Analysis of Weather- and Climate-Related Disasters in Mountain Regions Using Different Disaster Databases

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Abstract

Mountains are fragile ecosystems with global importance, providing key ecosystems services within mountainous areas but also for the lowlands. However, mountain regions are prone to natural disasters and exposed to multiple hazards. In this chapter, we present four disaster databases (EM-DAT, NatCatSERVICE, DesInventar, Dartmouth) that store information about spatiotemporal occurrence and impacts of natural disasters in mountain areas. Quality and completeness of the four databases are compared and analyzed regarding reliability for weather- and climate-related natural disasters. The analysis 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 database. Main limitations regarding sustainable mountain development are the inhomogeneity in database definitions, spatial resolutions, database purposes and lack of data registration for human and economic losses. While some individual

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disasters such as the Kedarnath flood in northern India in 2013 have been robustly linked to changes in climate, there is generally insufficient evidence to attribute any overall increasing disaster frequency to climate change. Damage due to hazard in mountain regions will increase irrespective of global warming, in regions where populations are growing and infrastructure is developed at exposed locations.

Keywords
Disaster risk reduction (DRR) · Disaster databases · Weather- and climate-related disasters · Mountain regions · Sustainable mountain development

Introduction

Mountains are fragile ecosystems with global importance as water towers for adjacent, densely populated lowlands. Mountains are sources of forests and timber, minerals, biodiversity hotspots, cultural diversity 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 et al. 2011). Mountains are therefore crucial regions for sustainable development and human well-being regarding food security and poverty mitigation (Singh et al. 2011).

However, mountain regions are prone to natural disasters, and they are exposed to multiple hazards such as avalanches, landslides, floods, debris flows and glacial lake outbursts (Kohler and Maselli 2009). 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. The United Nations International Strategy for Disaster Reduction (UNISDR 2009a) 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. Natural disasters are the consequences of events triggered by natural hazards that overcome local response capacities within a vulnerable and exposed population and seriously affect the social, political and economic development of a region. Natural disasters occur worldwide, and economic losses due to extreme natural hazards have increased substantially in recent decades (Kron 2000; IPCC 2012, 2014). In response to further warming, many climate- and weather-extremes are expected to increase in frequency and severity in the ongoing century (IPCC 2012). Globally, the highest death toll due to natural disasters is concentrated in developing countries (Alcántara-Ayala 2002).

A number of studies (e.g. Kääb et al. 2005; Carrivick and Tweed 2016) indicate a continuous threat from glacial hazards to human lives and infrastructure in high mountain regions.

Depending on their tectonic and geomorphological situation and their climatic conditions, the hazard potential varies greatly from one mountain region to the other, from one valley to the other. Various studies (e.g. IPCC 2012; Kohler et al. 2014) determine that the increases of natural disasters are directly related to human activity. For example, population change, urbanization or environmental degradation are among key drivers for this increasing disaster trend observed in the past (Huppert and Sparks 2006; IPCC 2014). Hence, damage due to hazards in mountain regions will increase irrespective of global warming, especially in regions where population is growing and infrastructure is expanding within exposed locations.

For a systematic registration of these events, various global, regional and local disaster databases record and store information about occurrence and impacts of natural disasters. Comprehensive disaster databases 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 (IFRC 2005; Munich 2012; Fuchs et al. 2013). Disaster databases 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 occurrence and impacts of disasters over time and space and supports preparedness and the mitigation of events. They are a primary tool for the analysis of disaster characteristics and trends and support disaster risk reduction and climate change adaptation (Huggel et al. 2015b). Several loss and damage databases have been developed over the last several decades with data at global, regional, national and sub-national levels (UNDP 2013).

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 maintained by Munich Re, the Centre for Research on the Epidemiology of Disasters (CRED), and Swiss Re defined a common terminology in consultation with the United Nations Development Programme (UNDP), the Asian Disaster Reduction Centre (ADRC) 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).

A number of disaster databases on a global, national and regional scale exist, but there is a research gap regarding their reliability for natural disasters occurring in mountain regions and especially for serving the needs of sustainable mountain development. Little has been known about weather- and climate-related natural disasters in mountain regions in the context of worldwide disaster databases. The present study is aimed at filling this knowledge gap and helps to better understand the importance of disaster occurrence in mountain regions, particularly in regard to ongoing global changes.

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 and main limitations of the various databases for weather- and climate-related natural disasters. 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 five selected mountain regions.

Study Regions

The focus of our study lies within five mountain regions: Hindu Kush-Himalaya, Andes, European Alps, the mountainous parts of Africa, and Central Asia. The selection is based on the research priority of the programme on Sustainable Mountain Development for Global Change (SMD4GC), to which this study is a contribution to. SMD4GC is the mountain programme by the Swiss Agency for Development and Cooperation (SDC), which aims at contributing to sustainable mountain development under uncertain changes in climatic, environmental and socio-economic conditions, focusing on poverty and risk reduction (Wehrli 2014).

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 (Singh et al. 2011). The Himalaya region consists of large thrust sheets formed from the basement of the advancing Indian continent, surmounted by many of the world's tallest peaks such as Mount Everest (8848 m a.s.l.), K2 (8611 m a.s.l.) and Annapurna (8091 m a.s.l.). 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. 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 (Stäubli 2016).

Kulkarni et al. (2013) divided the HKH region into three subregions (western, central and eastern) primarily based on climate and topography; the western subregion has two major rainy seasons, whereas the two other zones only have one. The HKH region covers the largest glaciated areas in the world outside of the Polar Regions. The glaciers 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 mountain area is home to 286 million people (Mountain Partnership 2014) 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. 2012).

Central Asia

The region of Central Asia covers an area of 4 million km^2 and has a population of 59 million (UNISDR 2009b) with an annual population growth of 0.7% in 2014 (mountain population 2012: 4 million; Mountain Partnership 2014). Central Asia includes the five countries Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan and Uzbekistan. 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 (and adjacent countries) are the two major mountain ranges in this region. The highest peak of Tien Shan is Jengish Chokusu (7439 m a.s.l.), Somoni peak (7495 m a.s.l.) the highest in the Pamir Mountains, located in Kyrgyzstan, and Tajikistan, respectively. Kyrgyzstan with 90% mountain-covered area, Tajikistan with 93%, contain the greatest mountain areas and are important as water source regions for the two main river systems Syr Darya in the Tien Shan mountains and Amu Darya in the Pamir (Stäubli 2016).

Most parts of Central Asia have a semi-arid or arid climate, but the western parts are more humid. Glaciers cover in total an area of about 12,000–14,000 km^2 in Central Asia; in Kyrgyzstan glaciers extend over 4% and in Tajikistan over 6% of the territory (Batjargal et al. 2012). 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).

African Mountains

Mountains in Africa generally occur widely scattered between the plateaus and plains that dominate the landscape. Approximately half of the African countries encompass mountains higher than 2000 m. The mountainous parts higher than 4500 m are concentrated in the north-western, central and eastern regions of the continent. These mountainous regions cover about 3 million km^2. The highest peak in the Atlas Mountains is Mount Toubkal at 4165 m a.s.l. The Ethiopian Highlands in north-eastern Africa include 90% of Ethiopia's 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 (5895 m a.s.l.) and Mount Meru (4565 m a.s.l.) in Tanzania, Mount Kenya (5199 m a.s.l.) in Kenya, Mount Elgon (4321 m a.s.l.) on the border of Kenya and Uganda and the Rwenzori Mountains with Mount Stanley (5109 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 (3482 m a.s.l.) (UNEP 2008).

The African mountain areas are home to 146 million people (Mountain Partnership 2014). The average population density in mountain areas is more than triple compared to the lowland areas with up to 40% of the population under the poverty line (UNEP 2015). Glacier distribution in Africa is limited to three specific geographic locations—the two volcanoes Mount Kenya and Kilimanjaro and the Rwenzori mountain range located in East Africa near the equator (UNEP 2013).

Andes

The Andes are the longest mountain range in the world with a length of about 8000 km, stretching along the entire South American continent. The Andes consist of a single mountain chain in Chile (Argentina) which widens in Peru and Bolivia to split into the eastern and western Cordilleras, separated by the high plateau of the Altiplano. Aconcagua (6968 m a.s.l.) is the highest peak of the Andes located in Argentina. The Andes cover an area of more than 2.5 million km^2 and are home to 73 million people (Mountain Partnership 2014) with a maximum of 50% of total population under poverty line in Peru (Stäubli 2016).

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 a dry season from May to September (subtropical influence) and a wet season from October to March. The tropical Andes had an estimated glacier area of about 1920 km^2 in the early 2000s, which corresponds to about 99% of all tropical glaciers in the world (Rabatel et al. 2013).

European Alps

The European Alps are a folded mountain range stretching along an arc of about 1200 km, from Nice to Vienna. They cover an area of about 191,000 km^2. 23 million people live in the European Alps (Mountain Partnership 2014), concentrated in towns and cities around the periphery and in low-lying valleys. Generally, migration is more important than natural population change, whereas population in the central and northern Alps is growing with a decrease of the eastern and southern Alps. Mont Blanc is the highest massif in the European Alps with an elevation of 4808 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 (Stäubli 2016). The Alpine glacier cover decreased from 4470 km^2 in 1850–2270 km^2 in 2000, which corresponds to an overall glacier area loss of almost 50% (Zemp et al. 2008).

Disaster Data and Methods

Disaster Databases Used in the Study

A number of disaster loss databases at global, regional, national and sub-national levels have been developed in the last several decades (UNDP 2013). 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 online global disaster identifier database (GLIDE database)], two regional, 50 national, four sub-national and one event-based (Hurricane Mitch) database.

The current study refers to four disaster databases, three with a global coverage (EM-DAT, NatCatSERVICE as listed above, plus 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 online 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 are primarily on the humanitarian aspects, whereas the reinsurance database NatCatSERVICE focuses more on the material losses (Kron et al. 2012). Table 1 gives an overview of the four databases used in this study and analyzes disaster databases and their different entries.

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. The main objectives of this 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 entry criteria is fulfilled (see Table 1; Below et al. 2009). 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" (Guha-Sapir et al. 2004).

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 (Red de Estudios Sociales en Prevención de Desastres en América Latina) 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. The DesInventar database reports disasters with any social loss. For the present study, the entry criterion for the data query in DesInventar has been modified according to the entry criterion of EM-DAT for a better comparability of these two datasets. The criteria are 10

Table 1 Overview of the four selected disaster databases

	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	79–present, (good accuracy from 1980)
Management	University of Louvain (CRED)	Universities/NGOs (LA RED)	University of Colorado	Munich RE
Number of entries	>21,000	>44,000	4225 floods between 1985 and 2014 (mountain and non-mountain regions)	>35,000
Accessibility	Open (raw data request)	Open	Open	Limited

Source Guha-Sapir et al. (2015), LA RED (2015), Dartmouth Flood Observatory (2007), Below et al. (2009)

people missing or killed or 100 people affected or victims.

The **Dartmouth Flood Observatory** (DFO) 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 catalogues, large-scale maps and images of river floods in the years from 1985 to the present (Prentzas 2006). 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).

The **NatCatSERVICE** is a private disaster database maintained by the Munich Reinsurance Company (Munich RE). 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 are registered. 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 2011). For our study, NatCatSERVICE provides global disaster data for mass movement disasters.

Assessment of Disaster Database Quality and Completeness

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).

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 have been 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. Our study includes only disaster entries with a clear geographical location (i.e., no empty field in the database, a clear identification regarding state, department or region is possible); 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).

Definition of Mountain Regions

In order to analyze disaster events in mountain regions, a mountain layer has been superimposed on the worldwide disaster data. For our analysis, at least 50% of the area of every state, department or region must be covered by mountains (definition from Kapos et al. 2000, see below) in order for an entry with this geographic location to be recognized as a mountain disaster. Because of the extremely diverse landforms of mountains, it is difficult to achieve consistency in description and analysis of these formations, and numerous mountain definitions exist in the literature. 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 (Fig. 1) follows the (UNEP) World Conservation Monitoring Centre (WCMC) and is based on Kapos et al. (2000), with the following three criteria: (1) elevation >2500 m a.s.l. (Class 1); (2) elevation 1500–2500 m a.s.l. and slope $\geq 2°$ (Class 2); (3) elevation 1000–1500 m a.s.l. and slope $\geq 5°$, or elevation 1000–1500 m a.s.l. and local elevation range >300 m a.s.l. (Class 3). To generate a mountain map of the study area based on the three mountain classes, the global SRTM digital elevation model (DEM) with a resolution of 1 km was applied. The lower limit of 1000 m a.s.l. for mountain areas was determined to exclude hilly and lowland regions (Stäubli 2016).

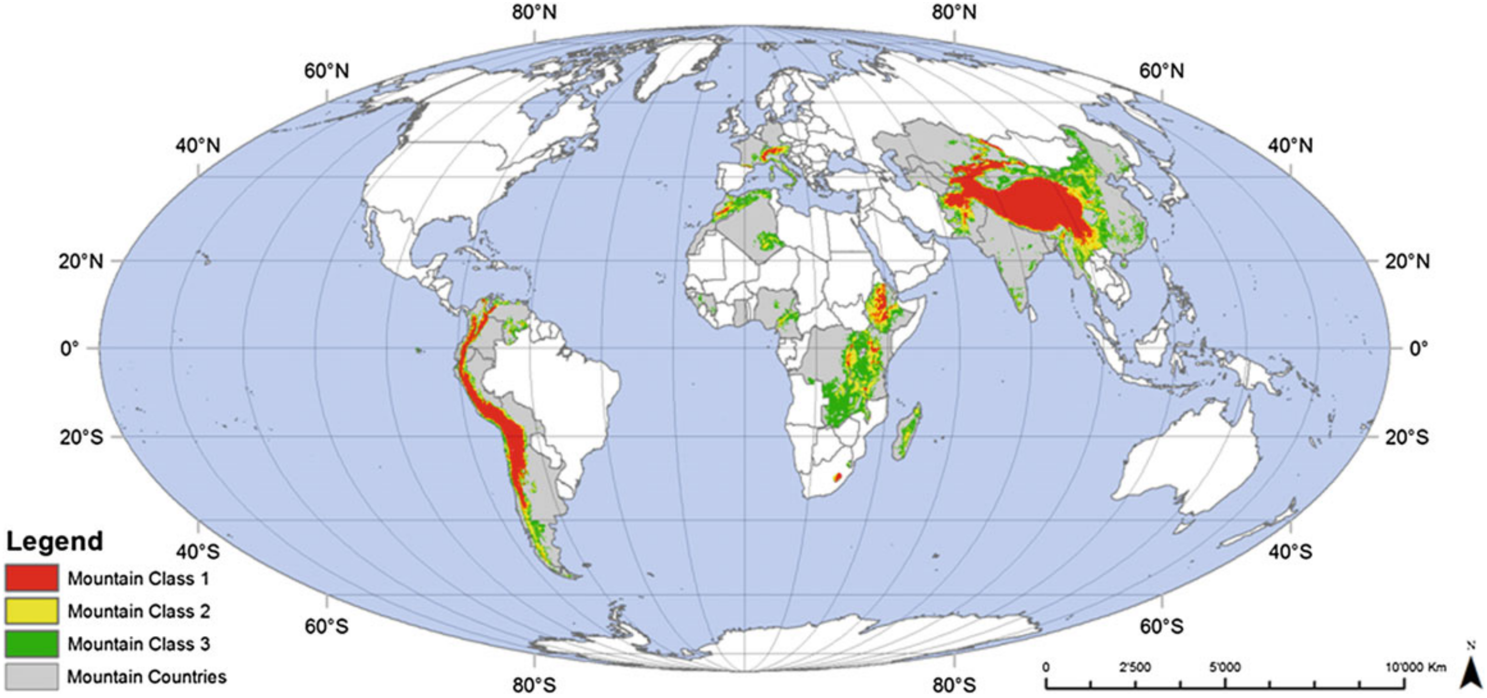


Fig. 1 Mountain regions based on the three mountain classes in the five study regions (in grey): Andes, Eastern and Northern Africa, European Alps, Central Asia and Hindu Kush-Himalaya

Classification of Disaster Types

The entries of EM-DAT and NatCatSERVICE are based on the same hierarchy and terminology of natural disasters. For the present study, only meteorological, hydrological and climatological disasters with the corresponding disaster types have been considered. Entry criterion for DesInventar has been modified according to the criterion of EM-DAT in order better compare the data. 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 have been 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
- Wild fire.

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 cause of this event. Hence, a flood could be triggered, for example, by a lake outburst or by a heavy precipitation event.

Analysis and Comparison of Regional Disaster Occurrence

In order to obtain an overview of the five mountain regions, the regional analysis aimed at investigating disaster trends with respect to disaster types and their occurrence in time and space. The regional 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 regional analysis is based on EM-DAT only, as EM-DAT is the only global database which provides freely available data, including across all six disaster types.

Quality and Completeness of Disaster Databases

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. Figure 2 summarizes database completeness regarding contents and number of registered disasters per database and mountain region. One main difficulty is related to the absence of entry criteria or impact threshold for entering a disaster event, except for the EM-DAT database. Nevertheless, the DesInventar methodology allows the collection of historical data on disaster losses in a systematic and homogeneous way at a low administrative level based on predefined definitions and classifications (UNDP 2013).

The accuracy and reliability of disaster data sources are highly influenced by the purposes of each database which results in different registered data entries. 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 biases in the two databases (Glave et al. 2008). The strengths of the accessibility for EM-DAT, DesInventar and Dartmouth are the access to disaster data without any restrictions or charges.

The value of the EM-DAT database lies in the fact that it is the most complete recorded disaster

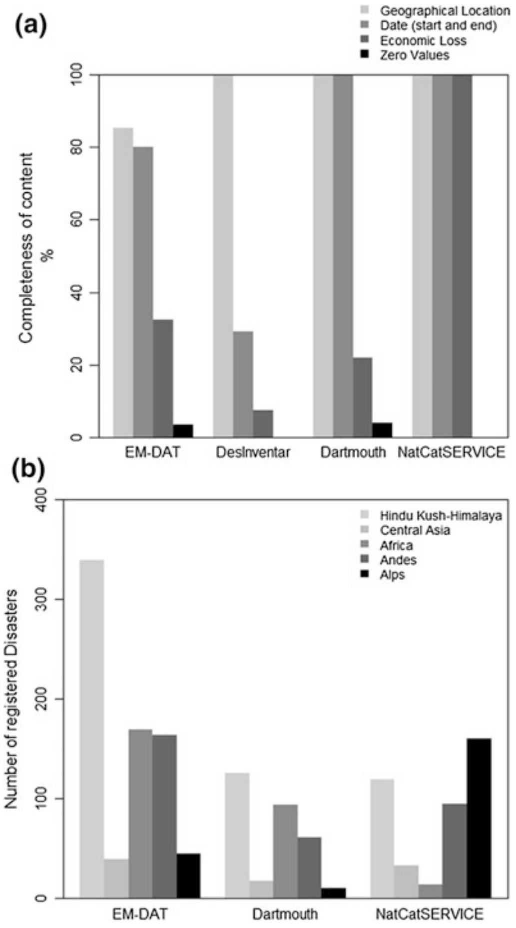


Fig. 2 Analysis of disaster database completeness of contents (**a**) and number of registered disasters per database and mountain region (**b**) for weather- and climate-related events during the time period 1980/1985–2011/2014 (source: EM-DAT, DesInventar, Dartmouth and NatCatSERVICE databases)

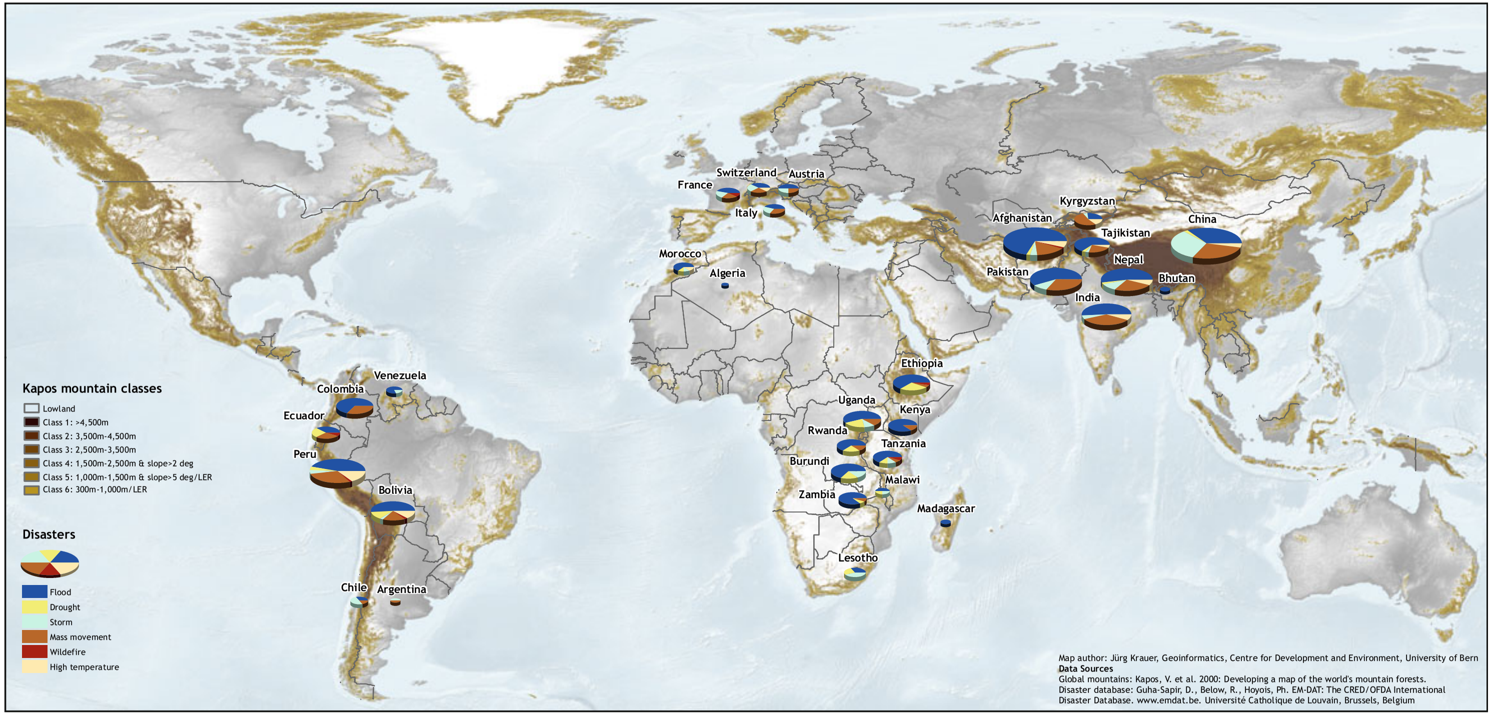
database with a global coverage and encompasses natural and technical (man-made) disasters. EM-DAT attributes disasters on state level, with additional indications to a particular region, whereas the spatial resolution of DesInventar identifies disasters on a regional, district or municipality level. The Dartmouth and NatCatSERVICE databases are geo-referenced with an exact geographical position expressed in latitudinal and longitudinal coordinates. 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. The value of the NatCatSERVICE database lies in the assessment of financial loss, representing the most important parameter for the reinsurance industry, as well as in its homogeneity and consistency of entry criteria applied over time. The magnitude of each loss (insured loss and economic loss) is registered for each event.

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.

Analysis of Regional Disaster Occurrence: The Diversity of Mountain Riskscapes

Mountain systems are very diverse and so is their exposure to natural hazards. Accordingly, the occurrence of major hydro-meteorological disasters between 1985 and 2014 in five selected mountain regions around the world (as recorded in the EM-DAT database) reveals a heterogeneous picture (Fig. 3). The impacts of these natural hazards on mountain people vary depending on their exposure and vulnerability.

As illustrated in Table 2, 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 286 million. The total number of recorded events for Eastern and Northern 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 and



Map author: Jürg Krauer, Geoinformatics, Centre for Development and Environment, University of Bern
Data Sources
Global mountains: Kapos, V. et al. 2000: Developing a map of the world's mountain forests.
Disaster database: Guha-Sapir, D., Below, R., Hoyois, Ph. EM-DAT: The CRED/OFDA International Disaster Database. www.emdat.be. Université Catholique de Louvain, Brussels, Belgium

Fig. 3 Natural disaster affected the Andes, the European Alps, the Pamir Mountains and Tien Shan in Central Asia, the North and East African mountains and the Hindu Kush-Himalaya between 1985 and 2014 differently. Six types of natural disasters taken from EM-DAT have been considered: storm, flood, mass movement, extreme temperature, drought and wild fire. The size of the pie charts is relative to the number of disasters. LER: local elevation range > 300 m (7 km radius) (cartography: Jürg Krauer, Centre for Development and Environment (CDE), University of Bern, Switzerland)

Table 2 Major hydro-meteorological hazards (mass movement (including avalanches, landslides and debris flows), flood, storm, extreme temperature, drought and wild fire), and their impacts between 1985 and 2014 in five mountain regions based on EM-DAT (Guha-Sapir et al. 2015)

Mountain region	Number of disasters	Economic loss (and per event) in million USD	Number of people killed (and per capita)	Number of people affected (and per capita)	Mountain population, 2012[a]
Hindu Kush-Himalaya (HKH)	323	44,690.4 (138.4)	26,991 (0.009%)	165,694,879 (57.931%)	286,019,683
Eastern and Northern Africa	163	1246.8 (7.6)	4881 (0.003%)	76,127,779 (52.104%)	146,108,040
Andes	150	3138.4 (20.9)	6664 (0.009%)	13,006,871 (17.795%)	73,090,954
Central Asia	39	257.4 (6.6)	700 (0.017%)	3,518,763 (87.698%)	4,012,359
European Alps	38	7245.0 (190.7)	607 (0.003%)	33,011 (0.145%)	22,814,551

Smaller events although affecting people and the local economy are not included following the EM-DAT entry criteria
[a] Mountain population (without lowlands) adapted from Mountain Partnership (2014), for countries used in this study; mountain areas according to Kapos et al. (2000)

people killed for Central Asia and the European Alps are comparable, yet the per capita death toll is much higher for Central Asia than for the European Alps. The differences between these two regions are even stronger for people affected. From a sustainable development perspective, it should be noted that all these data do not capture the frequent small events that threaten people's livelihoods.

Monsoon-Triggered Floods in the HKH

The HKH region was most affected by disasters due to floods (52.6% of all registered disaster types), followed by mass movement (28.5%) and storm disasters (13%). The localization of these hazards shows three main affected zones: western zone (northern parts of Afghanistan and Pakistan), central zone (north-western India) and eastern zone (western China). The seasonal frequency of disasters is highly influenced by the monsoon pattern, as more than 80% of the annual precipitation is provided by the summer monsoon. Thus, the number of flood disasters in the mountainous regions of the HKH indicates a significant high frequency in July. For example, the 2013 Kedarnath disaster in northern India (see Box 1) was linked to early onset of heavy monsoon rainfall triggering catastrophic failure of a small moraine-dammed glacial lake (Allen et al. 2016). Alone in Nepal, 21 out of 1466 identified glacial lakes were assessed as potentially critical (ICIMOD 2011), and it is clear that increased infrastructure and habitation within high mountain regions of HKH is increasing the risk to such events (Schwanghart et al. 2016).

Central Asia: Mass Movements in Kyrgyzstan and Floods in Tajikistan

The mountainous parts of Central Asia are most affected by disasters due to floods (48.7%) and mass movements (35.9%). In Kyrgyzstan, landslides are the most widely distributed hazard type and about 5000 potentially active landslides sites have been identified, especially in the southern part of the country. Landslides are predominantly concentrated in the foothills of the Fergana Basin and mainly occur during the rainy season between fall and spring. Rainfall is the main triggering factor of landslides in the mountainous regions of Kyrgyzstan and Tajikistan. Tajikistan is most exposed to flood disasters, due to its mountainous topography with a high amount of precipitation and large number of existing glacier lakes. Floods in Tajikistan are often caused by outburst from glacial lakes, but other causes such as extraordinary meteorological conditions have also been assigned (see Box 2).

Box 1 Kedarnath flood disaster in northern India in June 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 (3553 m a.s.l.), which is the site of a very famous Hindu pilgrimage (Sati and 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 (3960 m a.s.l.), which was dammed by the lateral moraine of the Chorabari glacier. The high volume of water caused an overflow and breach of the loose-moraine dam resulting in a glacial lake outburst flow (GLOF) (Uniyal 2013; Allen et al. 2016). This event killed and affected thousands of local people and pilgrims and destroyed infrastructure including highways and bridges. Socio-economic factors such as heavy deforestation, road construction, unplanned extension of settlement, mining and hydropower development may have increased the downstream damage (Shrestha et al. 2015).

Disaster data from the two global databases EM-DAT and Dartmouth Flood Observatory indicate numerous entries and make reference to the diverse information regarding geographical location and human and economic losses. The databases 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 north-northeast India and Gujarat, Karnataka and Kerala states located on the west coast of India. 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 number of people killed according to EM-DAT is 6054, whereas Dartmouth registers 5748 people killed. Additionally, EM-DAT registers 4473 people injured and 500,000 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 gives an affected area of about 131,743.41 km^2 and provides a severity index, the magnitude and an exact geographical location (centroid).

Box 2 Unusual 'heat wave' hitting high mountain areas in Tajikistan in July 2015

In July 2015, extraordinary meteorological conditions with high temperatures in the mountainous regions of Tajikistan led to intensified melting of ice and snow in high altitudes. The preliminary assessment suggests that the increased air temperature combined with unusually high amount of precipitation during the dry season triggered a series of mudflows and resulted in floods and increased levels of water in the rivers of the basins of Gunt, Panj, Vakhsh and Kafernigan.

While many settlements and infrastructure assets (irrigation infrastructure, roads, bridges, buildings and power lines) were affected all over Tajikistan, the high mountain valleys with steep slopes in the western Pamir (Gorno-Badakhshan Autonomous Oblast, GBAO) were most seriously hit, displacing a rather large number of people (~10,000 according to EM-DAT). The most remarkable flood event was registered in the village of Barsem, 2’400 m a.s.l., where a series of debris flows over a period of 4 days around July 18 had spilled some 1.5 million m^3 debris on the fan where the village is situated. While early assessments presumed a glacial lake outburst (GLOF) event, this hypothesis was mostly rejected later and melting of ice and snow as well as deteriorating permafrost in steep morainic depositions at high altitude leading to massive erosion in the ravine is being assumed as the cause (Zimmermann et al. 2016).

This event also formed a lake of 2 km length by damming the river Gunt, creating a lake outburst risk threatening the downstream settlements as well as a nearby hydropower station. A total of 80 houses were destroyed or flooded, leaving the same number of families without housing, and ~2 km of the main power line was completely destroyed. The international road connecting Khorog with Murgab and Osh was interrupted for 6 weeks.

The Dartmouth Flood Observatory registers not a single major event like the Barsem debris flows and damming of lake, but embraces the whole series of events happening in GBAO in July 2015. This event is listed with an ID number (*4273*) and is also time stamped with a *start* and *end* date. The main cause indicated is ‘*snow melt’* and refers to a single location in GBAO (*centre point*), not making reference to specific geographic locations other than the region and by linking to regional news sources. The EM-DAT database is less specific and lists the event as a *hydrological* disaster *flood* event with *two occurrences* which was affecting *10,802* people in Tajikistan. There is no time stamp or specific cause mentioned in the EM-DAT database.

Based on the analyzed case, the information provided in the global databases seems rather sparse and inconsistent, and while there might be some usefulness for research based on such global databases, the benefit for local communities and action on the ground remains limited. However, detailed documentation and analysis of such particular cases like the Barsem events will shed light into various issues related to future risks (particularly when considering climate change) and necessary structural and non-structural measures.

Drought and Flood Disasters in Eastern Africa

The mountain regions of East Africa are the most disaster-prone regions of Africa (Ethiopian and East African Highlands). The most frequent disasters in Africa are caused by floods (65%), followed by droughts (18.4%) and storms (8.6%). However, droughts affect much more people than floods and storms. Floods and droughts in some regions of Africa have been linked with the El Niño Southern Oscillation (ENSO), i.e. teleconnection patterns as far as to the equatorial Pacific Ocean (cf. Box 3 for ENSO influence in South America). There is a tendency for rainfall to be above average in most parts of East Africa during ENSO years and for rainfall deficits to occur during the following year; relatively wet conditions were observed during the

March–May and October–December rainfall seasons of the El Niño years (Indeje et al. 2000). Drought events may be underestimated as they are more difficult to define and do not destroy infrastructures. Hence drought events are less visible and data availability is not always ensured.

Disaster-Prone Central Andean Region

The Andes are most frequently affected by floods (50% of the registered disaster events) and mass movement disasters (28.7%), with most events taking place during the austral summer (December to February). The orographic effects of the Andean Cordillera lead to abundant precipitation at high elevations. These effects result in floods, causing damage in the densely populated foothills of the Andes. The Central Andes of Peru and Bolivia are most disaster-prone to natural disasters in the entire Andes. An important reason for the frequent occurrence of floods in South America are the El Niño and La Niña variations of the ENSO phenomenon. During events such as El Niño and La Niña, Latin America in general, and particularly the Andean region, is affected by many climatic events such as frosts, hailstorms, rainfall, landslides, floods, droughts, cold and heat waves. These events negatively affect the population in a significant way both personally, with damages to health, loss of human life, as well as material, as the destruction of houses and infrastructure, losses in agriculture and livestock, etc. For example, the impact of El Niño leads to increased rainfall particularly on the coasts of Ecuador, the northern part of Peru and the southern zones of Chile (see Boxes 3 and 4 for case studies from Peru, Bolivia and Chile).

Box 3 Impacts of the strong 2015–2016 El Niño event in Peru and Bolivia

The 2015–2016 El Niño event was considered among the three strongest such events recorded since 1950 (WMO 2015). It began its genesis in the second half of 2014 and had its full development in 2015, reaching its highest values of sea surface temperature (SST) anomalies in the last couple of months of that year. This event lasted approximately through the first half of 2016 and once the event terminated, the Pacific Ocean quickly switched to a neutral ENSO phase. Since the second semester of 2016, there was a slight cooling in the central equatorial Pacific that approached the threshold of a short and weak La Niña event. After this slight cooling period, the equatorial Pacific again warmed. By the end of January 2017, there were positive temperature anomalies in the South American coast, which added to the seasonal weakening of the South Pacific Anticyclone. This allowed the displacement of the intertropical convergence zone (ITZ) even more towards the south (CIIFEN 2017).

Peru

During the 2015–2016 El Niño event, the Andean region of Peru was affected by cold waves, droughts and floods from approximately May to July 2015. Heavy snow and frost affected the regions located above 3500 m a.s.l. The temperature in some places reached −15 °C, severely affecting life and health of the population, as well as basic services, livelihoods (agriculture and livestock) and infrastructure. Already by March 2016, a total of 20 people had died, 28 had been badly injured, 8729 injured and 103,267 affected (Redhum 2016). In total, approximately 165,710 people were affected and 100 lost their homes during the 2015–2016 El Niño phenomenon in several departments of the country. In addition, 529 homes were damaged, 11 collapsed and 11 became inhabitable (IFRC 2015). During the drought, the agricultural sector was the most affected one and several provinces declared emergencies. Therefore, the

Government of Peru (2016) launched a drought prevention and mitigation plan for 2016. By the end of March 2016, more than 13 million of soles (~4 million USD) had been invested in emergency response to the drought (WFP 2016a). On 30 September 2016, the Peruvian Government declared emergency due to the imminent danger of water shortages in several Arequipa districts.

Following the 2015–2016 El Niño event, on 11 December 2016, emergency was declared for seven Andean provinces in the Lima region due to water shortages. Conversely, shortly afterwards, too much water became also a problem, and by 17 January 2017, approximately 2645 people were affected and 1122 houses, 15.3 km of roads and 41.11 km of streets were damaged in Arequipa by persistent rainfalls.

Bolivia

According to reports from Bolivia's Civil Defence, around 100,000 households may have been affected by both excessive rainfall and drought in 109 municipalities in the country during the 2015–2016 El Niño. By 21 December 2015, a state of emergency was declared in 27 municipalities in three departments due to drought. In February 2016, the drought continued to affect the southern regions of Altiplano and Chaco. From May 2016, seven occidental regions were particularly affected, including the cities of Oruro and La Paz where more than 70,000 families were affected by the drought (OCHA 2016a). As of 31 July, 160,000 people were affected by the drought and 104 municipalities had declared state of emergencies. The most affected sectors were water distribution, sanitation, hygiene and food security (OCHA 2016b). By 22 September, an operation was executed to save and protect livelihoods of 40,000 people affected by the drought in the department of Oruro (WFP 2016b). On 21 November, the Government of Bolivia (2016) declared a state of emergency due to the water shortages in large strips of the country, considered to be the worst drought in 25 years. By the end of 2016, the drought had affected 173 of the 339 municipalities in eight provinces.

Directly linking large-scale weather or climate phenomena to disaster losses is complex, but the Ministry of Defence of Bolivia has concluded that the severe weather conditions caused by the 2015–2016 El Niño event directly affected around 60,000 people in Bolivia and left 19 dead between November 2015 and March 2016. Likewise, 31,000 hectares of crops and 15,800 heads of cattle were affected according to a report by the Civil Defence (Pan American Health Organization 2016).

Box 4 Flash floods and mudflows in northern Chile in March 2015

Between 24 and 26 March 2015 when the so-called Bolivian or Altiplano winter ended, and as a product of a segregated atmospheric low-pressure area where cold air at high elevation was hit by warm and moist air coming from the Amazon basin, a series of devastating floods (flash floods) with a statistical recurrence period of 15–20 years occurred in the Atacama region (75,166 km^2) in northern Chile, in the most arid desert of the world. Engineering works in the Copiapó riverbed conducted during the last 10–15 years, mainly near the confluence of the Quebrada Paipote (tributary river) with the main river, have reduced the overall run-off capacity of the system. During the great flood of March 2015, both the Copiapó River and the Quebrada Paipote overflowed. Much of the inundation in the city of Copiapó was in fact derived from the Quebrada Paipote and not from the overflow of the Copiapó River (Tassara et al. 2016). 50% of the urban area of Copiapó was affected by this event. The Chilean National Geology and Mining

Service (Sernageomin) registered a run-off of 1200 m^3/s of the Quebrada Paipote on 25 March 2015 (Quebrada Paipote is a dry riverbed; it flows only when precipitation in the Altiplano is abundant). The impact generated by the hydro-meteorological phenomenon affected several cities at the coast and in the mountains, including the city of Copiapó. The development of industrial mining activities, urban growth, watershed interventions and the degree of exposure of the population and its infrastructures underline the importance of priorities in territorial planning, especially in the new context of adaptation to climate change. After this hydro-meteorological event, water remedial works and cleaning of the Quebrada Paipote were carried out, allowing that the rains of January 2017 did not produce any damages.

Disaster data from one national source and two global databases provide information on the areas affected, and the social and economic losses. At the national level, Sernageomin describes the event in the "First National Cadastre of Natural Disasters" published in 2017. This publication registers the main disasters related to geologic processes in Chile since 1980 (Sernageomin 2017). At the global level, the event is registered by EM-DAT and the Dartmouth Flood Observatory (DFO). In all cases, the event is described as a flash flood/mudslide caused by heavy rainfall. According to Sernageomin, the event mainly affected the cities of Copiapó and Chañaral, and other locations in the region of Atacama. EM-DAT and Dartmouth indicate that the event affected three regions in northern Chile (Atacama, Antofagasta and Coquimbo), without specifying differences in the level of damages and losses. The number of people killed according to EM-DAT is 178, whereas Dartmouth registers 27 and Sernageomin 28 people killed. The latter also registers 59 missing. Additionally, EM-DAT indicates 193,881 people affected. Dartmouth registers a total of 29,741 people affected and 2514 displaced. Sernageomin does not provide information on the number of affected people. Dartmouth also provides information on the number of homes destroyed (2071) and damaged (6254). Indications of economic losses appear in Sernageomin and EM-DAT records with a total of 1500 million USD. EM-DAT also provides information on insured losses (500 million USD). Data reported by Sernageomin was provided by the Chilean National Treasury Department. It is worth noting that according to this source, the value corresponds to budget reallocations (1000 million USD) and resources obtained from national funds (500 million USD) used for the response and rehabilitation of the affected areas. In other words, the value would not represent the total damages. In terms of specific information about the flood, Dartmouth gives the duration in days of the event (15 days, from March 25 to April 8), an affected area of about 154,773 km^2 and provides a severity index and the magnitude.

European Alps: Flood and Avalanche Disasters

According to EM-DAT, floods (44.7%), mass movements (28.9%) and storms (21.1%) occur most frequently in the European Alps. The impacts of the orographic effects with concentrated rain on the windward side of mountains are important with significant impacts on lowland areas, especially riverine floods. Most mass movement and flood events in the European Alps occurred during winter and early spring months (December to April), due to the combination of meltwater from snow with extreme precipitation events.

Comparison of the Five Mountain Regions Through Time

Figure 4 shows the weather- and climate-related disasters in the five selected mountain regions from 1985 to 2014, as recorded in the EM-DAT database. The African countries (solid black line) exhibit a low number of disasters in the first 10 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 European Alps (black dashed) during the 30 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 spatiotemporal trends of disaster occurrence in the five mountain regions on a country level over the time period 1985–2014 are illustrated in Fig. 5. The results of the spatiotemporal occurrence of disasters indicate that the three most disaster-prone regions arc the Andes, the mountainous parts of East Africa and the HKH region.

Climate Change Increasing Risks of Natural Hazards

EM-DAT reveals a clear increasing trend in disaster frequency over the past three decades, most significantly for the HKH region (cf. Figs. 4 and 5). While some individual disasters such as the Kedarnath flood (see Box 1) have been robustly linked to changes in climate (Singh et al. 2014), there is generally insufficient evidence to attribute any overall increasing disaster frequency to climate change. Poor land

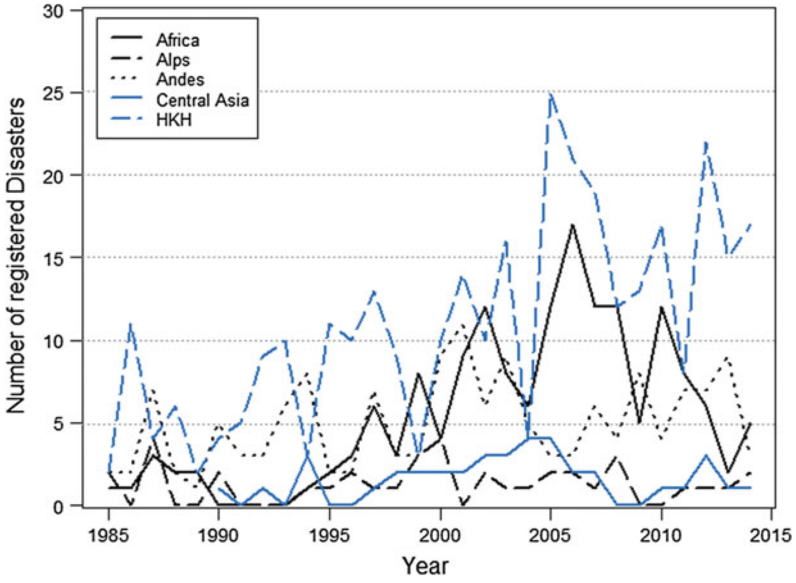


Fig. 4 Number of weather- and climate-related disasters in the five selected mountain regions for the time period 1985 (Central Asia from 1990) to 2014 (*Source* EM-DAT database)

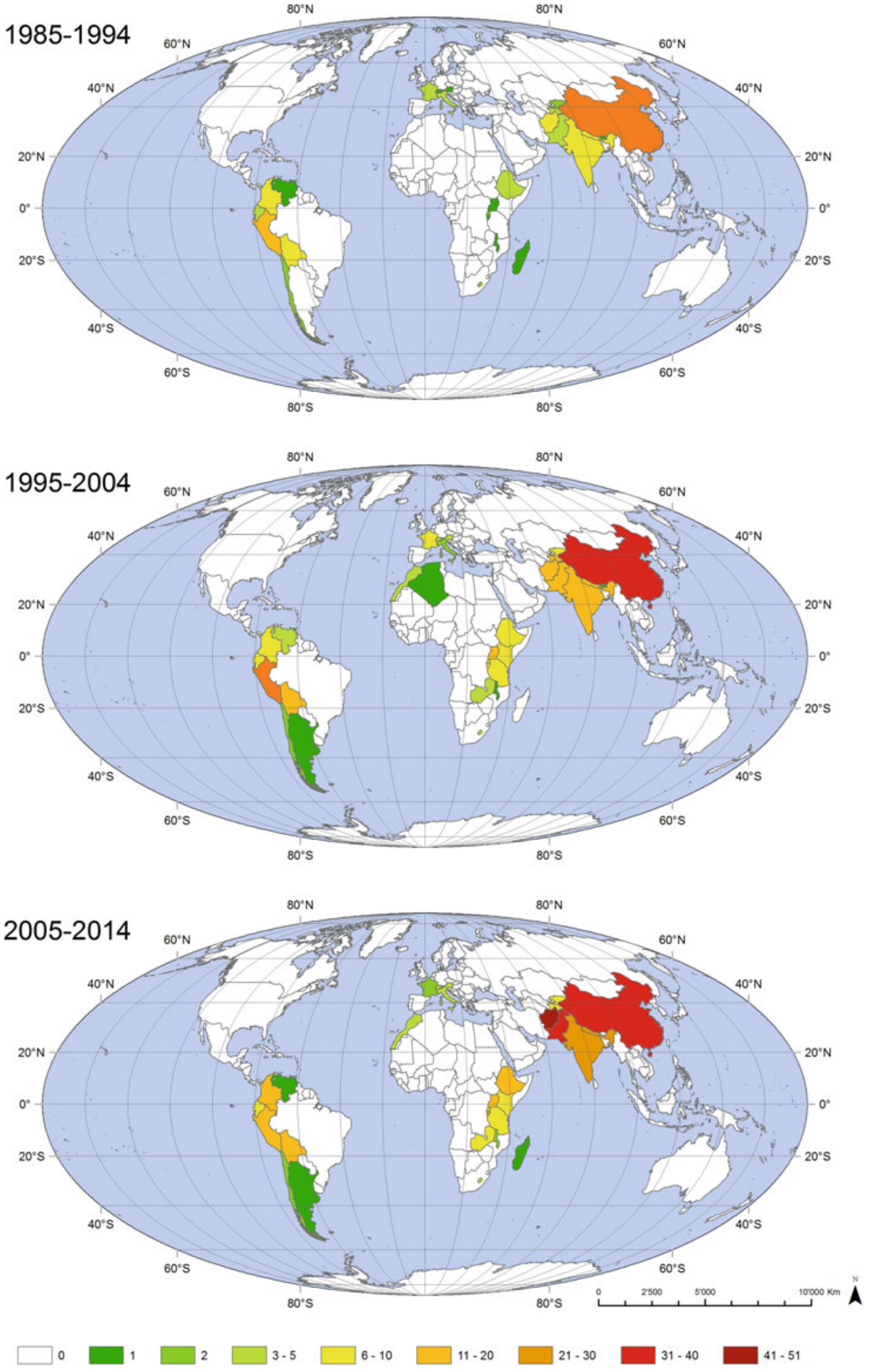


Fig. 5 Spatiotemporal trends of disaster occurrence in the five mountain regions at the level of countries over the time period 1985–2014 (*Source* EM-DAT database)

management practices and increasing exposure of people and assets could equally be important drivers of any apparent trend in disasters, while the recording of disaster events may also have become more reliable over recent years. Nonetheless, our understanding of physical processes and scenario modelling suggests continued climate change will lead to vastly altered mountain landscapes in the future, with associated implications for hazards and impacts on livelihoods and sustainable mountain development.

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 and Beniston 1998; Kääb et al. 2005; Huggel et al. 2015a). Furthermore, with growing population, land-use changes and higher exposure, the frequencies and intensities of natural disasters in mountain areas are expected to increase in future.

There is a high probability that the risks of natural hazards will increase in the future both as a consequence of projected climate change, and additional stressors such as poor land-use practices and governance, or tourism expansion, and ecosystem degradation. Climate change will alter the magnitude and frequency of hydro-meteorological hazards owing to projected increases in extremes of temperature and precipitation in many mountain regions. While temperature extremes, and thereby related extreme melt events (short- or long-term, e.g. snow melt in spring, or extreme glacier melt during summer heat wave), are projected to increase globally, there is greater uncertainty and variation in future projections of heavy rainfall events (Seneviratne et al. 2012). In general, the climate models show a trend of currently wet regions getting wetter, and dry regions becoming dryer, meaning flooding and landslides can be expected to increase most dramatically across tropical mountain regions.

Irrespective of extremes, the ongoing retreat of glaciers and degradation of permafrost in response to changes in global mean temperature will lead to further hazards in high mountain regions (Korup 2014). As just one example, new glacial lakes will continue to expand in response to warming, meaning that the risk of ice or rock avalanches smashing into a lake and triggering catastrophic downstream flooding is of paramount concern across populated high mountain regions of Asia, North and South America and Europe (Haeberli et al. 2016).

Conclusions

The comparative analysis of the quality and completeness of the four selected databases (EM-DAT, NatCatSERVICE, DesInventar and Dartmouth), for weather- and climate-related natural disasters, 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. The study emphasizes the main limitations in using such data for informing 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 regional analysis and the disaster risk statistics in the time period 1980–2014 emphasize that floods and mass movement (avalanche, landslide and debris flow) disasters are most frequent and imply the highest relative threat 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. Investigation of the occurrence of natural disasters in the five mountainous regions with data from the EM-DAT database indicated the highest absolute number of disasters for the Hindu Kush-Himalayan (HKH) region. However, note that if we consider the number of recorded disasters per capita, Central Asia was affected the most of all five mountain regions.

The disaster frequency from 1985–2014 indicated an increasing trend of weather- and climate-related disasters for the most disaster-prone regions of the HKH, Andes and African mountains, whereas no obvious trends could be recognized in the European Alps and the mountainous parts of Central Asia, where hazards were registered with a lower frequency. In future, 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.

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