4.4°C in summer and +2.2 and +3.9°C in winter (Sorg et al. 2012). A study from UNRCCA (2014) indicates the effect of global warming and climate change on the high mountains of central Asia. It is predicted that glaciers will melt more rapidly with consequences for water balance and natural disasters such as landslides and floods due to glacial lake outbursts, thereby affecting the socio-economic development of the region.

6.3.3 Flood and Drought Disasters in Eastern Africa

Figure 12 B illustrates the number of weather- and climate-related natural disasters for Africa in the time period 1985 to 2014. The most frequent disasters in Africa were floods (65.0%), followed by droughts (18.4%) and storms (8.6%). The graphic indicates a low number of registered events in the first years from 1985 to 1996, with a following irregular increasing trend to a peak in 2006 with 14 registered disasters. From there, the trend decreases again to a lower level. The high occurrence of floods in the year 2006 (14 events) was due to exceptionally heavy precipitation in southeastern Ethiopia and northeastern Kenya between October and December 2006. Flash floods and overflow of rivers and dams have caused loss of human life with damage to property, displacement of people and increased incidence of disease. Also, heavy precipitation in East Africa in 2002 caused floods and mudslides in Rwanda, Kenya, Burundi, Tanzania and Uganda (Niang et al. 2013).

Regarding the country-level based spatiotemporal trends of disaster occurrence (1985-2014) (Figure 17), there is clear evidence for the mountain regions of East Africa as the most disaster-prone regions of the continent. Over the time period, Uganda suffered from 27 disasters, followed by Ethiopia (26 disasters), Burundi (23 disasters) and Tanzania, Rwanda and Kenya each with 16 disasters. Thus, the mountainous parts of the Ethiopian and East African Highlands are most affected by natural hazards. Focusing more on the details, figure 20 indicates the most disaster affected states of these regions. There is a clear indication of an increasing number of natural hazards during the three decades from 1985 to 2014. Changes in extreme precipitation patterns over East Africa have led to droughts and heavy rainfall which have been experienced more frequently during the last 30-60 years (Niang et al. 2013). The high occurrence of disaster in East Africa is also a result of the high population density in Ethiopia, Uganda, Rwanda and Burundi compared to other mountainous countries of Africa.

Floods and droughts in Africa in some countries are linked with the El Niño Southern Oscillation (ENSO) events (Boko et al. 2007). A study from Indeje et al. (2000) analyzed the influence of ENSO patterns for East Africa. The findings show a tendency for above-average rainfall from October to March in most parts of East Africa during ENSO years, whereas rainfall deficits occur during the following year. This effect may also explain the highest occurrence of drought in 1999 with five events (Figure 13), as a response to a major ENSO event in 1997/98 resulting in a rainfall deficit in East Africa in the following year. As a result, El Niño events are largely favorable for crop cultivation in East Africa. Nevertheless, associated challenges from floods and diseases, human deaths and displacements and infrastructure destruction may have a high negative impact (FAO 2014).

The disaster risk statistics for Africa (Table 9) indicate the highest relative vulnerability for flood events with a value of about 0.402. These circumstances demonstrate the high importance of flood disasters in the past 35 years for the region analyzed in the study.

Table 9: Disaster risk statistics Africa (1985-2014). (Source: EM-DAT database).

Disaster type	No. of disasters	No. of disasters/year	Total no. of deaths	Deaths/year	Relative vulnerability (deaths/year/million[1])
Drought	30	1	924	31	0.168
Extreme Temp.	1	0.03	0	0	0
Flood	101	3.37	2208	74	0.402
Mass movement	10	0.33	526	18	0.096
Storm	14	0.47	61	2	0.011
Wildfire	2	0.07	0	0	0

[1] 183 million people from mountainous states of Africa

The high total number of flood disasters in Africa highlights the great need for early warning systems. As an example, Ethiopia suffered from a total number of 16 floods in the observed time period. The evidence of recent flooding coupled with predicted increasing precipitation in East Africa makes Ethiopia extremely vulnerable. Therefore, flood hazard in Ethiopia may continue as a result of increasing population, increased land and forest degradation and encroachment of people to settling in close to flood-prone areas (Moges 2007).

Contrary to expectations, the disaster trend of Africa shows a relatively low registration of droughts (18.4%) with a relative vulnerability of about 0.168. However, the number of drought events seems to be underestimated for a number of reasons. As a comparison, Dilley et al. (2005) calculated the global distribution of drought risk, wherein the Sub-Saharan Africa and East Africa were marked as the regions with highest vulnerability for drought mortality, worldwide. One reason may be due to the fact that droughts are a “slow-onset” hazard, as they develop gradually and are difficult to define. Unlike other hazards, droughts do not destroy infrastructure, so the impacts are less visible and data availability is not always ensured (Smith 2013). One important fact is the lack of information about drought incidence in the data from the EM-DAT database. For instance, since ten drought entries in Africa do not provide clear spatial indications, they are not included in the current study because of the defined data extraction procedure.

The Palmer Drought Severity Index (PDSI) is one measuring system for droughts which was developed by Palmer in 1965. The PDSI is a soil moisture algorithm calibrated for homogenous regions. The index is based on moisture inflow, outflow and storage. However, a study from (Ntale & Gan 2003) indicates that the PDSI was designed for the USA, and did not give reasonable results for some drier parts of East Africa. Nevertheless, the findings of the 2003 study show that precipitation data alone could explain most of the variability of East African drought.

The highest number of droughts was registered in Ethiopia with seven disasters reported between 1985 and 2014. A study from Lukamba (2010) showed that Ethiopia is highly vulnerable to droughts and has recorded a growing number of events in the period 1980 to 2000. The main cause of the increased frequency of dry periods is an increasing scarcity of rain. The most affected people are the pastoralists or agro-pastoralists in the southern and southeastern part of Ethiopia. The reason lies in their sensitivity to climatic changes because their livestock depend on the availability of water and pasture which is negatively affected by climate change.

Temperatures in Africa are predicted to rise faster than the global average increase during the 21st century. The northern part of the Atlas Mountains has experienced a strong decrease in the amount of precipitation received in winter and early spring over the last few decades. Estimated higher temperatures and declining rainfall would reduce snowpack in the Atlas Mountains reducing supplies of seasonal meltwater for lowland areas. The equatorial and southern parts of eastern Africa have experienced a significant increase in temperature since the early 1980s with an increase in seasonal mean temperature in many areas of Ethiopia, Kenya and Uganda over the last 50 years. Precipitation patterns in eastern Africa indicate a high temporal and spatial variability, whereby rainfall has decreased over the last three decades over eastern Africa between March and May/June. Also the monsoonal summer precipitation (June-September) has declined over the last 60 years in eastern Africa (Niang et al. 2013). However, future projections show a likely increase in annual mean rainfall in East Africa with an increase in the number of extremely seasons of about 20% (i.e. 1 in 5 of the seasons are extremely, as compared to 1 in 20 in the control period in the late 20th century (Christensen et al. 2007).

6.3.4 Disaster-prone Central Andean Region

The disaster trend of the Andes (Figure 12 A.) in the time period from 1985 to 2014 shows an alternating tendency with a maximum of eleven disasters in the year 2001 and a minimum of one disaster in the year 1989. The Andes were most frequently affected by floods (50.0%) and mass movement (28.7%) disasters.

A principal reason for the frequent occurrence of floods in South America is the natural phenomenon El Niño. Pacific Ocean and atmospheric conditions fluctuate between El Niño (warming) and La Niña, with cooler temperatures in the tropical Pacific as phases of the El Niño-Southern Oscillation (ENSO). The fluctuations occur irregularly at two to seven year intervals. The impact of El Niño leads to increased rainfall on the coasts of Ecuador, the northern part of Peru and southern zones of Chile. Future climate change may affect the frequency and intensity of ENSO events. In Ecuador, Peru and Bolivia, the effects of a disruption of ENSO patterns will be drought in the mountainous and Andean zones, implying retreat of glaciers with changes in water availability and local biodiversity. The precipitation in Colombia and Venezuela will be reduced, whereas rainfall in Argentina will increase (McCarthy 2001). The El Niño event which occurred between May 1997 and April 1998 was one of the strongest ever recorded and the most severe event in the last 25 years (FAO 2014). Figure 14 indicates seven registered events for the year 1997 with a flood in Bolivia, a winter storm in Chile, a mudslide, a forest fire and a tropical storm in Peru and a flood and a drought event in Ecuador. La Niña phases influenced South America with drier conditions due to decreased cloud production and rainfall (Suplee 1998). Thus, as a result of the La Niña year 1988/1989, only two flood and one mass movement disasters were registered.

With reference to the most disaster-prone mountainous states of the Andes (1985-2014) (Figure 18), there is clear evidence of a highest exposure to weather- and climatic-related natural disasters for the Central Andes (Peru and Bolivia). The most disaster-prone state of Peru is Cusco (7 events), followed by Apurimac, Puno, Cajamarca and Amazonas, each with 3 events. The most disaster-prone Bolivian states are Cochabamba (7 events) and La Paz (5 events). The northern and southern parts of the Andes were less affected with up to two disasters in Venezuela and Colombia, and a maximum of two disasters in Argentina and Chile. One explanation of these trends is the population distribution of the Andes, where the central and northern Andes are the most densely populated areas, compared to mountainous regions in Chile and Argentina in the southern Andes.

Referring to the time of occurrence of flood and mass movement disaster types in the Andes (Figure 35), most events take place during the austral summer (DJF) with a high number of mass movement events in July and flood events in June. The Andean climate in the most disaster-prone mountain regions along the eastern and western slopes with adjacent lowland areas exhibits a high degree of contrast. The tropical and sub-tropical latitudes between 5°S (northern Peru) and 30°S (central Chile and Argentina) experience cold and arid conditions along the Pacific coast extending into the western slopes of the Andes. Warm, moist and rainy conditions are dominant over the eastern slopes (Garreaud 2009). This fact may result in increased occurrence of disasters when combined with highland-lowland interaction of the Andes due to the accumulation effect of wind masses.

The monsoon reaches South America during the austral summer (DJF) and brings moist, warm air masses from the tropical Atlantic. Flowing westwards, these winds are blocked by the steep Andes Mountains and turn southwards, meeting cold and dry winds which lead to abundant rainfall at high elevations. This orographic effect may result in floods, causing damage in the densely populated foothills of the Bolivian and Argentinean Andes (Davies 2014). However, the influence of mountain characteristics for flood disasters far away from the Andes in the most eastern part of Argentina seems to be less important and other reasons such as heavy local precipitation and storm events may be likely triggers for these flood events.

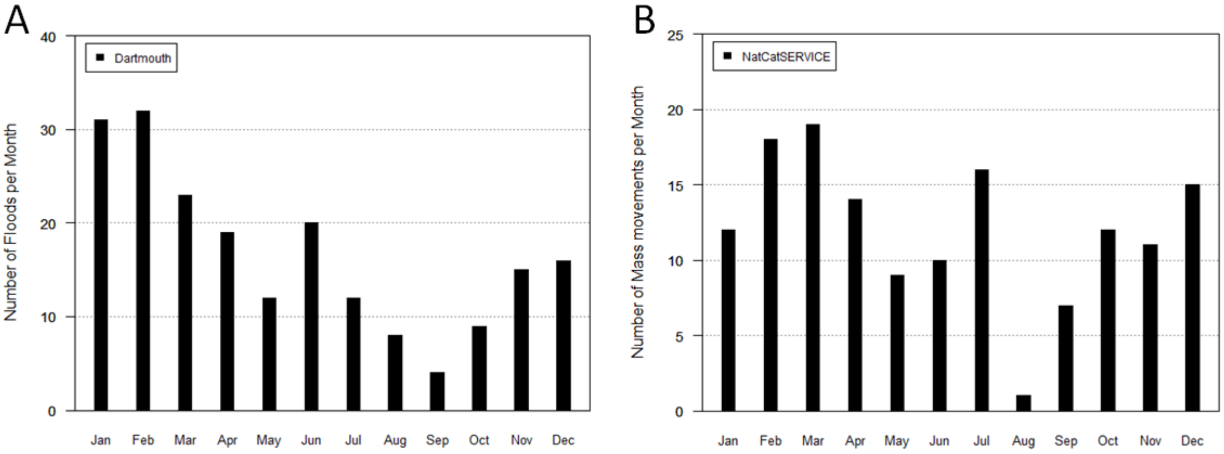

Figure 35: Time of occurrence of mass movement and flood disasters for mountain and non-mountain regions of the Andes in the time period 1980/85-2014. (Source: NatCatSERVICE and Dartmouth databases).

The main spatial occurrence of mass movement disasters is located in the Central and Northern Andes with significant incidence in Bolivia, Peru, Ecuador and Colombia (Figure 35 B). The NatCatSERVICE database registers only a few events for the southern parts of the Andes, with Chile and Argentina and seeming to be less prone to these types of events. Landslide events with associated damage of drainage systems in the Andes have been most commonly triggered by earthquakes, extreme periods of precipitation and rapid snowmelt in mountainous regions in the past (Trauth et al. 2000). The Andean flood distribution indicates also a high incidence of events in the mountain regions of the Central and Northern Andes. However, the Dartmouth database registers the highest number of flood events in the non-mountainous regions in the eastern part of the Andes in Bolivia and Argentina (Figure 35 A). The high frequency of disasters in the northern Andes, especially in Colombia can be attributed to the circumstance that these regions are among the most densely populated mountain regions in the world (Ariza et al. 2013).

The disaster statistics of the Andes (Table 10) show the highest relative vulnerability for mass movement disasters with a value of about 1.310, closely followed by the vulnerability to floods with 1.276 and extreme temperatures with 0.862. It becomes apparent that impacts from mass movements on mortality are severe, as the number of people killed is almost the same for floods and mass movements, whereas the total number of events for floods (75 events) is much higher than for mass movements (43 events).

Table 10: Disaster risk statistics Andes (1985-2014) . (Source: EM-DAT database).

Disaster type	No. of disasters	No. of disasters/year	Total no. of deaths	Deaths/year	Relative vulnerability (deaths/year/million[1])
Drought	9	0.3	0	0	0
Extreme Temp.	12	0.4	1508	50	0.862
Flood	75	2.5	2209	74	1.276
Mass movement	43	1.4	2285	76	1.310
Storm	8	0.27	663	22	0.379
Wildfire	3	0.1	8	0	0

[1] 58 million people from mountainous states of the Andes

Mean temperatures in the Andes have increased approximately 0.1°C/decade, whereas precipitation has slightly increased in the second half of the 20th century in the inner tropics and decreased in the outer tropics. The IPCC 2013 shows an increase in precipitation in northwest Peru and Ecuador, whereas a rainfall decrease is registered in southern Chile, southwest Argentina and southern Peru. The glacier-retreat trend has intensified, reaching critical conditions in the Andean countries. Deforestation rate has been increasing mainly due to agricultural expansion and land degradation has intensified for the entire region. The frequency and intensity of weather and climate extremes is likely to increase for the observed regions (IPCC 2013).

6.3.5 Flood and Avalanche Disasters in the Alps

The trend of disaster occurrence in the Alps from 1985 to 2014 (Figure 11) indicated no clear trends and the situation was relatively stable. Floods (44.7%), mass movements (28.9%) and storms (21.1%) occurred most frequently. Several papers (e.g. Beniston et al. 2011; Einhorn et al. 2015; Gobiet et al. 2014) studied Alpine temperatures from the past. For instance, (Rebetez & Reinhard 2008) compared monthly temperature data in Switzerland for the 20th century (1901-2000) with data for the last thirty years (1975-2004). The mean decadal trend during the 20th century is +0.135°C, with +0.57°C during the last three decades. These increasing trends are more than twice as high as the average temperature trends in the Northern Hemisphere. The impact of increasing temperature for the cryosphere in the Alps may influence the Alpine environment with less snow, accelerated glacier retreat and permafrost degradation.

The three major snow avalanche disasters which occurred in 1999 can be explained by the extreme winter conditions with heavy snowfall in February 1999. The analysis indicated the high occurrence of avalanches in general, as nine out of a total of eleven mass movement disasters appeared as avalanches.

The only wildfire event occurred in 2003 was caused by the European heat wave in the summer of that year, triggered by large-scale blocking patterns (Beniston 2007). The temperatures of this record-breaking heat wave have exceeded the 1961-1990 mean by approximately 3°C which corresponding to an excess of up to 5 standard deviations (Schär et al. 2004). However, the Alps were most frequently affected by flood events, especially riverine floods (Figure 12). In summer 2005, two flood events were registered in Switzerland and Austria, due to the heavy precipitation on 20-23 August in the Alpine region. The Alps were affected by severe floods accompanied by river-bank erosion, sediment transport, debris flows and landslides. These events caused the most catastrophic flood damage in the last 100 years regarding loss of life and damage to infrastructure, communication routes and agriculture in the European Alps (Beniston 2006).

For future projection of frequency, intensity and seasonality of Alpine flood events, various aspects such as increased temperature, change in rainfall patterns and land cover changes have to be integrated (Einhorn et al. 2015). Direct relationships between severe wind storms and ongoing warming trends in the Alpine region are difficult to discern because of the rare occurrence of these events (Beniston 2007). The extreme temperature disaster in 2012, which occurred as a cold wave, was triggered by a cold spell covering a large part of Europe under the influence of very cold air originating from the Russian anticyclone (Letestu & Ulrich 2013). A study from Fuchs et al. (2013) in the European Alps reveals that major losses are associated with an increase in land use, population density and economic activities. Thus, the increased population and infrastructure in Alpine valleys would inevitably have negative impacts, regardless of climate change (Einhorn et al. 2015).

The distribution of mass movement disasters indicates a high incidence of disaster in the Alps, especially in the mountain regions of Austria, France, Italy and Switzerland (Figure 28). The occurrence of flood events in the Alps is very low for mountains and widely distributed for non-mountain areas. Thus, the effects on areas impacted by flood disasters in the analyzed mountain regions occurred at locations some distance from areas above 1000 m a.s.l. However, the influence of mountain characteristics as flood generators is important with significant impacts on lowland areas. The time of occurrence of mass movement events for the Alps is highest in the winter months (DJFM) (Figure 36).

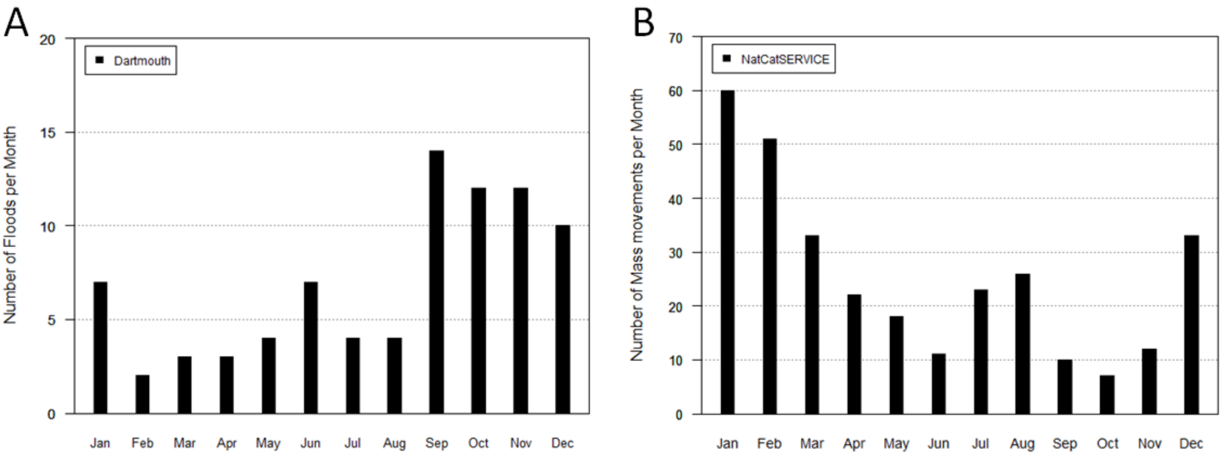

Figure 36: Time of occurrence of mass movement wet and flood disasters for mountain and non-mountain regions of the Alps in the time period 1980/85-2014. (Source: NatCatSERVICE and Dartmouth databases).

These patterns are to be expected, as the most registered mass movement events in the Alps appeared as avalanches, occurring on steep slopes in combination with heavy snowfall during winter. A study of climate change impacts on mass movements in the European Alps from Stoffel et al. (2014) showed that mass movement events are expected to occur less frequently during summer, whereas the increased rainfall in spring could alter debris-flow activity during the months March, April, November and December. However, no clear trends have been identified in the frequency and quantity of avalanches in the Alps over the past century and the relationship between avalanche activity and climate change is still poorly documented (Jomelli et al. 2007). However, a study from Huggel et al. (2012) indicated that landslide processes are linked to climate change, especially through precipitation, with some cases through temperature-induced changes in snowfall.

The highest registration of flood events in the Alps is between September and January. One reason may be that meltwater from snow and ice from mountainous regions serves as a major source of floodwater in the Alps. However, snowmelt floods in the snow-dominated regions of the Alps in spring are projected to decrease due to a shorter snow season in combination with less snow accumulation in warmer winters (Dankers & Feyen 2008).

Table 11 Disaster risk statistics Alps (1985-2014) (Source: EM-DAT database).

Disaster type	No. of disasters	No. of disasters/year	Total no. of deaths	Deaths/year	Relative vulnerability (deaths/year/million[1])
Drought	0	0	0	0	0
Extreme Temp.	1	0.03	0	0	0
Flood	17	0.57	372	12	1.797
Mass movement	11	0.37	201	7	0.971
Storm	8	0.27	29	1	0.140
Wildfire	1	0.03	5	0	0.028

[1] 6.9 million people from mountainous states of the Alps

The disaster risk statistics of the Alps (Table 11) show the highest relative vulnerability of about 1.797 for flood events. The second highest values are calculated for mass movement disasters, especially avalanches, with a value of about 0.971, followed by storm disaster with 0.140 and wildfire with 0.028.

Future climate patterns in the European Alps indicate a projected temperature increase of 0.3 to 0.45°C per decade to 2100 above 1961 to 1990 mean values, with higher projected increases in summer and autumn and increased frequency of summer heat waves (Beniston 2004). Precipitation changes are predicted with a higher north-south gradient with increased precipitation in the north (especially in winter) and strongly decreased precipitation in the south (especially in summer). Thus, significant increases in high precipitation patterns, particularly in winter, may be expected for northern and western Switzerland and in autumn in the Alpine zone, with no visible trends in summer, whereas winter precipitation in the eastern Alps is expected to increase in the northwest and decrease in the south and east. Precipitation intensity is expected to increase in all areas (Gobiet et al. 2014).

6.4 Mountain Significance for Natural Disasters and Sustainable Development

The current study illustrates the importance of mountains as disaster-prone areas, regarding SMD. Thus, mountain regions are primarily influenced by ongoing climatic changes and increased population density, leading to enhanced pressure on their natural resources such as water and biodiversity. Mountain regions are water towers of the world and contain more than half of the global biodiversity hotspots.

The study indicates the significance of database quality and completeness for a usefulness application of numerous database systems. Therefore, disaster data analysis are crucial for a better understanding of hazard risk and vulnerability patterns and measures the impacts on the mountain population regarding SMD, economy and environment. Furthermore, accurate disaster analysis helps to identifying characteristics of disasters and trends and is an evaluation of disaster loss-reduction efforts.

With reference to the occurrence of mass movement and flood disasters in the regions of the Andes and the Alps with data from the NatCatSERVICE and Dartmouth databases (Figure 27/28), there is evidence of a higher occurrence of mass movement disasters in mountainous areas compared to flood events, for both regions. These trends are also visible in the three other mountain regions (Appendix A.7). However, there is a significant difference in the type of mass movement events which occurred in the Alps and the Andes. The most widely distributed types in the Andes were the 81 landslide events, 11 mudslides and 3 snow avalanches. In contrast, the 128 events in the Alps occurred as snow avalanches, by 27 mudslides and 5 landslides. Crosta & Frattini (2008) find, that landslide triggering thresholds differ from one region to another based on hydro-climatological and geophysical properties such as regional and local precipitation characteristics and patterns, slope morphometry, soil characteristics, lithology, climate and geology. Nevertheless, mass movement distribution patterns seem to be directly related to mountain characteristics, enhanced precipitation and certain slope gradient properties. Hence, avalanches and landslide hazards occur almost exclusively in mountain regions (Kohler & Maselli 2009), independent of the level of development of the two mountain regions.

Although there are few registered flood events in the Alps, there is a high degree of highland-lowland interaction whereby watershed damage may increase flooding and sediment transport to the regions downstream. A study from Keiler et al. (2010) investigated climate change and geomorphological hazards in the eastern European Alps. They showed the connectivity of the heavy precipitation event in the European Alps in summer 2005 with resulting process chains and cascade effects resulting from a mountain-hazard event. These mountain disaster events lead to high sediment transport through landslides and other processes with significant impacts on valley settlements downstream. Nevertheless, not only water-induced hazards are important for the lowland population but also water as a resource for lowland people is highly influenced by mountain climates and vegetation (Beniston et al. 2011).

The analysis of natural disasters in mountain regions highlights the important component in the assessment of the probability of occurrence of future natural hazards in mountainous regions. Thus, the question is whether global (climatic) changes can be expected to have an impact on the occurrence of future disasters. It is likely that climate change will alter the magnitude and frequency of water-driven hazards in mountain regions such as permafrost degradation, ice avalanches, and failure of glacier dams with possible glacier lake outburst floods. The mountain hazards such as floods, debris flows, landslides and avalanches are among the most sensitive to climate change. Thus, the number of people affected by these hazards is likely to increase in the future (Kohler et al. 2014). However, the character and severity of the impacts of climate extremes depend not only on the extremes themselves but also on exposure and vulnerability. These are influenced by a wide range of factors, including anthropogenic climate change, natural climate variability, socioeconomic development and land use change (increased urbanization) (IPCC 2014). Therefore, socio-economic factors including demographic changes influence vulnerability and exposure, whereas climate change has an impact on the frequency and magnitude of hazards (Kohler et al. 2014). The data analysis indicates that climate-related disasters in mountainous regions are mostly increasing with a range of trends observed in the regions studied. However, the current evidence for these trends is not conclusive regarding the main causes. As climate-related factors such as temperature and precipitation changes may be contributing factors to the current increasing trend, socio-economic vulnerability such as urbanization, land use changes and deforestation have to be considered as potential causes for the rise of these weather- and climate-related disasters in mountainous regions (Brauch et al. 2011).

A study of progress and perspectives on sustainable mountain development (SMD) from Ariza et al. (2013) indicates the key global trends of the past 20 years affecting SMD. They conclude that similar trends influence several mountainous regions regarding SMD. Hence, many armed and non-armed conflicts exist in mountain regions, hindering their development. Continuous global population and economic growth have increased pressures on mountain resources and increased environmental degradation, especially in poor countries. Ongoing climate change has increased political interest in mountain regions, particularly regarding glacier melting and enhanced the risk of natural disasters in different regions.

However, the five mountain regions HHK, Africa, Andes, Alps and Central Asia have been additionally affected by specific regional conflicts and issues. Thus, the Andes have suffered from increased urbanization and population density in mountains, resulting in higher pressure on, and unsustainable use and exploitation of natural resources. Further impacts have been climate change, land use change, glacier retreat and mountain ecosystem degradation, which have affected the quality and availability of mountain water for utilization in agriculture and urban centers. Changes in climate in the Andes are expected to increase temperatures with uncertainties in the change of precipitation.

Many mountain people in Africa suffer from extreme poverty and their isolated communities are unable to attract investment for development. The growing population density in Africa has increased the pressure on scarce resources such as arable land. Thus, these regions continue to lag behind average global development.

Continuous population growth in combination with an increasing need for water have decreased the water resources of the ten major river systems in the HKH region. The rate of global warming in the HKH, especially at higher altitudes, is three to five times the global average. Hence, increased snow and glacial melt and more frequent extreme weather events such as floods and droughts have occurred in the HKH region, affecting livelihood risks, poverty, food insecurity and social injustice. The extreme vulnerability and the risks result from deforestation, desertification and socio-economic transformation.

Central Asia has suffered from an abrupt transition from planned economies to market-based economies in the Pamir and the Tien Shan regions. Explorative mining of natural resources such as gold, mercury and uranium by foreign companies has increased the number of environmental hazards. Climate change has increased the incidence of natural hazards such as floods, mudflows and landslides with a series of glacial lake outburst floods occurring in the region.

The European Alps have profited from political stability and economic development. The Alps are characterized by a rich institutional landscape which has increased development. However, land use changes have led to a reduction in the number of farms and resulted in a gap between central and peripheral areas. Several mountain regions are losing younger populations, who represent an important resource for future development in these mountainous areas.

Future targets are to reduce the number of deaths and people affected and decrease the economic losses in the aftermath of natural disasters. There is a need to strengthen resilience and adaptive capacity to climate-related hazards and natural disasters, especially in poor and vulnerable mountain regions, with a reduction of their exposure and vulnerability to extreme weather- and climate-related events. Therefore, the SMD4GC project tries to increase the resilience of mountain populations in these vulnerable and hazard-prone environments, while specific knowhow on mountains on a national, regional and global level is essential in order to contribute to sustainable mountain development, disaster risk reduction and climate change adaptation.

7 Conclusion and Outlook

This section refers to the research questions as a conclusion of this study with the outlook including further investigations of natural disasters in mountain regions based on data from disaster databases.

7.1 Conclusion

- The analysis emphasizes the different processing methods of the four databases applied to disaster data extraction for in mountain regions. The quality of resolution highly depends on the database structure and organization, whereby geo-referenced data (NatCatSERVICE and Dartmouth) are more accurate and better locatable than state-based data (EM-DAT). The correlation of the total number of disasters from the four databases for flood and mass movement data indicates highly varying results for coefficient of determination (R^2) values. The main reasons for this circumstance are database characteristics such as the diverse data sources, entry criteria and spatial resolutions. However, the most reliable and consistent loss indicator for all global databases is the number of fatalities. Indications of people affected or displaced are highly inaccurate and must be regarded more as a proxy for the disaster intensity rather than as an exact loss indicator. The quality of economic damage metrics is highly dependent on the purpose of the different databases, where the most reliable economic loss data are provided by the reinsurance NatCatSERVICE database. The three other data sources exhibit substantially deficient and discontinuous data entries.

- The main limitations of the disaster databases used in the study are different, as the databases are based on diverse structures. However, one common weakness is the inconsistent definition of database entries for all datasets which limits an accurate data comparison. Another important limitation is caused by the different database sources and the weak declaration of them. As the Dartmouth and the DesInventar databases refer to data originating primarily from newspaper sources, their quality of resolution is highly dependent on the location. Thus, disasters occurring in outlying areas and mountainous regions may be less completely reported than centrally located areas with a better coverage of newspaper reports. An exact declaration of the originating source of registered events is missing in all databases. One specific weakness of the NatCatSERVICE database is the lack of public access to disaster data, whereas all of the other three databases provide open data accessibility without restrictions. Thus, unfortunately, only mass movement data were provided by the reinsurance database for the present study. The purpose of each database is crucial, regarding the distribution of disasters in the five mountain regions. Thus, the reinsurance company lists most events for the Alps with little occurrence in Africa, whereas all other disaster databases register the majority of events for the HKH, followed by Africa and the Andes. In general, sustainable disaster databases must be based on a clear data collection methodology with consistency over time, and data validated by a quality assurance procedure. Geo-referenced disaster entries enhanced the accuracy of an event location, especially for selected areas such as mountainous regions.

- Investigation of the occurrence of natural disasters in the five mountainous regions (1980-2014) with data from the EM-DAT database indicated the highest number of disasters for the HKH region. This area was affected by 323 disasters, particularly by monsoon-triggered flood events which constituted 52.6% of all disaster types. In Africa, the East African highlands and the Ethiopian highlands were most impacted by natural hazards, where floods occurred most frequently (65.0%), followed by drought events (18.4%). The study revealed the Central Andes as the most disaster-prone area of the Andean region with a total of 150 registered disasters which mainly occurred as floods (50.0%) and mass movement disasters (28.7%). Central Asia and the Alps suffered less frequently from natural disasters with 39 events in the Alps and 38 events in Central Asia. Flood and avalanche disasters constituted the majority of events in the Alps, whereas Central Asia was most affected by flood and several mass movement events. The study emphasized the importance of mountains as regions of high vulnerability to natural disasters, and the fact that highland-lowland interactions must be considered in the assessment of mountain hazards.

- The disaster frequency over the time period 1980-2014 indicated a remarkable increasing trend of weather- and climate-related disasters for the most disaster-prone regions of the HKH, Andes and Africa, whereas no obvious trends could be recognized in the Alps and Central Asia where hazards were registered with a lower frequency. The inaccurate data record in the initial phases and the more accurate registration and management of the four databases in recent years may have influenced the increased number of events registered in the last decade. However, there is a high probability that natural disasters will continue to increase in the future under projected climate change, with changing precipitation patterns and expected higher temperatures particularly in mountain regions. The study emphasized the importance of population density for vulnerability to natural disasters and associated human and economic losses. Thus, damage due to hazards in mountain regions will increase irrespective of global warming, in regions where populations are growing and infrastructure is developed at exposed locations.

7.2 Outlook

The findings from this study may be taken as a basis for further investigations regarding disaster data processing for mountain regions and to illustrate the importance of the quality and reliability of disaster databases for an accurate usefulness of these data. According to numerous limitations of the databases, there is a need for more homogenous, complete and reliable data registration for social and economic loss parameters on a global and local scale.

The results of this study illustrate disaster trends in the five mountain regions and give an overview of the spatiotemporal disaster distribution according to the type of event.

With ongoing climate change, weather-and climate-related disasters will likely increase with growing population and higher exposure of mountain people. Sustainable development therefore is important for protecting mountain environments to provide natural resources and to ensure the well-being for mountain and lowland communities.

Therefore, further analyses about future changes concerning environmental and socio-economic issues in mountain regions are indispensable for sustainable mountain development, whereby disaster data analyses help to identify the characteristic of disasters and trends and are a crucial approach for disaster loss-reduction efforts.

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A. Appendix

A.1 Study Regions with related Mountain States

A.1.1 HKH

Table 12: HKH countries with mountain states and coverage of percentage of mountain covered area of these states

Countries	Mountain "States"	% Mountain Area of the States
Afghanistan	**22 out of 33 Provinces in Afghanistan:**	
	- Badakhshan	98.8%
	- Badghis	60.3%
	- Baghlan	81.8%
	- Bamyan	99.3%
	- Ghazni	67.7%
	- Ghor	93.6%
	- Kabul	70.5%
	- Kapisa	91.9%
	- Khost	94.4%
	- Kunar	89.9%
	- Laghman	74.9%
	- Logar	70.8%
	- Maidan Wardak	95.7%
	- Nangarhar	56.5%
	- Nuristan	99.8%
	- Paktia	80.1%
	- Perwan	94.1%
	- Samangan	80.5%
	- Sar-e Pol	78.6%
	- Takhar	71.5%
	- Urozgan	90.9%
	- Zabul	55.5%
Bangladesh	**0 out of 7 Divisions of Bangladesh:**	-
Bhutan	**19 out of 20 Districts of Bhutan:**	
	- Bumthang	99.9%
	- Chukha	78.0%
	- Dagana	86.7%
	- Gasa	100.0%
	- Haa	99.8%
	- Lhuntse	99.7%
	- Mongar	86.6%
	- Paro	99.3%
	- Pemagatshel	70.7%
	- Punakha	99.8%
	- Samdrup Jongkhar	53.2%
	- Samtse	64.1%
	- Thimphu	99.6%
	- Trashigang	97.1%
	- Trashiyangste	99.1%
	- Trongsa	99.3%

	-	Tsirang	68.4%
	-	Wangdue Phodrang	98.4%
	-	Zhemgang	72.6%
China	**3 out of 22 Provinces of China:**		
	-	Sichuan	71.1%
	-	Yunnan	81.1%
	-	Qinghai	99.8%
	1 out of 5 Autonomous Regions of China:		
	-	Tibet (Xizang)	100.0%
India	**5 out of 29 States of India:**		
	-	Arunachal Pradesh	74.7%
	-	Himachal Pradesh	80.5%
	-	Jammu and Kashmir	89.1%
	-	Sikkim	94.2%
	-	Uttarakhand	74.9%
Myanmar (Burma)	**0 out of 7 States of Myanmar (Burma):**		-
Nepal	**10 out of 14 Administrative Zones of Nepal**:		
	-	Mechi	66.0%
	-	Kosi	54.3%
	-	Sagarmatha	51.8%
	-	Bagmati	82.2%
	-	Gandaki	73.1%
	-	Dhawalagiri	97.7%
	-	Rapti	67.1%
	-	Karnali	99.8%
	-	Seti	70.3%
	-	Mahakali	63.5%
Pakistan	**4 out of 8 Provinces of Pakistan:**		
	-	Khyver Pakhtunkhwa	58.0%
	-	Federally Administered Tribal Areas	60.9%
	-	Gilgit Baltistan	99.6%
	-	Ashad Kashmir	71.7%

A.1.2 Central Asia

Table 13: Central Asian countries with mountain states and coverage of percentage of mountain covered area of these states

Countries	Mountain “States”	% Mountain Area of the States
Kazakhstan	**0 out of 14 Regions of Kazakhstan:**	-
Kyrgyzstan	**7 out of 8 Regions of Kyrgyzstan:**	
	- Batken	88.3%
	- Chuy	70.4%
	- Jalal-Abad	87.5%
	- Naryn	90.4%
	- Osh	94.0%
	- Talas	89.6%
	- Issyk Kul	76.3%
Tajikistan	**3 out of 5 Regions of Tajikistan:**	
	- Sughd	69.2%
	- Tadzhikistan Territories	91.5%
	- Gorno-Badakhshan	99.9%
Turkmenistan	**0 out of 5 Regions of Turkmenistan:**	-
Uzbekistan	**0 out of 12 Regions of Uzbekistan:**	-

A.1.3 Africa

Table 14: African countries with mountain states and coverage of percentage of mountain covered area of these states

Countries	Mountain "States"	% Mountain Area of the "State"
Demo. Rep. of the Congo	**0 out of 11 Provinces of Demo. Rep. of the Congo:**	-
Malawi	**9 out of 28 Districts of Malawi:**	
	- Chitipa	87.0%
	- Mzimba	87.9%
	- Rumphi	55.7%
	- Dedza	63.7%
	- Dowa	83.1%
	- Kasungu	79.2%
	- Lilongwe	92.5%
	- Mchinji	66.4%
	- Ntchisi	76.6%
Madagascar	**3 out of 22 Regions of Madagascar:**	
	- Itasy	78.1%
	- Analamanga	75.5%
	- Amoron'i Mania	62.1%
Tanzania	**15 out of 29 Regions of Tanzania:**	
	- Arusha	65.5%
	- Dodoma	64.0%
	- Geita	88.6%
	- Iringa	51.6%
	- Kagera	62.4%
	- Katavi	61.1%
	- Kigoma	62.6%
	- Manyara	71.4%
	- Mara	52.2%
	- Mbeya	70.1%
	- Njombe	60.2%
	- Shinyanga	63.1%
	- Simiyu	60.5%
	- Singida	75.7%
	- Tabora	55.7%
Uganda	**75 out of 111 Districts of Uganda:**	
	- Jinja	96.2%
	- Kumi	86.6%
	- Iganga	94.2%
	- Kamuli	59.9%
	- Namutumba	84.1%
	- Soroti	62.2%
	- Mukono	78.7%
	- Pallisa	62.4%
	- Sembabule	100.0%
	- Mpigi	80.3%
	- Koboko	68.8%
	- Maracha	94.2%
	- Kampala	100%
	- Kiboga	68.1%
	- Wakiso	68.8%

	- Luweero	64.7%
	- Mubende	96.9%
	- Mityana	99.0%
	- Kitgum	65.3%
	- Gulu	53.0%
	- Lira	80.8%
	- Masindi	53.9%
	- Kabarole	72.5%
	- Kyenjojo	98.5%
	- Kibale	93.2%
	- Kapchorwa	99.6%
	- Bukwa	93.9%
	- Sironko	99.3%
	- Mbale	95.5%
	- Manafwa	99.3%
	- Bugiri	81.6%
	- Busia	97.6%
	- Butaleja	56.6%
	- Tororo	83.8%
	- Kotido	78.6%
	- Amuria	53.7%
	- Kaabong	83.5%
	- Abim	92.4%
	- Moroto	97.9%
	- Nakapiripirit	61.6%
	- Rakai	70.4%
	- Kasese	55.1%
	- Kamwenge	85.0%
	- Ibanda	99.2%
	- Isingiro	94.9%
	- Mbarara	99.7%
	- Ntungamo	84.2%
	- Rukungiri	59.5%
	- Kabale	78.9%
	- Kisoro	72.8%
	- Kanungu	78.6%
	- Zombo	52.6%
	- Bukedea	70.1%
	- Luuka	94.1%
	- Budaka	93.6%
	- Kibuku	50.3%
	- Buikwe	64.6%
	- Butambala	98.2%
	- Gomba	99.8%
	- Kyankwanzi	52.8%
	- Alebtong	87.9%
	- Agago	80.4%
	- Kiryandongo	52.4%
	- Kyegegwa	100%
	- Kween	91.2%
	- Bulambuli	59.8%
	- Napak	53.9%
	- Amudat	99.8%
	- Lwengo	100.0%
	- Lyantonde	100.0%
	- Bukomansimbi	100.0%

	- Kalungu	91.2%
	- Sheema	61.8%
	- Buhweju	85.8%
	- Bududa	98.5%
Zambia	**7 out of 10 Provinces of Zambia:**	
	- Central	58.5%
	- Copperbelt	89.7%
	- Luapula	66.5%
	- Muchinga	53.0%
	- Northern	65.0%
	- North-Western	71.6%
	- Southern	50.1%
Algeria	**1 out of 49 Provinces of Algeria:**	
	- Naâma	52.2%
Cameroon	**2 out of 10 Provinces of Cameroon:**	
	- Nort-west	56.4%
	- West	50.4%
Ethiopia	**5 out of 9 States of Ethiopia:**	
	- Amhara	72.6%
	- Harari	90.4%
	- Oromia	69.2%
	- Southern Nations	55.8%
	- Tigray	65.7%
	1 out of 2 City Administrations of Ethiopia:	
	- Dire Dawa	92.6%
Ghana	**0 out of 10 Regions of Ghana:**	-
Guinea	**0 out of 8 Regions of Guinea:**	-
Kenya	**3 out of 8 Provinces of Kenya:**	
	- Central	62.8%
	- Nyanza	69.5%
	- Western	68.1%
Lesotho	**10 out of 10 Districts of Lesotho:**	
	- Berea	63.9%
	- Butha-Buthe	88.1%
	- Leribe	71.1%
	- Mafeteng	57.7%
	- Maseru	75.5%
	- Mohale's Hoek	82.9%
	- Mokhotlong	96.9%
	- Qacha's Nek	90.8%
	- Quthing	90.3%
	- Thaba-Tseka	95.5%
Morocco	**4 out of 16 Regions in Morocco:**	
	- Souss-Massa-Drâa	51.3%
	- Oriental	53.7%
	- Tadla-Azilal	54.4%
	- Fès-Boulemane	54.2%
Nigeria	**0 out of 36 States of Nigeria:**	-
Swaziland	**0 out of 4 Regions of Swaziland:**	-
Burundi	**12 out of 17 Provinces in Burundi:**	
	- Bubanza	55.6%
	- Bujumbura Rural	59.6%
	- Cankuzo	71.9%
	- Cibitoke	73.4%
	- Karuzi	51.1%

	- Kirundo	88.0%
	- Makamba	55.9%
	- Muramvya	63.7%
	- Muyinga	74.2%
	- Ngozi	65.0%
	- Rutana	87.3%
	- Ruyigi	77.8%
Rwanda	**5 out of 5 Provinces of Rwanda:**	
	- Kigali	91.5%
	- Southern	62.8%
	- Western	79.8%
	- Northern	81.5%
	- Eastern	90.0%

A.1.4 Andes

Table 15: Andean countries with mountain states and coverage of percentage of mountain covered area of these states

Countries	Mountain "States"	% Mountain Area of the States
Colombia	**11 out of 32 Departments of Colombia:**	
	- Bogota, Capital District	100.0%
	- Boyaca	83.0%
	- Caldas	68.1%
	- Cauca	61.4%
	- Cundinamarca	71.0%
	- Huila	70.7%
	- Norte de Santander	52.2%
	- Quindio	96.8%
	- Riseralda	87.3%
	- Tolima	57.5%
	- Calle del Cauca	57.2%
Ecuador	**13 out of 24 Provinces of Ecuador:**	
	- Azuay	88.9%
	- Bolivar	72.9%
	- Canar	79.4%
	- Carchi	88.7%
	- Chimborazo	98.6%
	- Cotopaxi	85.3%
	- Imbabura	92.5%
	- Loja	70.6%
	- Morona Santiago	53.5%
	- Napo	99.4%
	- Pichincha	79.8%
	- Tungurahua	71.0%
	- Zamora-Chinchipe	89.7%
Peru	**16 out of 25 Departments of Peru:**	
	- Amazonas	51.3%
	- Ancash	78.9%
	- Apurimac	99.9%
	- Arequipa	82.8%
	- Ayacucho	97.7%
	- Cajamarca	88.0%
	- Callao	89.7%
	- Cusco	80.4%
	- Huancavelica	99.9%
	- Huanuco	67.0%
	- Junin	79.4%
	- La Libertad	67.0%
	- Lima	77.1%
	- Moquegua	89.4%
	- Pasco	63.5%
	- Tacna	65.6%
Bolivia	**5 out of 9 Departments of Bolivia:**	
	- La Paz	61.2%
	- Oruro	100.0%
	- Cochabamba	67.7%
	- Potosi	99.9%

	- Chuquisaca	79.2%
Argentina	**3 out of 27 Provinces of Argentina:**	
	- Jujuy	86.0%
	- Catamarca	73.6%
	- San Juan	64.7%
Chile	**5 out of 15 Regions of Chile:**	
	- Tarapaca	74.0%
	- Antofagasta	75.1%
	- Atacama	70.7%
	- Coquimbo	57.1%
	- Arica y Parinacote	85.0%
Venezuela	**1 out of 23 States of Venezuela:**	
	- Mérida	71.1%
	1 out of 1 District of Venezuela:	
	- Capital District	68.0%

A.1.5 Alps

Table 16: Alpine countries with mountain states and coverage of percentage of mountain covered area of these states

Countries	Mountain “States”	% Mountain Area of the States
Austria	**4 out of 9 States of Austria:**	
	- Tyrol	85.2%
	- Carinthia	55.2%
	- Salzburg	71.2%
	- Vorarlberg	63.2%
France	**5 out of 95 Departments of France:**	
	- Alpes-de-Haute-Provence	52.1%
	- Hautes-Alpes	78.0%
	- Alpes-Maritimes	53.2%
	- Lozère	57.0%
	- Savoie	70.1%
Germany	**0 out of 16 States of Germany:**	-
Italy	**7 out of 110 Province of Italy:**	
	- Aostatal	91.7%
	- Belluno	67.8%
	- Bozen (Südtirol)	85.3%
	- L'Aquila	57.8%
	- Sondrio	83.2%
	- Trient	70.1%
	- Verbano-Cusio-Ossola	64.5%
Slovenia	**9 out of 212 Municipalities of Slovenia:**	
	- Bohinj	70.7%
	- Bovec	63.3%
	- Jezersko	78.2%
	- Kranjska Gora	72.6%
	- Luce	51.2%
	- Solcava	77.1%
	- Trzic	56.6%
	- Crna na Koroskem Crnomelj	55.7%
	- Zirovnica	53.7%
Switzerland	**9 out of 26 Cantons of Switzerland:**	
	- Uri	88.0%
	- Schwyz	52.2%
	- Obwalden	69.5%
	- Nidwalden	50.1%
	- Glarus	78.9%
	- Appenzell Innerrhoden	54.7%
	- Graubünden	92.8%
	- Ticino	67.5%
	- Valais	89.4%

A.2 Disaster Database Quality Assessment

Table 17: Disaster database quality assessment for the global EM-DAT database

		EM-DAT
Methodology	Concept and definitions:	Use of standard definitions
	Entry criteria:	Yes (10 killed and/or 100 affected and/or state of emergency or call for international assistance)
	Disaster classification:	Hierarchical: classification from broad categories to tailored disaster types
	Data collection:	Standardized collection form
	Data entry:	Standardized entry form
	Data analysis:	Interactive graphs and maps available online
	Disaster identification number:	Yes (unique ID)
	Database system:	SQL database
Accuracy and Reliability	Data sources:	UN, governmental and non-governmental agencies, insurance companies, research institutes and press agencies.
	Database:	Monthly validation process, internal cross error checking
	Training:	Guidelines
Serviceability	Outputs and functions:	Online querying and data extraction with different country profiles, disaster lists, maps and trends figures. Annual statistical review, CRED Crunch, statistical annex of the world disasters report. Charts and tables provided
	Interpretability:	Internally updated on a daily basis, publicly accessible information
	Timeliness/Periodicity:	Updated every three months
	Interoperability:	GLIDE included but no really used
	User documentation:	Guidelines and FAQ available
	Main users:	International and national community, Research centers, Universities and Private sectors
Accessibility	Access to the database:	No cost and restrictions to access data, but limitations to access raw data
	Contact details:	Available (contact@emdat.be)
Credibility	Transparency:	Information available on website
	Expertise:	25 years experience in data collection and database management
	Quality management:	Yearly quality data control
	Impartiality:	Yes
Prerequisites and Sustainability	Institutional framework:	EM-DAT is developed and maintained by Centre for Research on the Epidemiology of Disasters (CRED), Louvain Brussels, Belgium
	Resources:	University, USAID/OFDA and others
	Collaboration network:	IFRC (International Federation of Red Cross and Red Crescent Societies), UNISDR (Secretariat for the International Strategy for Disaster Reduction), USAID (U.S. Agency for International Development), ADRC (Asian Disaster Reduction Center), UNDP (United Nations Development Program), UNDP/GRIP (Global Risk Identification Program), OCHA (Office for the Coordination of Humanitarian Affairs), PreventionWeb, ProVention (Provention Consortium) and the World Bank
	Continuity:	Long experience in data collection and management

Table 18: Disaster database quality assessment for the regional DesInventar database(Source: Below et al. 2010)

	DesInventar, e.g. Nepal	
Methodology	Concept and definitions:	Use of standard definitions
	Entry criteria:	None
	Disaster classification:	Hierarchical: classification from broad categories to tailored disaster types
	Data collection:	Standardized collection form
	Data entry:	Standardized entry form
	Data analysis:	Through DesConsultar software and separate analysis in Excel
	Disaster identification number:	Yes (unique serial number)
	Database system:	SQL database
Accuracy and Reliability	Data sources:	National newspapers, government, priority given to the media, no source checking
	Database:	Standard compilation procedure, no standard validation procedures but random checking
	Training:	Initial training, lack of follow-up
Serviceability	Outputs and functions:	Online querying and data extraction, analytical reports
	Interpretability:	No supporting documents
	Timeliness/periodicity:	Yearly basis
	Interoperability:	No use of GLIDE, common format of the database shared with all DesInventar databases
	User documentation:	Guidelines available
	Main users:	Government, NGO's
Accessibility	Access to the database:	No cost and restrictions to access to data (accessible from 1971 – 2011)
	Contact details:	Available (www.desinventar.net)
Credibility	Transparency:	Information available on website
	Expertise:	Database-related conferences and papers
	Quality management:	Management supportive of quality improvement
	Impartiality:	Database not used for resource allocations
Prerequisites and Sustainability	Institutional framework:	Basic functions of database maintained independently
	Resources:	Lacking (except data entry)
	Collaboration network:	None
	Continuity:	Long-term objective of institutionalizing disaster inventory at local and national level

Table 19: Disaster database quality assessment for the global NatCatSERVICE database

	NatCatSERVICE	
Methodology	Concept and definitions:	Use of standard definitions
	Entry criteria:	Yes (Any property damage and/or person dead)
	Disaster classification:	Hierarchical: classification from broad categories to tailored disaster types
	Data collection:	Standardized collection form
	Data entry:	Standardized entry form
	Data analysis:	Annual statistics from 2004 onwards, informative maps and different analysis through their website, analyses from 1980 up to now, historical data sets (from 0079)
	Disaster identification number:	Yes (unique ID)
	Database system:	Oracle Database and SQL Server
Accuracy and Reliability	Data sources:	National insurance companies, international agencies (e.g. UN, EU, Red Cross), NGOs, scientific sources and weather and warning services, international and national daily press (faktiva, Reuters, AP)
	Database:	Systematic evaluation of daily press reports, from local to international levels
	Training:	Guidelines (database methodology)
Serviceability	Outputs and functions:	Annual statistics, significant natural disasters, focus analyses, catastrophe portraits, disaster-related brochures
	Interpretability:	Event listings, tables, maps and statistics provided
	Timeliness/periodicity:	Twice per year
	Interoperability:	No use of GLIDE
	User documentation:	Database methodology
	Main users:	Insurance industry and clients, scientific institutes, researchers, political committees, general public, media
Accessibility	Access to the database:	Partially accessible to the public, more is available to clients
	Contact details:	Available (www.munichre.com)
Credibility	Transparency:	Information available on website
	Expertise:	35 years experience in data collection and database management (complete global data record since 1980)
	Quality management:	Continuous data quality assessment
	Impartiality:	Objective, part of the finance industry
Prerequisites and Sustainability	Institutional framework:	NatCatSERVICE is developed and maintained by Munich RE
	Resources:	60 offices worldwide, clients in over 150 countries, national and international insurance associations
	Collaboration network:	NGOs (ECLAC, International Federation of Red Cross and Red Crescent, OCHA/DHA, United Nations, USAID/OFDA), weather services, global databases on natural disaster (EM-DAT, Swiss Re)
	Continuity:	Long experience in data collection and management, from 1980 until today for all natural loss events

Table 20: Disaster database quality assessment for the global Dartmouth database

		Dartmouth
Methodology	Concept and definitions:	Use of standard definitions
	Entry criteria:	None
	Disaster classification:	Only Floods
	Data collection:	Standardized collection form
	Data entry:	Standardized entry form
	Data analysis:	Global and regional analysis, global archive map of extreme flood events thru their website
	Disaster identification number:	Yes (unique archive number)
	Database system:	SQL?
Accuracy and Reliability	Data sources:	News, governmental, instrumental and remote sensing (NOAA AVHRR, Canadian/American Radarsat SAR, European Space Agency ERS SAR)
	Database:	-
	Training:	Archive Notes with additional information concerning created maps and tables
Serviceability	Outputs and functions:	Different publications thru their website
	Interpretability:	Charts and maps provided with explanatory notes
	Timeliness/periodicity:	Daily update
	Interoperability:	-
	User documentation:	Archive notes with additional information concerning created maps and tables, FAQ available
	Main users:	Research, educational, national and regional water ministry personnel (e.g. Global Risk Information Platform, PreventionWeb, Humanitarian Early Warning Service)
Accessibility	Access to the database:	No cost and restrictions to access to data (accessible from 1985 – 2015)
	Contact details:	Available (www.dartmouth.edu)
Credibility	Transparency:	Information available on website
	Expertise:	Data collection and database management since 1985
	Quality management:	-
	Impartiality:	-
Prerequisites and Sustainability	Institutional framework:	-
	Resources:	-
	Collaboration network:	Water organizations (e.g. U.S. Geological Survey), Global Flood Partnership (GFP)
	Continuity:	Long experience in flood data collection and management, from 1985 until today with a good data reliability after 1995

A.3 Comparative Analysis of the Completeness of Contents of the four Databases

Table 21: Comparative analysis of the completeness of contents by databases, indicators and regions

Database	Region/Country	Selected indicators	No. records	%
EM-DAT Mountain and non-mountain regions (1985-2014)	**HKH**	**Total no. records**	**1,195**	**100.00%**
		Geographical location	1,115	93.31%
		Economic Loss[1]	518	43.35%
		Date (start and end)	1000	83.68%
		Zero values	23	1.92%
	Central Asia	**Total no. records**	**60**	**100.00%**
		Geographical information	54	90.00%
		Economic Loss[1]	23	38.33%
		Date (start and end)	51	85.00%
		Zero values	1	1.67%
	Africa	**Total no. records**	**459**	**100.00%**
		Geographical location	413	89.98%
		Economic Loss[1]	57	12.42%
		Date (start and end)	329	71.68%
		Zero values	9	1.87%
	Andes	**Total no. records**	**414**	**100.00%**
		Geographical location	360	86.96%
		Economic Loss[1]	106	25.60%
		Date (start and end):	305	73.67%
		Zero values	15	3.42%
	Alps	**Total no. records**	**257**	**100.00%**
		Geographical location	169	65.76%
		Economic Loss[1]	184	71.60%
		Date (start and end)	220	85.60%
		Zero values	24	9.34%
DesInventar (Andean countries, mountain states) (1985-2011)	**Colombia**	**Total no. records**	**2,851**	**100.00%**
		Geographical location	2,851	100.00%
		Economic loss[2]	245	8.59%
		Infrastructural loss[3]	365	12.80%
		Duration (in days)	38	1.33%
		Zero values	0	0.00%
	Ecuador	**Total no. records**	**143**	**100.00%**
		Geographical location	143	100.00%
		Economic loss[2]	5	3.50%
		Infrastructural loss[3]	21	14.69%
		Duration (in days)	11	7.69%
		Zero values	0	0.00%
	Peru	**Total no. records**	**585**	**100.00%**

		Geographical location	585	100.00%
		Economic loss[2]	157	26.84%
		Infrastructural loss[3]	208	35.56%
		Duration (in days)	278	47.52%
		Zero values	0	0.00%
	Bolivia	**Total no. records**	**514**	**100.00%**
		Geographical location	514	100.00%
		Economic loss[2]	11	2.14%
		Infrastructural loss[3]	238	46.30%
		Duration (in days)	211	41.05%
		Zero values	0	0.00%
	Argentina	**Total no. records**	**16**	**100.00%**
		Geographical location	16	100.00%
		Economic loss[2]	0	0.00%
		Infrastructural loss[3]	1	6.25%
		Duration (in days)	12	75.00%
		Zero values	0	0.00%
	Chile	**Total no. records**	**85**	**100.00%**
		Geographical location	85	100.00%
		Economic loss$_2$	6	7.06%
		Infrastructural loss[3]	1	3.53%
		Duration (in days)	12	16.47%
		Zero values	0	0.00%
	Venezuela	**Total no. records**	**113**	**100.00%**
		Geographical location	113	100.00%
		Economic loss[2]	5	4.42%
		Infrastructural loss[3]	2	1.77%
		Duration (in days)	18	15.93%
		Zero values	0	0.00%
Dartmouth Mountain regions (1985-2014)	**HKH**	**Total no. records**	**126**	**100.00%**
		Geographical location	126	100.00%
		Economic Loss[4]	39	30.95%
		Date (start and end)	126	100.00%
		Zero values	3	2.38%
	Central Asia	**Total no. records**	**17**	**100.00%**
		Geographical information	17	100.00%
		Economic Loss[4]	8	47.06%
		Date (start and end)	17	100.00%
		Zero values	1	5.88%
	Africa	**Total no. records**	**94**	**100.00%**
		Geographical location	94	100.00%
		Economic Loss[4]	19	20.21%
		Date (start and end)	94	100.00%
		Zero values	1	6.56%
	Andes	**Total no. records**	**61**	**100.00%**

		Geographical location	61	100.00%
		Economic Loss[4]	7	11.48%
		Date (start and end):	61	100.00%
		Zero values	4	1.99%
	Alps	**Total no. records**	**9**	**100.00%**
		Geographical location	9	100.00%
		Economic Loss[4]	1	11.11%
		Date (start and end)	9	100.00%
		Zero values	0	
				0.00%
NatCatSERVICE Mountain regions (Avalanches and Landslides) (1980-2014)	**HKH**	**Total no. records**	**119**	**100.00%**
		Geographical location	119	100.00%
		Economic Loss[5]	119	100.00%
		Date (start and end)	119	100.00%
		Zero values	0	0.00%
	Central Asia	**Total no. records**	**33**	**100.00%**
		Geographical location	33	100.00%
		Economic Loss[5]	33	100.00%
		Date (start and end)	33	100.00%
		Zero values	0	0.00%
	Africa	**Total no. records**	**14**	**100.00%**
		Geographical location	14	100.00%
		Economic Loss[5]	14	100.00%
		Date (start and end)	14	100.00%
		Zero values	0	0.00%
	Andes	**Total no. records**	**95**	**100.00%**
		Geographical location	95	100.00
		Economic Loss[5]	95	100.00%
		Date (start and end)	95	100.00%
		Zero values	0	0.00%
	Alps	**Total no. records**	**160**	**100.00%**
		Geographical location	160	100.00%
		Economic Loss[5]	160	100.00%
		Date (start and end)	160	100.00%
		Zero values	0	0.00%

[1] Total damage ('000 USD)/reconstruction damage ('000 USD)/total insured damage ('000 USD)

[2] Losses USD/ Losses local currency

[3] Infrastructural loss (damage in crops (Ha)/damages in roads (meters))

[4] Damage (USD)

[5] Direct overall loss (in million)

A.4 Disaster Database comparative Overview

Table 22: Comparative overview of the four used disaster databases

Name of database	**EM-DAT**	**DesInventar**	**NatCatSERVICE**	**Dartmouth**
Owner	CRED	LA RED	MunichRe	University of Colorado
Number of entries	19000	Depends on the country	30000	-
Period covered	1900 - present	Depends on the country	1980 (even from 79AD) onwards	1985 – present
Spatial range	Global	Local (South America, Africa, Asia)	Global	Global
Spatial unit	National level	National, sub national, local level	National level	National level
Disaster Type	Natural and technological disasters	Natural and technological disasters	Natural hazards	Floods
Geo-referenced	No	Yes, but not for all entries	Yes	Yes
Loss indicators	Human loss, Economic loss	Human loss, Physical damage, Economic loss	Human loss, Physical damage, Economic loss	Human loss, Physical damage, Economic loss
Loss indicators related to people	Killed, injured, homeless, affected, total affected	Deaths, missing, injured, affected, victims, evacuated, relocated	Death toll, injured, missing, evacuated, displaced, affected, diseases	Dead, displaced
Main sources	UN agencies, US Government agencies, official governmental sources, IFRS, research centers, Lloyd's, reinsurance sources, press, private	Government agencies, NGOs and research institutes	MunichRe branch offices, insurance associations, insurance press, scientific sources, weather services, governmental and non-governmental organizations	News, governmental, instrumental and remote sensing sources
Priority source	UN agencies	News media	Munich RE branch offices, insurance associations	News
Entry criteria	10 or more people killed, or 100 or more people affected, or declaration of a state of emergency or call for international assistance	No minimum threshold - any event that may have had any effect on life, properties or infrastructures	Entry if any property damage and/or any person sincerely affected (injured, dead), before 1970 only major events	Large floods with damage to structures/agriculture, and/or fatalities
Search engine	Country, disaster group, disaster type, time period	Geographic unit, GLIDE number, disaster type, cause, time range, variable range		Country, time period
Access	Public, on-line (raw data request)	Public, on-line	Limited access	Public, on-line
Web address	www.emdat.be	www.desinventar.net	www.munichre.com/geo	www.dartmouth.edu/floods

A.5 Disaster Database Entry Fields

Table 23: Comparative overview of the four used disaster databases and their entries related to human- and economic losses

	EM-DAT (UNEP)	**DesInventar (LA RED)**	**NatCatSERVICE (MunichRe)**	**Dartmouth**
Related to location and event	Disaster number (DISNO): Unique disaster number for each disaster event (8 digits: 4 digits for the year and 4 digits for the disaster number). E.g. 19950324	Serial number	MR-number Unique number for each loss event giving the year, month, disaster group, and a 3 digit cat-number. E.g. MR200901A005	Register number (DFO)
	Country	Data Cards	Geographical information	GLIDE Number
	Disaster group	Event	Generic group	Country
	Disaster sub-group	Code Region	Disaster group	Nations
	Disaster main type	Region	Disaster main type and sub-type	Detailed locations
	Disaster sub-type	Code Provincia	Date (start and end)	Date (start and end)
	Date (start and end)	Provincia	Description of the event (severity)	Duration (d)
		Code Comuna		Main cause
		Comuna		Severity
		Location		Affected sq km
		Date (YMD)		Magnitude
		Comments		Centroid X, Centroid Y
		Cause		Comments
		Description of Cause		
		Source		
		Magnitude		
		GLIDE Number		
		Duration (d)		
		Fichas.latitude		
		Fichas.longitude		
Related to people (number of persons)	Killed	Deaths	Killed	Dead
	Injured	Missing	Missing	Displaced
	Homeless	Insured, sick	Injured	
	Affected	Affected	Homeless	
	Total affected	Victims	Evacuated	
		Evacuated		
		Relocated		
Related to housing (usually quantitative)		Houses damaged	Housing damaged	
		Houses destroyed	Housing damaged/destroyed	
		Crops and woods (Hectares)	Boats	
		Livestock	Cars	
		Educational centers	Health centers	

		Hospitals	Public buildings	
		Roads affected (Mts.)		
		Other losses		
Economic loss	Total estimated damage ('000 USD): a value of all damages and economic losses directly or indirectly related to the disaster.	Loss value local	Overall loss in million USD/EUR: direct, tangible monetary impact of a disaster.	Damage USD
	Reconstruction damage ('000 USD): are the costs for the replacement of lost assets. They must take into account present construction or purchase costs of goods, as well as the additional cost of prevention and mitigations measures to reduce damage from future disasters.	Loss value USD	Insured loss in million USD/EUR: monetary loss paid out by the worldwide insurance industry.	
	Insured damage ('000 USD): Economic damages which are covered by the insurance industry.		MunichRe share USD/EUR	
Related to infrastructure and other sectors (qualitative)		Transport sector	Roads/railways/bridges	
		Communications	Water supply	
		Aid organizations installations	Electricity/Communication	
		Agriculture and fishing	Infrastructure damage	
		Water supply	Business interruption	
		Sewerage	Industry	
		Education	Construction sites	
		Power/Energy	Agriculture	
		Industry	Fishery/Aquaculture	
		Health Sector	Marine/Offshore	

A.6 Disaster Database Definitions of Loss Indicators

Table 24: Comparative overview of definitions of loss indicators from used disaster databases

EM-DAT[1]	DesInventar[2]	NatCatSERVICE[3]	Dartmouth[4]
Killed Number of people confirmed dead and number missing and presumed dead	**Deaths** The number of person whose deaths were directly caused. When final official data is available, this figure should be included with corresponding observations, for example, when there are differences between officially accepted figures and those of other sources. **Missing** The number of persons whose whereabouts since the disaster is unknown. It includes people who are presumed dead, although there is no physical evidence. The data on number of deaths and number of missing are mutually exclusive and should not be mixed.	**Killed** The number of people confirmed dead. **Missing** The number of people declared missing.	**Dead** News reports are usually specific about this, but occasionally there is only mention of 'hundreds' or 'scores' killed; in this case we estimate as follows: "hundreds"=300; "scores"=30; "more than a hundred =110 (number given plus 10%). If there is information on the number of people 'missing', the DFO does not include them in the total of deaths. We require an exact number for analytical purposes, but caution that our numbers are never more than estimates.
Injured People suffering from physical injuries, trauma or an illness requiring medical treatment as a direct result of a disaster.	**Injured, sick** The number of persons whose health or physical integrity is affected as a direct result of the disaster. This figure does not include victims who die. Those who suffer injuries and or illness, if the event is related to a plague or epidemic, should be included here.	**Injured** The number of people suffering from physical injuries.	No equivalent data
Homeless Number of people whose house is destroyed or heavily damaged and therefore need shelter after an event.	No equivalent data	**Homeless** The number of people needing immediate assistance for shelter.	**Displaced** This number is sometimes the total number of people left homeless after the incident, and sometimes it is the number evacuated during the flood. News reports will often mention a number of people that are 'affected', but we do not use this. If the only information is the number of houses destroyed or damaged, then DFO assumes that 4 people live in each house. If the news report only mentions that "thousands were evacuated", the number is estimated at 3000. If the news reports mention that "more than 10,000" were displaced then
Affected People requiring immediate assistance during a period of emergency, i.e. requiring basic survival needs such as food,	**Evacuated** The number of persons temporarily evacuated from their homes, work places, schools, hospitals, etc. If the information refers to families, calculate the number of people according to available indicators.	**Evacuated** The number of people forced to leave their homes.	

water, shelter, sanitation and immediate medical assistance; this may include displaced or evacuated people.	**Relocated** The number of persons who have been moved permanently from their homes to new sites. If the information refers to families, calculate the number of people according to available indicators. **Victims** The number of persons whose goods and/or individual or collective services have suffered serious damage, directly associated with the event. For example, partial or total destruction of their homes and goods; loss of crops and/or crops stored in warehouses, etc. If the information refers to families, calculate the number of people according to available indicators. **Affected** The number of persons who suffer indirect or secondary effects related to a disaster. This refers to the number of people, distinct from victims, who suffer the impact of secondary effects of disasters for such reasons as deficiencies in public services, commerce, work, or because of isolation. If the information refers to families, calculate the number of people according to available indicators.		the DFO number is 11,000 (number plus 10%). If the only information is the number of families left homeless, then DFO assumes that there are 4 people in each family.
Total affected Sum of injured, homeless, and affected.	No equivalent data	No equivalent data	No equivalent data

(Source: Guha-Sapir et al. 2015; LA RED 2015; Dartmouth Flood Observatory 2007; Wirtz &Below 2009).

A.7 Additional Maps and Charts

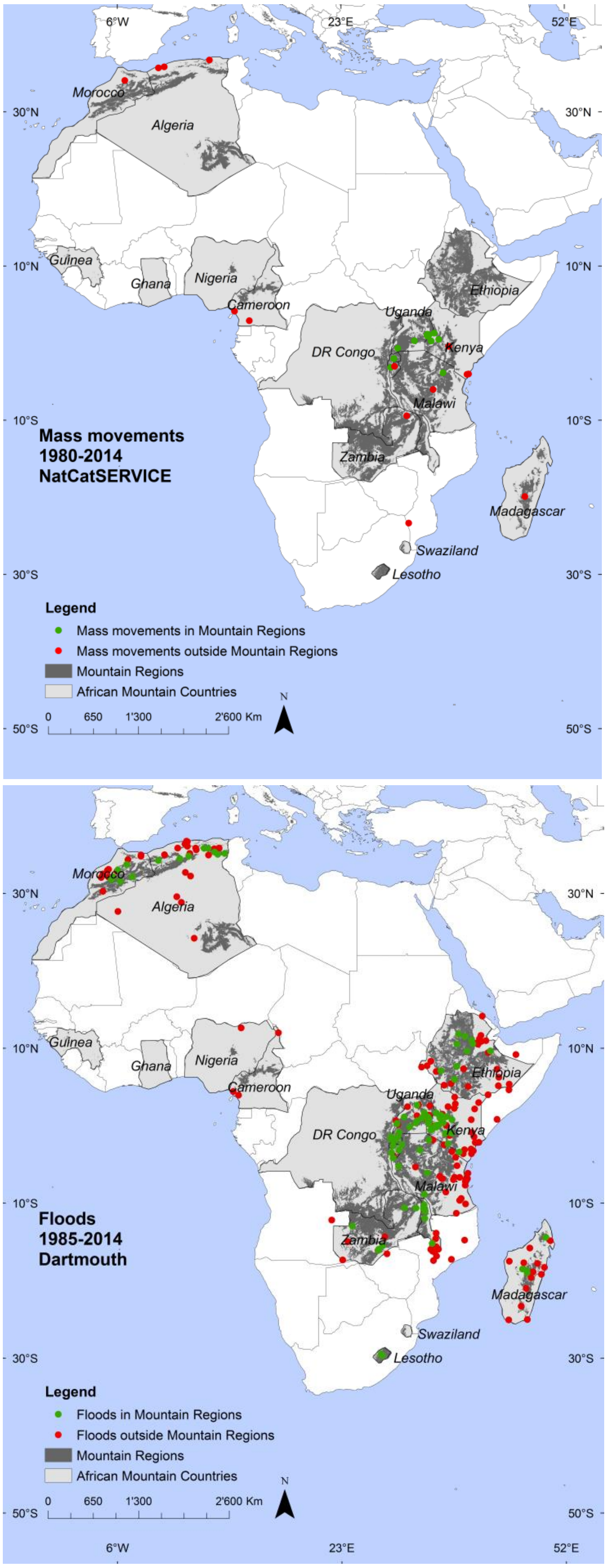

Figure 37: Mass movement and flood disasters in Africa. Above: Number of registered mass movement disasters in the Andes (1980-2014), based on data from the NatCatSERVICE database. Below: Number of registered flood disaster in the Andes (1985-2014), based on data from the Dartmouth database. Green points indicate disasters inside mountain regions and red points are disasters outside mountains regions.

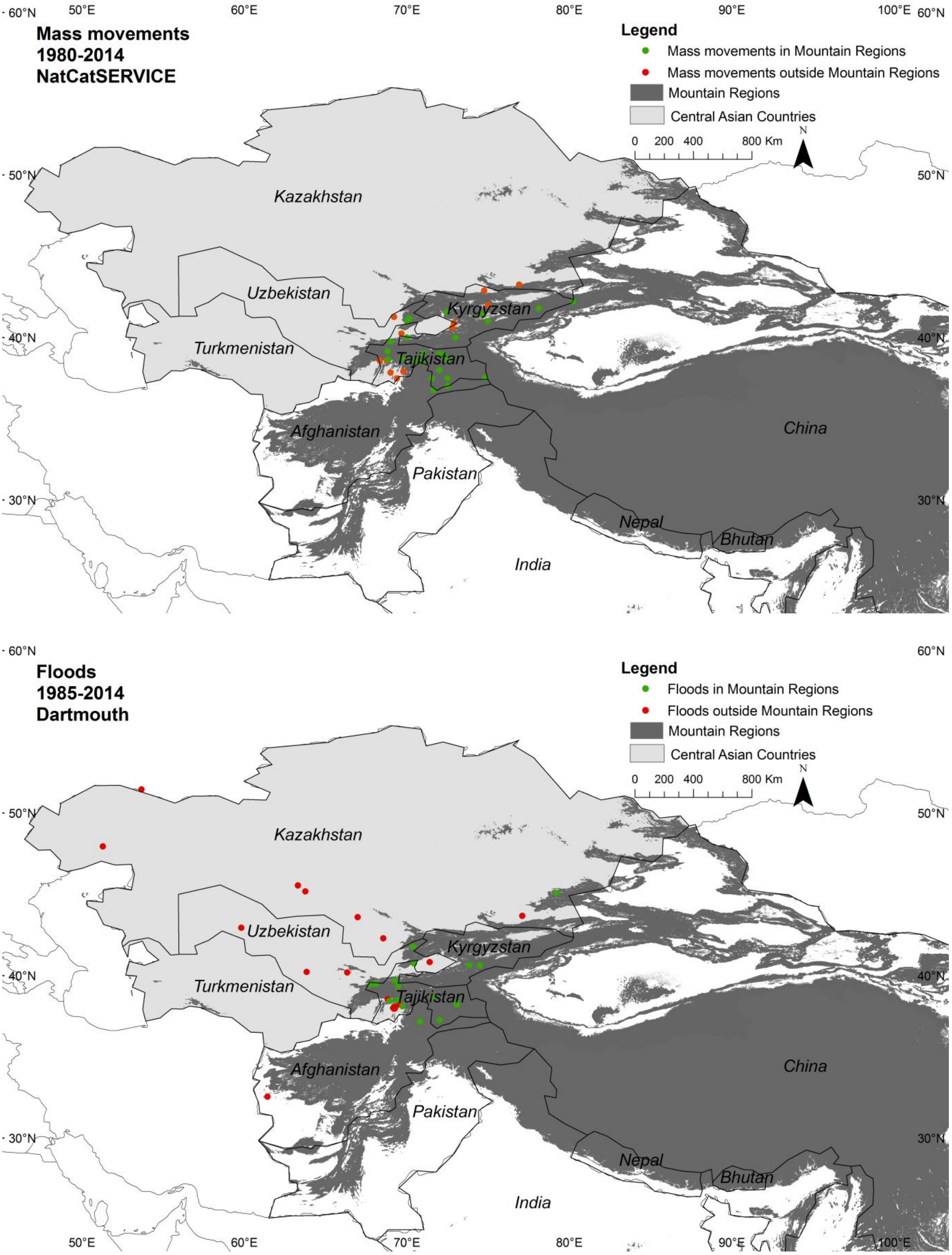

Figure 38: Mass movement and flood disasters in Africa. Above: Number of registered mass movement disasters in the Central Asia (1980-2014), based on data from the NatCatSERVICE database. Below: Number of registered flood disaster in the Andes (1985-2014), based on data from the Dartmouth database. Green points indicate disasters inside mountain regions and red points are disasters outside mountains regions.

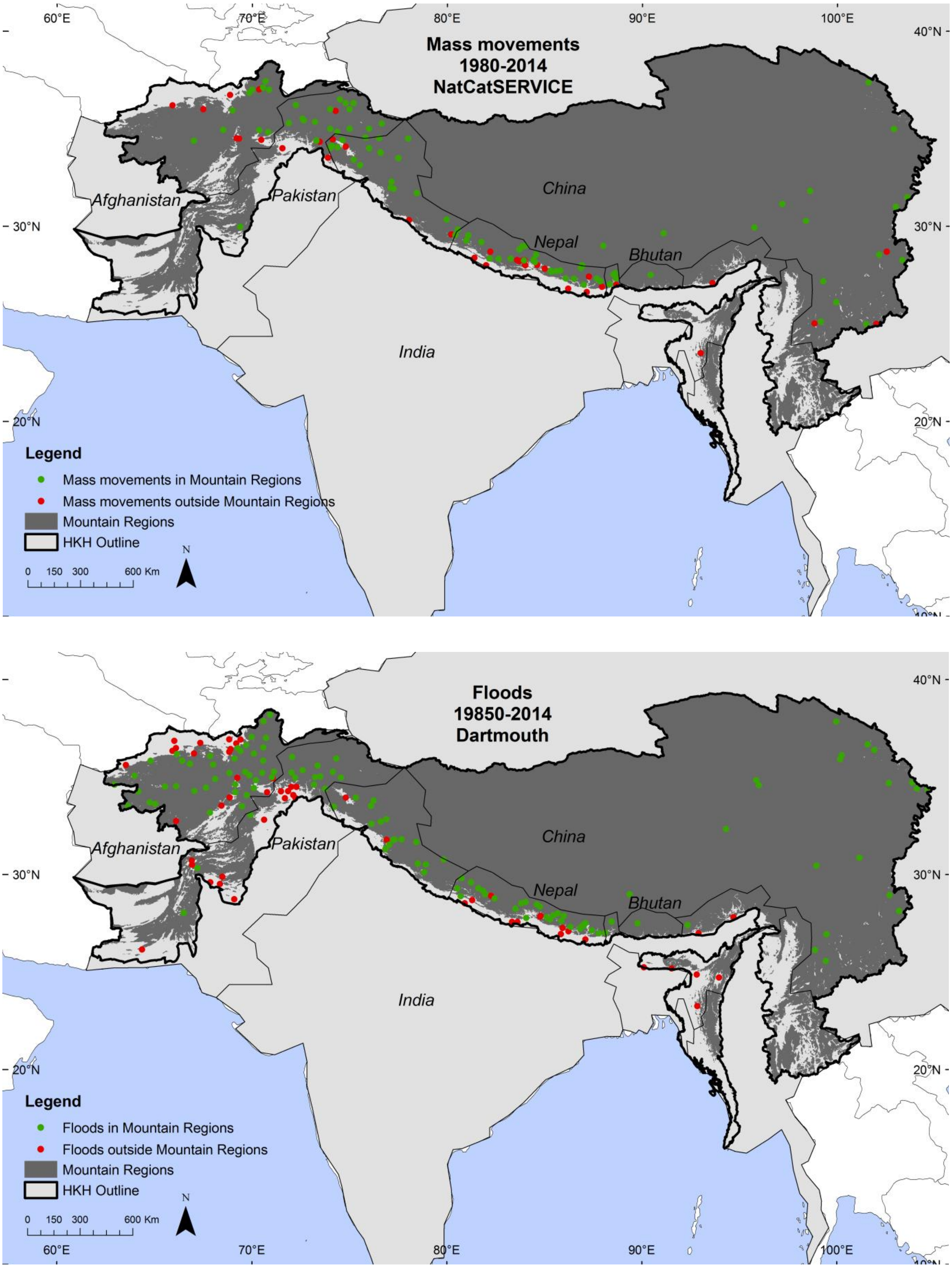

Figure 39: Mass movement and flood disasters in the HKH. Above: Number of registered mass movement disasters in HKH (1980-2014), based on data from the NatCatSERVICE database. Below: Number of registered flood disaster in HKH (1985-2014), based on data from the Dartmouth database. Green points indicate disasters inside mountain regions and red points are disasters outside mountains regions.

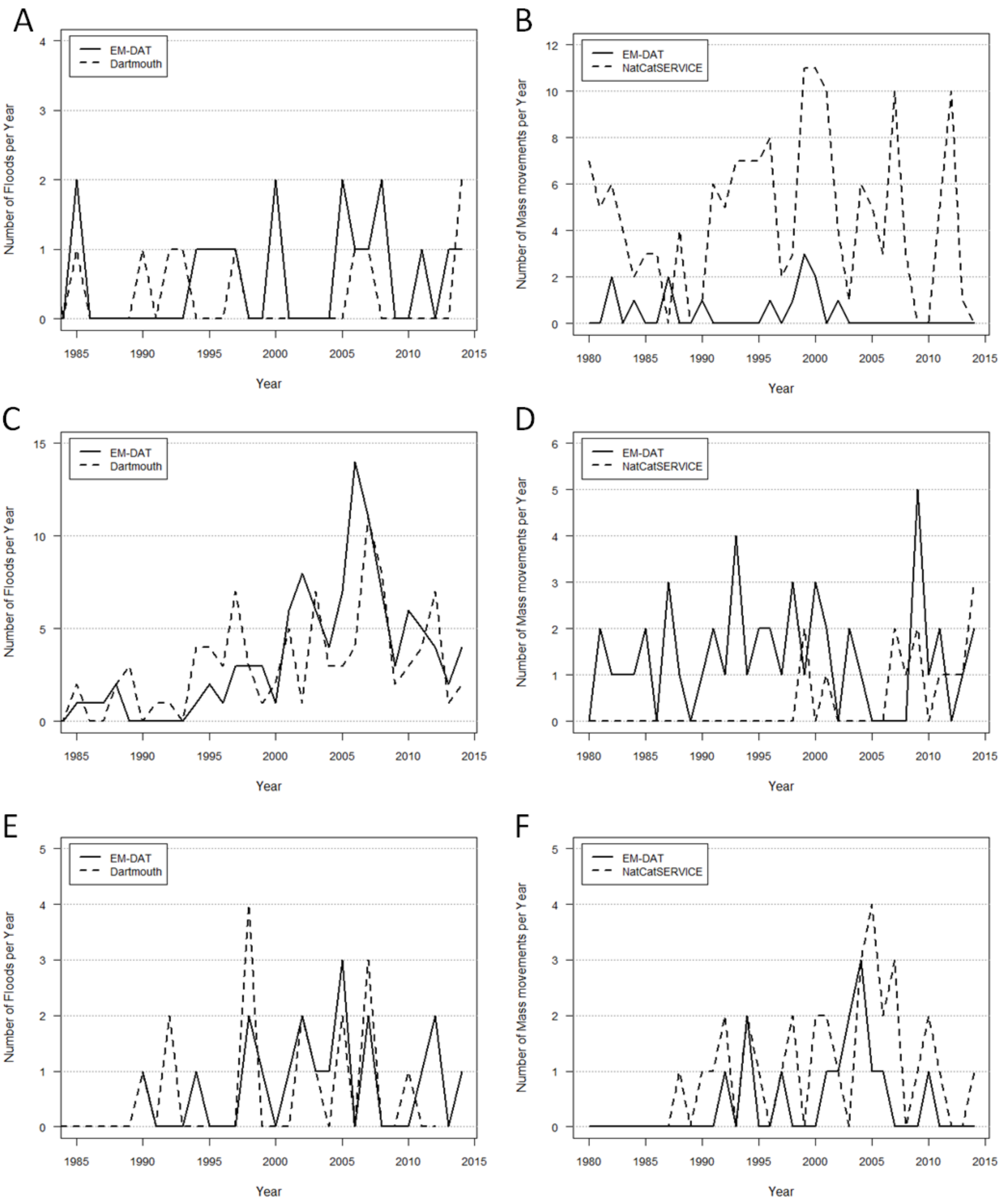

Figure 40: Number of flood and mass movement disasters . (A) Floods and (B) mass movements in the Alps, (C) floods and (D) mass movements in Africa, (E) floods and (F) mass movements in Central Asia. (Source: EM-DAT, Dartmouth and NatCatSERVICE databases).

B. Personal Declaration

I hereby declare that the submitted thesis is the result of my own, independent, work. All external sources are explicitly acknowledged in this thesis.

Bern, January 29, 2016 Anina Stäubli